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ECLIPSE

Evaluating the **Cl**imate and Air Quality **I**m**p**acts of **S**hort-Liv**e**d Pollutants

Collaborative Project

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Report on strategies that maximize co-benefits and minimize trade-offs

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SUMMARY

The study has identified 20 measures that could together reduce the GWP100 from short-lived substances by 60%. The main mitigation potential is in developing countries.

The key mitigation potential is associated with methane measures, while the net effects of many BC measures on GWP100 are limited.

The largest mitigation potential is found for operations of large multi-national and national energy companies and municipalities, compared to measures that require investments at poor households in developing countries.

These measures for short-lived substances have important co-benefits on a wide range of development goals, including improved human health from air pollution.

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Dissemination Level		
PU	Public	X
PP	Restricted to other programme participants (including the Commission Services)	
RE	Restricted to a group specified by the consortium (including the Commission Services)	
CO	Confidential, only for members of the consortium (including the Commission Services)	

Contents

1 Introduction

Economic activity and several natural processes result in emissions of air pollutants and greenhouse gases leading to environmental impacts and adverse effects on human health. A variety of technical and regulatory measures is available to control the emissions from anthropogenic sources. While measures addressing methane (CH_4) emissions typically have little impact on releases of other substances, mitigation of BC will result, in most instances, in changes in emissions of several co-emitted pollutants.

Climate policies under the UNFCCC framework currently address only greenhouse gases (GHGs) with relatively long lifetimes. In addition to these longer-lived GHGs, shorter-lived substances (especially ozone and aerosols including black carbon) – collectively called short-lived climate pollutants (SLCPs)– also can make significant contributions to climate change, especially in the near term, but are currently not included in the UNFCCC. At the same time, these substances deteriorate air quality at the hemispheric, regional and local scales and contribute to a wide range of harmful effects on human health and vegetation. Because of their air quality impacts, these substances are already subject to specific air quality management strategies throughout the world. However, these strategies do currently not consider climate impacts or how the synergies between air quality and climate change strategies could be maximized.

To capture the full climate and public-health implications as well as other air pollution-related impacts of each measure, it is important to look at the suite of pollutants affected by any considered control option. An integrated approach is also necessary because co-emissions associated with both BC and precursors of tropospheric ozone (O_3) differ markedly from one sector and source to another, which is particularly important in relation to the reduction of climate impacts. Cooling aerosols such as organic carbon (OC) or sulphate (SO_4^{2-}) can potentially offset the climate benefits of reducing BC depending on the relative amounts of these pollutants in each source/sector emission profile, as well as the location of the emission source. Similarly, addressing tropospheric O_3 by mitigating either CH_4 or NO_X would have different climate impacts. Finally, the regional nature of the impacts of SLCFs is of particular relevance to identifying effective mitigation strategies for these components.

This report summarizes work conducted under the FP7 ECLIPSE project to identify a set of emission reduction measures that would simultaneously benefit climate change and local air quality. Considering the simultaneous co-control of multiple pollutants, this sub-set of effective air pollution control measures selects those measures that deliver, under future conditions, maximum reductions of climate warming substances while minimizing the reduction of pollutants that have a cooling effect on climate.

2 Methodology

In order to identify win-win measures, the GAINS model quantifies the effect of each of the considered measure on all emissions, in order to assess their effectiveness in simultaneously responding to air quality and climate mitigation.

This report assesses the climate impacts of the approximately 2000 emission control measures that are contained in the databases of the Greenhouse gas – Air Pollution Interactions and Synergies (GAINS) model (Amann et al. 2011) along two alternative climate impact metrics. The GAINS model quantifies, for each of these mitigation, their impacts on the emissions of all pollutants that are affected (i.e., CH_4, CO, BC, OC, SO_2, NO_x, VOC, CO_2) in each of the 168 source regions (Klimont et al. 2009; Kupiainen and Klimont 2004b) developed at the International Institute for Applied Systems Analysis (IIASA).

A variety of technical and regulatory measures is available to control emissions from anthropogenic sources. While measures addressing methane (CH_4) emissions typically have little impact on releases of other substances, mitigation of BC will result, in most instances, in changes in emissions of several co-emitted pollutants. Therefore, to understand the full climate and public-health implications as well as other air pollution-related impacts of each measure, it is important to look at the suite of pollutants affected by any considered control option.

The GAINS model considers all key documented pollution control options. It is important to consider that all BC measures reduce fine particulate matter ($PM_{2.5}$), and that ozone precursors are by both BC and CH_4 measures. Therefore, all the considered measures lead to air quality improvements.

In a further step, the net effect of these emission changes on radiative forcing and temperature increase at the global scale has been estimated for each measure, and measures have been ranked accordingly.

2.1 The choice of appropriate climate indicators

For quantifying the climate impacts of emission changes, this report applies two climate impact indicators (metrics) that have been developed within ECLIPSE WP4. These two metrics reflect the impacts of emissions for two different time horizons, i.e., 20 and 100 years.

To capture the response of near-term term temperature increase, the GTP20 (the Global Temperature Potential over 20 years) is used. Alternatively, to describe the contribution to long-term climate change, this report employs the GWP100, i.e., the Global Warming Potential over 100 years.

In WP4, numerical values for these metrics have been computed for four different world regions (i.e., Europe, China, Marine Shipping, and the Rest of the World), and distinguish emissions during the summer and winter half years, respectively. The assessment here applies the seasonal climate metrics to seasonal emissions, with different temporal patterns for different pollutants, sectors and world regions (Table 1).

To mimic the implementation of emission control policies as realistically as possible, these metrics assume gradual linear phase-in of a given emission reduction policy/measure over 15 years, and persistence of the regulation after its full implementation. As discussed in the WP4 reports, this temporal pattern, which reflects the impacts of actual policy decisions, delivers different results than the analysis for pulse emissions, which has been frequently used in the past.

Table 1: Climate metrics used for the selection of the ECLIPSE set of emission controls

	GTP 20	GWP 100
SO2 Europe Summer	-818.94	-224.741
SO2 Europe Winter	-270.239	-74.1614
SO2 China Summer	-487.475	-133.777
SO2 China Winter	-204.605	-56.1497
SO2_WD Summer	-933.578	-256.201
SO2_WD Winter	-601.399	-165.041
BC Europe Summer	5224.121	1432.293
BC Europe Winter	2297.104	629.7952
BC China Summer	4991.767	1368.589
BC China Winter	1954.981	535.9955
BC Rest of the World Summer	6881.022	1886.564
BC Rest of the World Winter	5275.636	1446.417
OC Europe Summer	-1606.65	-440.401
OC Europe Winter	-862.762	-236.493
OC China Summer	-1176.6	-322.52
OC China Winter	-543.154	-148.885
OC Rest of the World Summer	-1332.79	-365.332
OC Rest of the World Winter	-1338.26	-366.831
NH3 Europe Summer	-102.063	-27.9826
NH3 Europe Winter	-66.5388	-18.2429
NH3 China Summer	-49.5783	-13.5928
NH3 China Winter	-95.1115	-26.0766
NH3 Rest of the World Summer	-38.8884	-10.662
NH3 Rest of the World Winter	-60.6873	-16.6386
OC Europe Summer	-1606.65	-440.401
OC Europe Winter	-862.762	-236.493
OC China Summer	-1176.6	-322.52
OC China Winter	-543.154	-148.885
OC Rest of the World Summer	-1332.79	-365.332
OC Rest of the World Winter	-1338.26	-366.831
NOX Europe Summer	-34.7161	-19.0901
NOX Europe Winter	-16.1697	-8.31161
NOX China Summer	22.18693	-4.28193
NOX China Winter	-31.4115	-14.0771
NOX Rest of the World Summer	-11.3297	-23.6612
NOX Rest of the World Winter	-18.4186	-26.1638
CO Europe Summer	15.28273	5.079139
CO Europe Winter	15.75916	5.418426
CO China Summer	14.86592	4.904716
CO China Winter	18.42923	6.087484
CO Rest of the World Summer	14.13252	4.786999
CO Rest of the World Winter	14.39564	5.053662
VOC Europe Summer	17.99427	10.58781
VOC Europe Winter	-6.52715	0.916499
VOC China Summer	30.74057	10.89361
VOC China Winter	26.03821	8.465533
VOC Rest of the World Summer	21.16068	11.95678
VOC Rest of the World Winter	11.37545	9.68094
CH_4 global	100.828	46.84704

2.2 The baseline emission scenario

While the emission reduction efficiencies for the various substances and the climate impacts of these substances are two important criteria, effective policy intervention strategies must also consider whether the emission reductions (or their climate impacts) that could be achieved with a specific measure in the future would be significant at the global scale. Otherwise, a strategy could include a myriad of measures, which individually contribute very little to the health and climate objectives, resulting in large regulatory and governance complexity.

To assess whether a specific measures could potentially achieve significant emission reductions, this study applies a baseline projection that outlines the likely development of future emissions that would emerge from currently anticipated economic growth paths, energy policy strategies, and the effects of the implementation of already agreed emission control regulations.

For this purpose, the study employs the global ECLIPSE V5 emission scenario that has been developed under WP1 of the ECLIPES project. This scenario, which is described in detail in ECLIPSE Deliverable D1.6 (Klimont et al., 2015), assumes the evolution of economic activity and energy consumption of the World Energy Technology Perspectives (ETP) project of the International Energy Agency (International Energy Agency 2012). To estimate future emissions, these activity trends are combined with the GAINS data on country-specific emission factors for the base year and an inventory of current emission control legislation in all countries and the timetables of introduction of the legally required measures.

The baseline 'current legislation' (CLE) projection simulates future emissions under the assumption that the currently decided emission control legislation will be fully implemented serves as starting point for the analysis.

In general, the ECLIPSE v5 emission projection suggests a clear decoupling between GDP, greenhouse gas emissions, and air pollutants. The ECLIPSE v5 'Current legislation' baseline suggests at the global scale for SO_2 declining emissions, and a sharp increase thereafter, due to steeply increasing coal consumption in developing countries, which do not require effective emission controls at the moment (Figure 1, Figure 2). Global NO_x emissions are projected to increase steadily by 30% until 2050, as the currently required emission control measures will not suffice to compensate the increase in traffic volumes that is projected in the energy scenario as a result of population growth, increased wealth, and changed life styles. For BC, emissions are expected to stabilize in the coming decades.

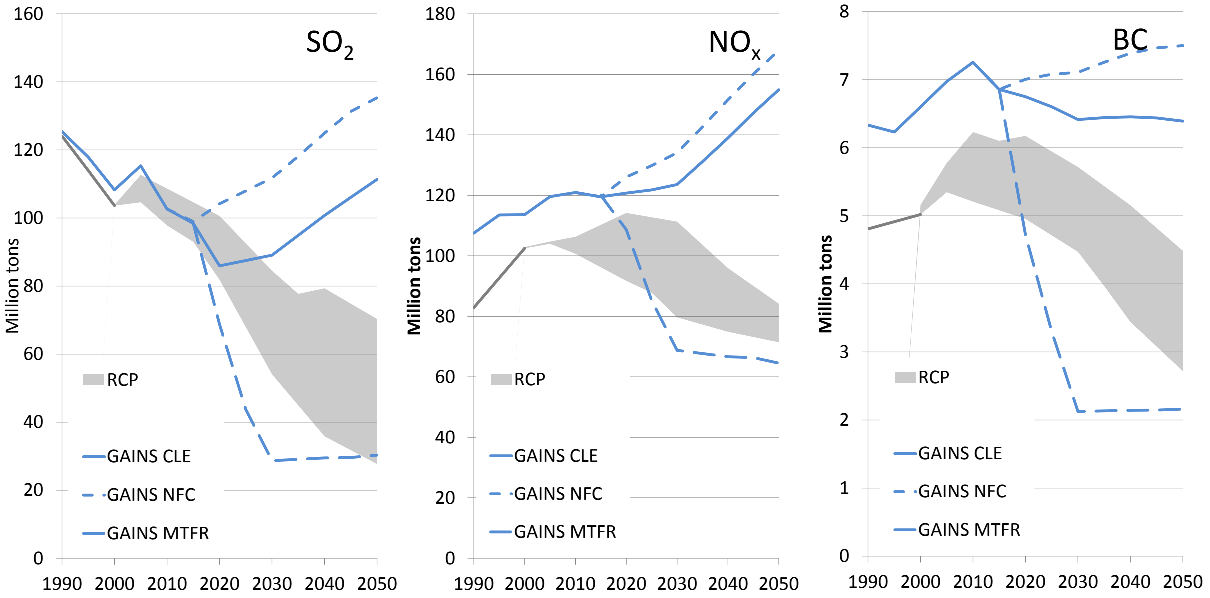

Figure 1: ECLIPSE emission scenarios of air pollutants as developed with the GAINS models, compared to the range of the RCP scenarios

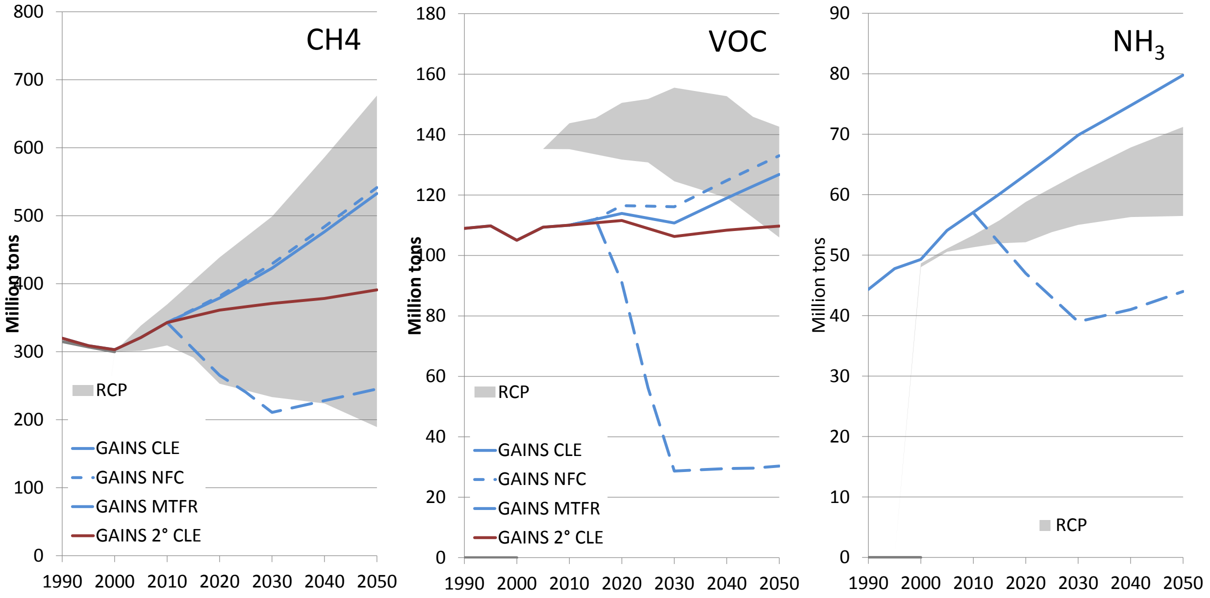

Figure 2: ECLIPSE emission scenarios of CH_4, COV and NH_3 as developed with the GAINS models, compared to the range of the RCP scenarios

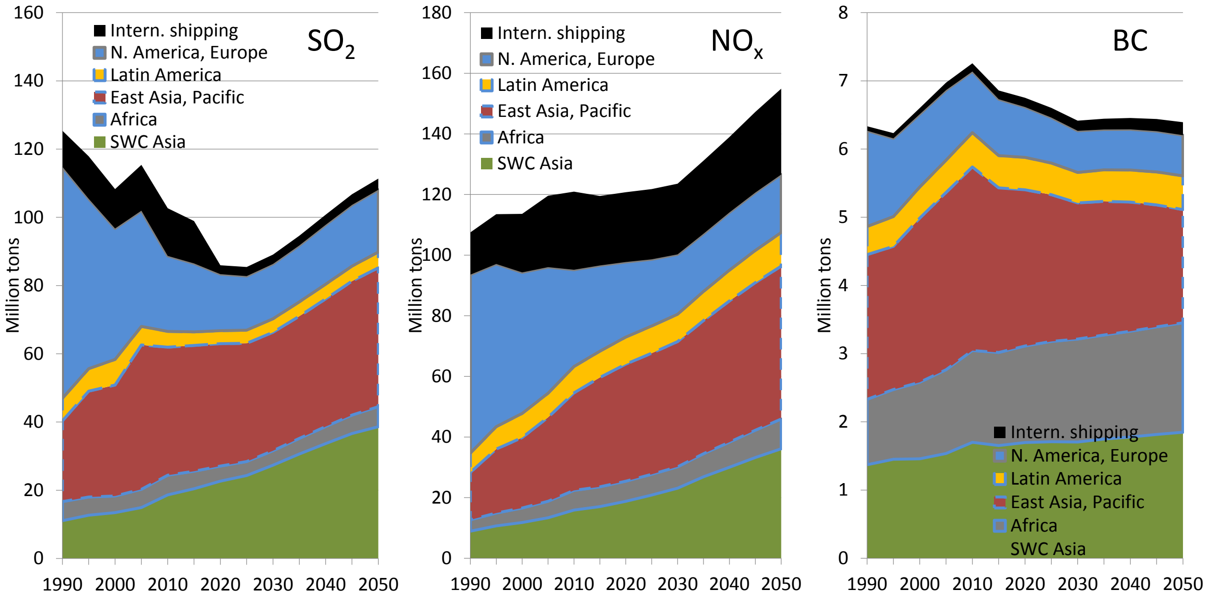

Figure 3: Current legislation emissions by UNEP world region

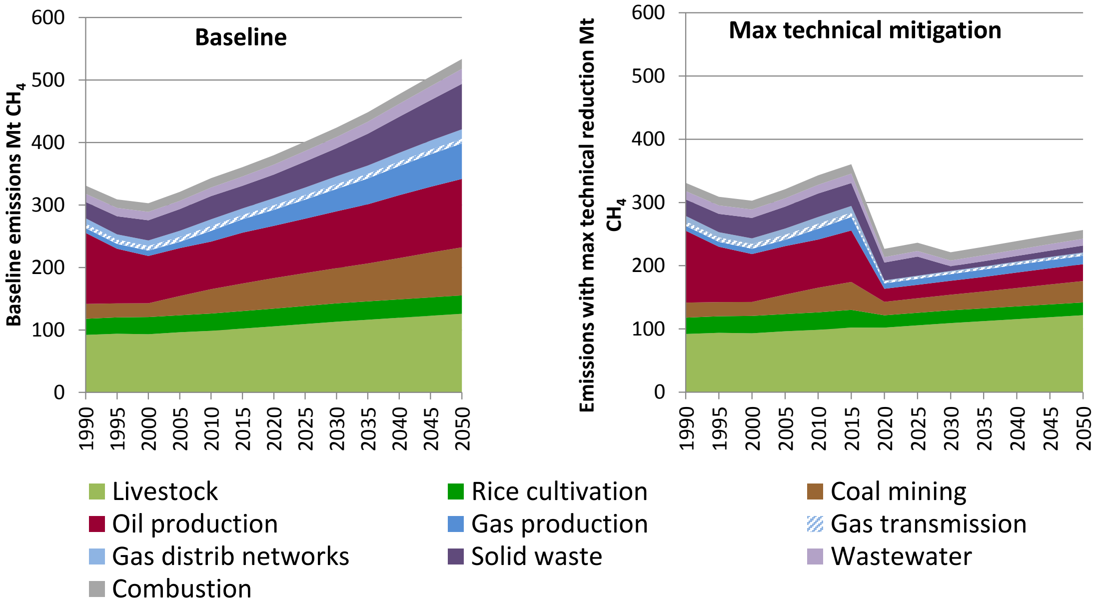

Figure 4: Baseline emissions and maximum emission reductions for CH$_4$, by sector

2.3 Measures that benefit air quality and climate

A variety of technical and regulatory measures is available to control emissions from anthropogenic sources. While measures addressing methane (CH_4) emissions typically have little impact on releases of other substances, mitigation of BC will result, in most instances, in changes in emissions of several co-emitted pollutants. Therefore, to understand the full climate and public-health implications as well as other air pollution-related impacts of each measure, it is important to look at the suite of pollutants affected by any considered control option. For SLCPs, the key measures are briefly summarized in the following Section.

2.3.1 Measures to reduce methane emissions

At a global level, three key sources contribute about 96 % of total anthropogenic CH_4 emissions – agriculture including livestock rearing and rice production (44%); fossil fuel production and distribution (35%), and waste and wastewater management (17%). More than 40 % of emissions originate in Asia, 25% in North America and Europe, including Russia, and 13% in each Latin America and Africa. Without further mitigation efforts, baseline CH_4 emissions are expected to grow by about 25% by 2030, with no significant changes in the regional and sectoral distributions. However, a host of proven mitigation measures is available which offer a significant reduction potential.

Agriculture: The technical mitigation options offering the greatest reduction potential in agriculture include reducing enteric fermentation emissions from cattle through dietary changes; reducing manure emissions through its treatment in anaerobic digesters; and intermittent irrigation of continuously flooded rice paddy-fields. Improved animal genetics and reproduction may offer some additional mitigation potential (IPCC 1996). Methane emissions from rice production could be further reduced by introducing at least one aeration period during the growing season in continuously flooded fields or through better nutrient management or the introduction of new cultivars (IPCC, 1996).

Fossil fuel production and distribution: Key emission sources include coal mining and gas and oil production. Pre-mining degasification of surface and underground coal mines, primarily implemented as a measure to increase workers' safety, is currently applied at large-scale facilities in many industrialized countries as well as to some extent in China, Ukraine and Russia and despite some technical limitations much wider application of degasification is technically feasible.

Recovery and oxidation of ventilation-air methane (VAM) is technically feasible at underground mines with CH_4 concentration levels in the ventilation air of at least 0.3%. While this measure is currently only applied at a few mines in Australia, China and the United Kingdom, it is considered technically feasible to control about 50% of the ventilation air emitted from underground coal mines in all countries, with the exceptions of South Africa and India where current VAM concentration rates are too low.

In most industrialized countries, more than 90% of the methane associated with oil and gas production is recovered and used. However, due to the necessary upfront investments, this percentage is typically less than 20% in developing countries, although it would be technically feasible in these countries to recover the gas at large scale facilities and control unintended fugitive emissions.

Without proper maintenance, CH_4 emissions from long-distance gas pipelines arise from inadequately-tightened compressor seals and valves or because pipelines are flushed with gas during start-ups. Experience in Western Europe, Japan and North America demonstrates that such losses can be greatly reduced through proper inspection and maintenance programmes.

Waste management: Many countries have introduced legislation both to divert biodegradable waste from landfills through separation and recycling, composting or incineration and to equip existing landfills with gas recovery. Based on this experience, diversion of all biodegradable waste away from landfills through separation and treatment and gas recovery from landfills, should be technically feasible in all countries, although financial resources will be required for implementation. The mitigation potential in the waste sector in 2030 is however conditional on that mitigation commencing very soon, as decomposition of biodegradable waste in landfills is slow with lags in emissions of, on average, 10 to 20 years. Purely mechanical, primary treatment of centrally collected wastewater, prevalent to varying extents in both developed and developing countries, constitutes a major source of CH_4 emissions. It should, however, be technically possible to upgrade all primary wastewater treatment to secondary or tertiary treatment by 2030, which would reduce emissions considerably.

2.3.2 Measures to reduce black carbon emissions

There are a number of proven control technologies to reduce BC emissions from several key sources. A brief discussion of those available for key sources is presented below, while much more detailed overviews can be found in, for example, the USEPA Report to Congress on Black Carbon (US-EPA, 2011), the Arctic Council Report (Peters et al. 2011) and Kupiainen and Klimont 2004a).

Transport: Measures in transport primarily address diesel-powered vehicles and include retrofitting older vehicles and equipment; accelerated retirement of old engines, enforcing new stricter PM standards, for example, Euro 6/VI requiring installation of diesel particle filters (DPF), the introduction of more stringent inspection requirements, and the encouragement of better maintenance practices – the last two have the potential to reduce the impact of high-emitting vehicles (super emitters). The most effective measure is the installation of DPFs, which requires ultralow sulphur diesel fuel, that result in removal of about 99 % of BC. However, the penetration of this option is limited by the rate of turnover of fleets. There are other measures than those identified above, for example the introduction of electric cars or promoting gasoline rather than diesel cars, which would have a similar impact to DPFs.

Residential combustion: While globally, emissions from cooking and heating with solid fuel in the developing world dominate this sector, in a number of Organisation for Economic Co-operation and Development (OECD) countries, including those of Scandanavia, the use of biomass for heating has increased, placing this sector among the larger contributors to BC emissions in the developed world. Therefore, it is necessary to distinguish between measures applicable to the OECD countries with a wide access to processed biofuels and technology, and the developing world where only limited access to modern fuels and technology is likely to exist in the short term. In the OECD, implementation of unified stringent BC emission standards combined with inspection regimes should be a priority, alongside incentives to replace or upgrade old stoves and boilers with modern stoves, fireplaces and biomass-pellet fuelled installations.

In the developing world, in parallel to programmes promoting the replacement of stoves with improved ones leading to better fuel efficiency and lower emissions, a move towards cleaner fuel, while slowly eliminating solid fuels, would result in significant BC emission reductions. Replacing biomass stoves with ones using cleaner fuels such as LPG or biogas would almost eliminate BC emissions from this sector. Clearly, replacing fuelwood with another fuel is a massive, difficult undertaking given the billions of people using biomass. It is assumed that the additional CO_2 emissions resulting from increased fossil fuel (e.g. LPG) use would more or less equal the current net CO_2 loss caused by unsustainable biomass fuel sourcing practices.

Brick kilns: Production of bricks in such traditional kilns as bull's trench and clamps is a large industry in many developing countries. Typically, poor quality coal, fuelwood, and garbage are used to fuel these inefficient kilns resulting in high emissions. Viable mitigation options include the replacement of these kilns with larger and more efficient ones – vertical-shaft brick kilns, tunnel or Hoffman kilns – that require about 50 % less fuel, and consequently produce fewer emissions.

Coke production: Modern coke-oven plants minimize emissions by capturing and recovering coke-oven gas while the small scale indigenous plants, mostly located in China, do not capture these emissions. The key measure is to phase out the old technology, a strategy China is already pursuing. Quick elimination of the old technology in parallel with the introduction of stricter emission and operation standards for new plants has proven feasible elsewhere and should be promoted.

Agriculture and forestry: Many countries have experience in reducing or eliminating open burning of agricultural crop residues (UNEP/WMO 2011). A regional agreement, the ASEAN Agreement on Transboundary Haze Pollution, was also concluded with the objective of preventing and monitoring transboundary haze pollution as a result of land and/or forest fires. Demonstration projects; exchange of information on the efficiency of no-burn methods, such as conservation tillage or soil incorporation; or even technical assistance to farmers could be implemented to reduce or largely eliminate this activity. Similarly, a campaign on the prevention and management of prescribed forest burning and wildfires, and greater resources devoted to fire monitoring and prevention would result in a reduced number of fires. When controlled burning is necessary, such as when fire plays a critical and natural ecological role, management techniques may help reduce emissions or limit their impacts.

Gas flaring: BC emissions from this sector are not yet well established, however, the few available measurements (Johnson et al. 2011), remote sensing data (Elvidge et al. 2009), and GAINS model estimates indicate it could be a significant source. Existing practice on improving flare performance, from, for example, Norway, could be used to assess the potential and means for future reductions of these emissions.

Marine shipping: There is only limited experience with measures reducing BC emission from ship engines. However, a recent review by Corbett *et al.* (2010) indicates a range of options that will be available in the next decade ranging from existing slide-valve technology and DPFs. The MARPOL convention on air pollution from ships, which is primarily aimed at reducing emissions of SO_2, does not expressly cover black carbon emissions. However, developments are taking place in this area in the context of the MARPOL convention.

Other sources: There are a large number of control measures that reduce PM emissions, including electrostatic precipitators and fabric filters, but in most cases the sources concerned emit only small amounts of BC, for example, large scale combustion and large scale production processes (Bond et al. 2004). Moreover, integrated control of such plants is often associated with control of SO_2 emissions the reduction of which will lead to net climate warming. An exception is stationary diesel generators, which are often operated in harsh conditions and in several regions do not need to comply with stringent legislation. Mitigation measures include retrofits and new engines; however, the potential for reduction is quite uncertain owing to only limited statistical data on fuel consumption and actual equipment in use. Finally, some only poorly researched BC sources, such as open domestic waste burning, could become future targets for the mitigation strategy where stricter enforcement of existing legislation and the introduction of additional burning bans could lead to reduction of emissions.

2.4 Measures with net benefits for climate

Most of the measures described above affect multiple emissions at the same time. While there are a few measures which results in trade-off (i.e., they reduce some pollutants and increase others, e.g., some end-of-pipe measures to control SO_2 emissions will increase CO_2), most of the measures result in lower emissions of all relevant substances.

The GAINS model quantifies this ‘co-control’ of each of the 2000 emission control measures, taking into account country-specific emission factors for each pollutant (which may vary widely across countries). However, although the co-control results in positive impacts for all pollutants, their net climate impact is less clear, as in many cases both warming and cooling substances will be reduced.

In a further step, the climate metrics discussed above have been used to rank the 2000 measures according to their net climate impacts. For each of these measures, the technical mitigation potential that could theoretically be achieved through a full application of these measures in the year 2030 has been analysed. This analysis considers the actual mitigation potential of each measure in each of the 168 world regions considered in GAINS, starting from the emissions of the ECLIPSE Baseline Current legislation scenario in 2030 (see ECLIPSE Deliverable 1.6).

2.4.1 Key measures at the global scale

If applied at the global scale, the identified measures bring nearly 40% reduction of projected baseline 2030 CH_4 emissions. A third of that potential is achieved by addressing emissions in gas and oil production in North America and Europe, Africa and S W and C Asia. Another third of the potential can be reduced from coal mining, especially from NE Asia, SE Asia and Pacific. The treatment of municipal waste could contribute one fifth of the reduction potential of which one half could be achieved in North America and Europe. Lastly, agriculture could contribute about one tenth of the global CH_4 mitigation potential in 2030.

If applied at the global scale, the key measures achieve 90% of the reduction potential for BC. It is important to realize that these BC measures have significant effects on various co-emitted substances, including reducing OC emissions (which is important for the net change in climate impact caused by the measures), and a number of O_3 precursors – CO, NMVOCs and NO_X, – which affect tropospheric O_3 concentrations.

For BC, measures addressing traditional biomass cook stoves would reduce most emissions the most in Africa and Asia whilst those addressing emissions from the transport sector, especially implementing Euro-6/VI vehicle emissions standards (including diesel particle filters), would bring about the largest reduction in BC emissions in Latin America and the Caribbean. In regions other than North America and Europe, simply eliminating high emitting vehicles would also have a significant beneficial impact on BC emissions. In North America and Europe, the largest BC emissions reductions would come from replacing current wood burning technologies in the residential sector with pellet stoves and boilers. Regionally, the potential differs depending on the source structure and the state of emission legislation.

The measures can be grouped into three groups of opportunities:

(i) Measures that affect emissions of methane and that can be implemented centrally by large national and international energy companies, municipalities and through modified agricultural practices. If implemented globally, these measures could reduce radiative forcing in 2030 by about one third compared to the baseline case.

(ii) Technical measures that reduce emissions of black carbon, mainly at small stationary and mobile sources. Together with the measures of group 1, these measures could reduce radiative forcing in 2030 by about half compared to the baseline case.

(iii) Non-technical measures to eliminate the most polluting activities, e.g., through improved enforcement of legislation or through economic and technical assistance to the poorest population. With these measures, global radiative forcing could be reduced by about two thirds in 2030 compared to the baseline case.

Table 2: Key measures to reduce radiative forcing from short-lived substances

Group 1: Technical measures for methane emissions:

- Extended recovery of coal mine gas
- Extended recovery and flaring (instead of venting) of associated gas from production of crude oil and natural gas
- Reduced gas leakage at compressor stations in long-distance gas transmission pipelines
- Separation and treatment of biodegradable municipal waste through recycling, composting and anaerobic digestion
- Upgrading primary wastewater treatment to secondary/tertiary treatment with gas recovery and overflow control
- Control of methane emissions from livestock, mainly through farm-scale anaerobic digestion of manure from cattle and pigs with liquid manure management
- Intermittent aeration of continuously flooded rice paddies
- Control of emissions during shale gas production

Group 2: Technical measures for black carbon emissions:

- Replacing traditional coke ovens with modern recovery ovens, including the improvement of end-of-pipe abatement measures (in developing countries)
- Replacing traditional brick kilns with vertical shaft kilns and Hoffman kilns where considered feasible (in developing countries)
- Introduction of improved biomass cook stoves in developing countries
- Wide-scale introduction of pellet stoves and boilers in the residential sector (in industrialized countries)
- Diesel particle filters for road vehicles and off-road mobile sources (excluding shipping)
- Reduced BC emissions from gas flaring
- Particle control at stationary engines
- Substitution of kerosene lamps

Group 3: Non-technical measures for black carbon emissions:

- Elimination of high-emitting vehicles in road and off-road transport (excluding shipping)
- Ban of open burning of agricultural waste
- Elimination of biomass cook stoves in developing countries

2.4.2 Impacts on emissions

This analysis identified 260 specific measures (out of the 2000) that would deliver net benefits for climate.

At the global scale, these measures would reduce, compared to the current legislation baseline projection, CH_4 emissions by about 45-50%, both in 2030 and 2050, BC emissions by 77%, and CO emissions by 92% (Table 3). While the selection algorithm attempts to minimize emissions of cooling substances, the co-control of the measures that reduce BC emissions will lead to a 70% cut in OC emissions. SO_2 emissions, however, are lower by 1% only. As a side effect, VOC and NO_x emissions will be reduced by 63% and 17%, respectively (Figure 5). The ECLIPSE baseline Current legislation projection suggests an increase in global CO_2 emissions by 150% between 1990 and 2050, accompanied by a growth in CH_4 by almost 60%. While the mitigation case will not affect CO_2 emissions greatly, it will revise the CH_4 trend and result in a 25% decline instead.

Table 3: Global emissions for the Baseline Current legislation (CLE) and ECLIPSE scenarios (Mt, CO_2 Gt)

		1990	2000	2010	2020	2030	2040	2050
CH_4	CLE	331.9	302.7	342.9	379.0	423.1	476.5	532.8
	ECLIPSE				317.6	212.0	229.5	246.8
SO_2	CLE	114.8	96.7	88.7	83.3	86.3	97.8	108.1
	ECLIPSE				81.4	85.1	96.8	107.3
NO_x	CLE	93.6	94.3	95.2	97.7	100.3	114.1	126.6
	ECLIPSE				84.8	83.0	94.6	104.5
VOC	CLE	113.4	109.3	110.0	113.9	110.7	119.0	126.8
	ECLIPSE				86.2	41.0	44.5	47.8
BC	CLE	6.3	6.5	7.1	6.6	6.3	6.3	6.2
	ECLIPSE				4.3	1.4	1.4	1.5
OC	CLE	13.2	13.9	15.1	13.9	13.5	13.7	13.7
	ECLIPSE				9.3	3.9	3.9	3.9
CO	CLE	541.7	555.9	568.1	565.0	522.3	549.3	564.7
	ECLIPSE				500.0	400.0	300.0	250.0
NH_3	CLE	44.3	49.3	57.1	63.3	69.9	74.8	79.8
	ECLIPSE				63.0	69.2	74.0	79.0
CO_2		22.2	25.0	32.7	39.3	44.0	50.2	55.9

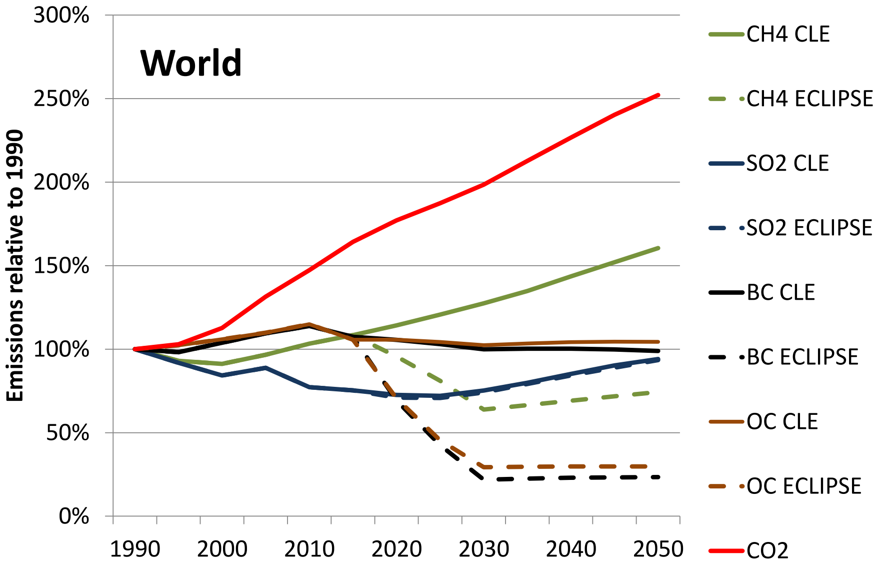

Figure 5: Trends of global emissions, relative to 1990

2.4.3 Impacts on climate indicator metrics

2.4.3.1 Global impacts

In terms of the climate impact metrics, the ECLIPSE measures would reduce the global forcing integrated over 100 years (GWP100) of the global emissions in 2030 and 2050 by about one quarter compared to the baseline (Figure 6). The ECLIPSE measures would have the largest impacts on emissions in other world regions than Europe and China (Figure 7).

For the GTP20 metrics, the ECLIPSE measure would reduce at the global scale the indicator by approximately 70% (Figure 8), again with the largest impacts from the ‘Rest of the World’ region.

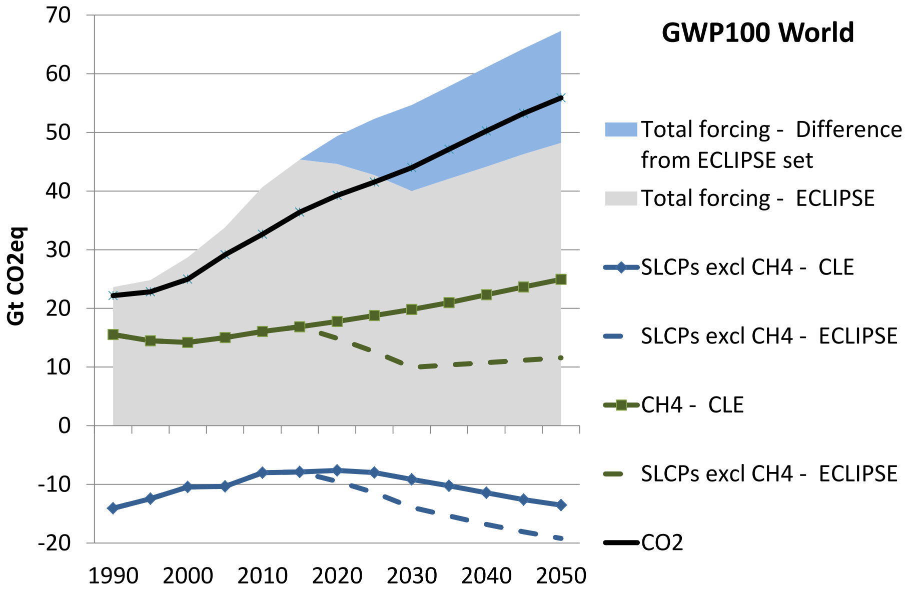

Figure 6: The GWP100 indicator of global emissions for the current legislation (CLE) baseline and the ECLIPSE scenario with the SLCP measures

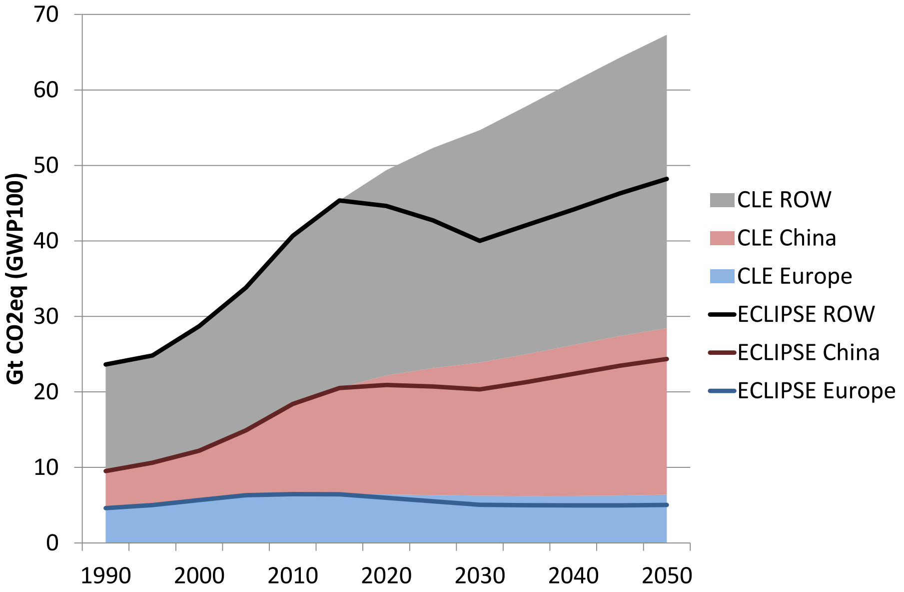

Figure 7: Contributions by the three world regions to the GWP100 indicator for the current legislation (CLE) baseline and the ECLIPSE scenario with the SLCP measures

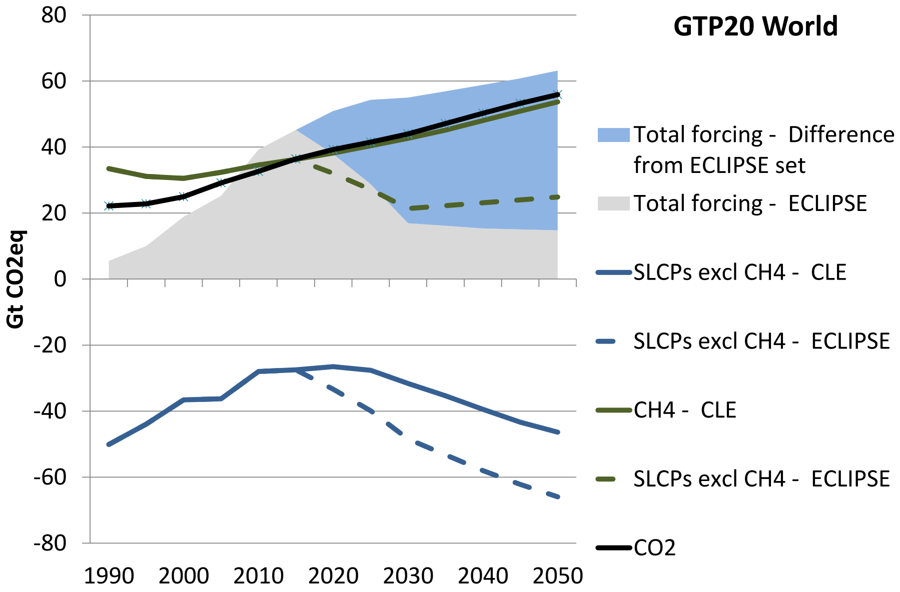

Figure 8: The GTP20 indicator of global emissions for the current legislation (CLE) baseline and the ECLIPSE scenario with the SLCP measures

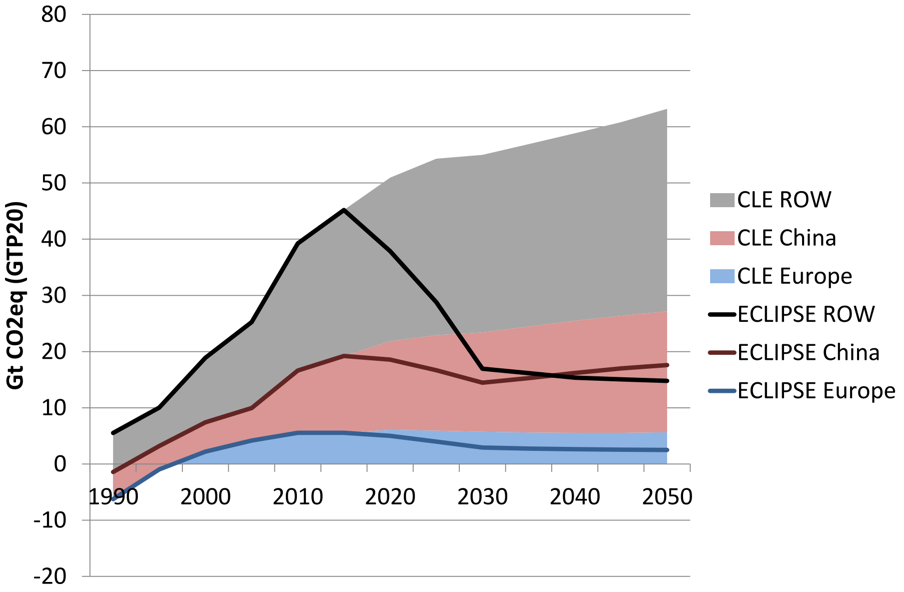

Figure 9: Contributions by the three world regions to the GTP20 indicator for the current legislation (CLE) baseline and the ECLIPSE scenario with the SLCP measures

2.4.3.2 Europe

The ECLIPSE set of measures will achieve significant reductions of warming SLCP emissions, i.e., CH_4 and BC. Cuts in cooling SLCP emissions, e.g., SO_2 and OC, are minimized in this set, and restricted to those measures where the climate impacts of the co-controlled warming SLCPs dominate the cooling effect. Thus, SO_2 emissions are hardly effected by the ECLIPSE measures, while the OC reductions are unavoidable side-effects of measures that are targeted at BC emissions. As shown in Figure 10, the ECLIPSE set wold reduce methane emissions in Europe by about two thirds by 2040, and BC emissions by three quarters. Similar reductions also occur for OC as a side effect, but SO_2 emissions remain unaffected.

Table 4: Emissions for the Baseline Current legislation (CLE) and ECLIPSE scenarios for Europe (kilotons, CO_2 Mtons)

		1990	2000	2010	2020	2030	2040	2050
CH_4	CLE	56.4	41.7	40.0	37.1	38.0	39.7	42.7
	ECLIPSE				29.2	16.7	17.3	18.0
SO_2	CLE	38.3	17.0	10.0	7.1	7.3	7.9	8.4
	ECLIPSE				7.0	7.2	7.8	8.4
NO_x	CLE	27.3	18.9	14.5	11.1	9.4	9.0	9.1
	ECLIPSE				9.5	7.8	7.7	7.8
VOC	CLE	26.5	17.7	12.1	10.0	9.2	9.1	9.2
	ECLIPSE				8.0	4.2	4.2	4.2
BC	CLE	0.8	0.6	0.6	0.4	0.4	0.3	0.3
	ECLIPSE				0.3	0.1	0.1	0.1
OC	CLE	1.3	0.9	0.8	0.7	0.6	0.6	0.6
	ECLIPSE				0.5	0.2	0.2	0.2
CO	CLE	91.0	61.7	46.5	36.3	33.8	34.6	35.5
	ECLIPSE				29.4	20.3	21.9	22.8
NH_3	CLE	7.6	5.8	5.3	5.4	5.5	5.6	5.7
	ECLIPSE				5.3	5.4	5.5	5.6
CO_2		7.2	5.9	5.8	5.6	5.4	5.4	5.5

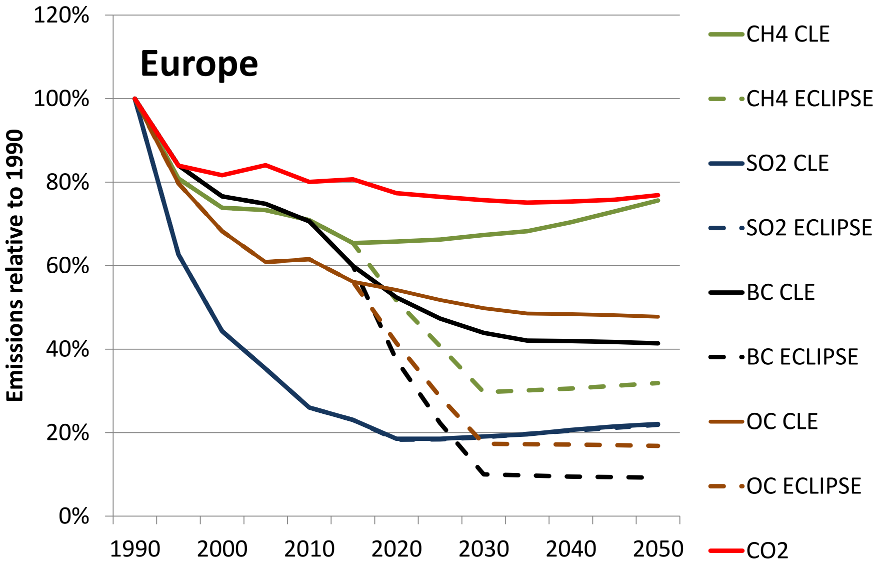

Figure 10: Evolution of emissions of the Baseline Current legislation (CLE) and the ECLIPSE scenarios for Europe (incl. European part of Russia), relative to 1990

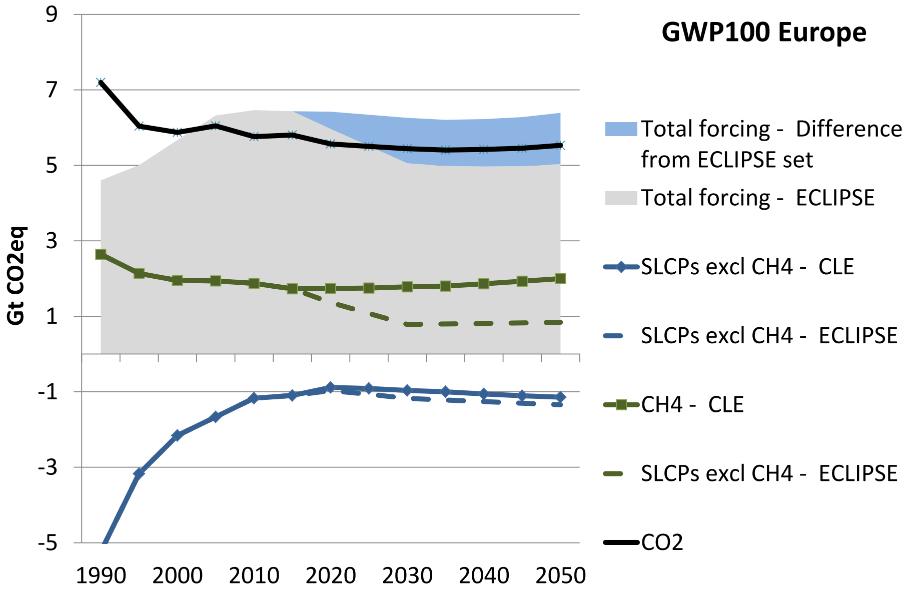

Figure 11: The GWP100 indicator of emissions from Europe for the current legislation (CLE) baseline and the ECLIPSE scenario with the SLCP measures

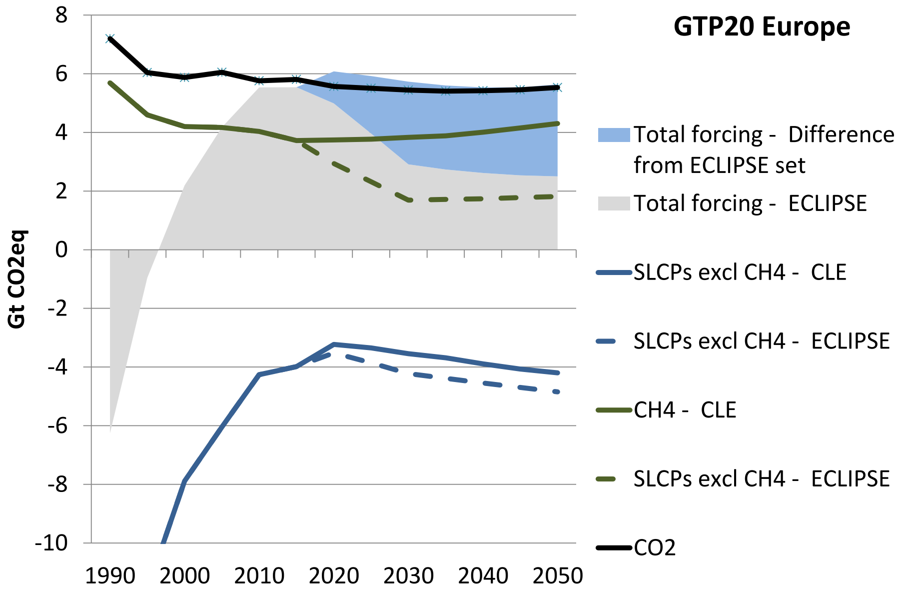

Figure 12: The GTP20 indicator of emissions from Europe for the current legislation (CLE) baseline and the ECLIPSE scenario with the SLCP measures

2.4.3.3 China

Table 5: Emissions for the Baseline Current legislation (CLE) and ECLIPSE scenarios for China (Mt, CO_2 Gt)

		1990	2000	2010	2020	2030	2040	2050
CH_4	CLE	33.7	36.3	51.6	60.7	68.7	79.9	92.2
	ECLIPSE				51.4	36.3	40.0	44.1
SO_2	CLE	16.3	25.7	31.2	28.9	26.7	28.0	30.0
	ECLIPSE				27.7	26.0	27.5	29.7
NO_x	CLE	8.0	13.5	23.0	29.2	31.1	34.8	37.0
	ECLIPSE				27.2	29.1	32.3	34.3
VOC	CLE	14.5	18.6	22.9	26.0	23.8	24.6	25.3
	ECLIPSE				19.5	8.2	8.5	8.7
BC	CLE	1.3	1.7	1.9	1.6	1.2	1.1	0.7
	ECLIPSE				1.1	0.3	0.3	0.3
OC	CLE	3.7	4.1	4.1	3.0	2.3	2.1	1.8
	ECLIPSE				2.1	0.9	0.8	0.7
CO	CLE	116.9	154.1	188.7	187.1	153.3	151.1	139.8
	ECLIPSE				156.2	110.3	113.0	110.2
NH_3	CLE	9.5	11.3	14.5	16.0	17.5	18.1	18.6
	ECLIPSE				15.9	17.3	17.9	18.5
CO_2		3.9	6.0	10.9	14.2	15.9	18.0	20.0

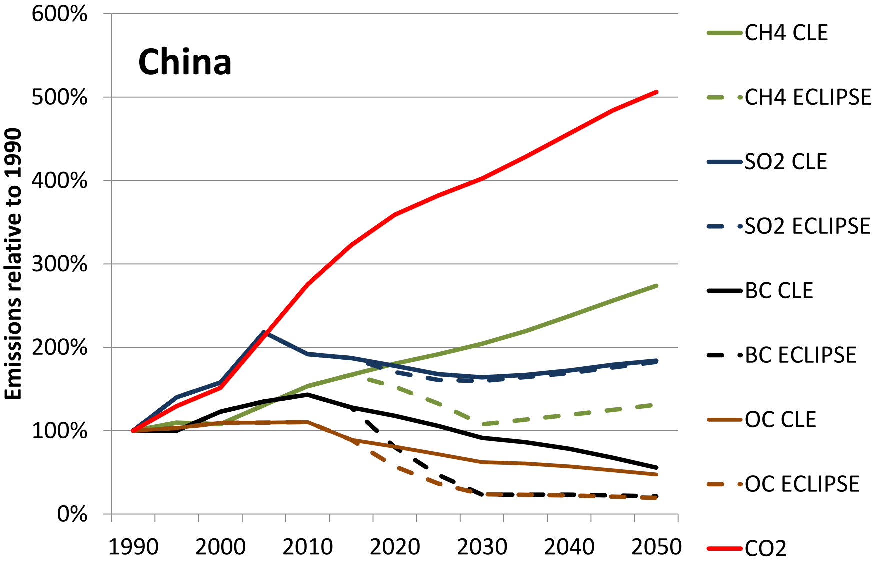

Figure 13: Evolution of emissions of the Baseline Current legislation (CLE) and the ECLIPSE scenarios for China, relative to 1990

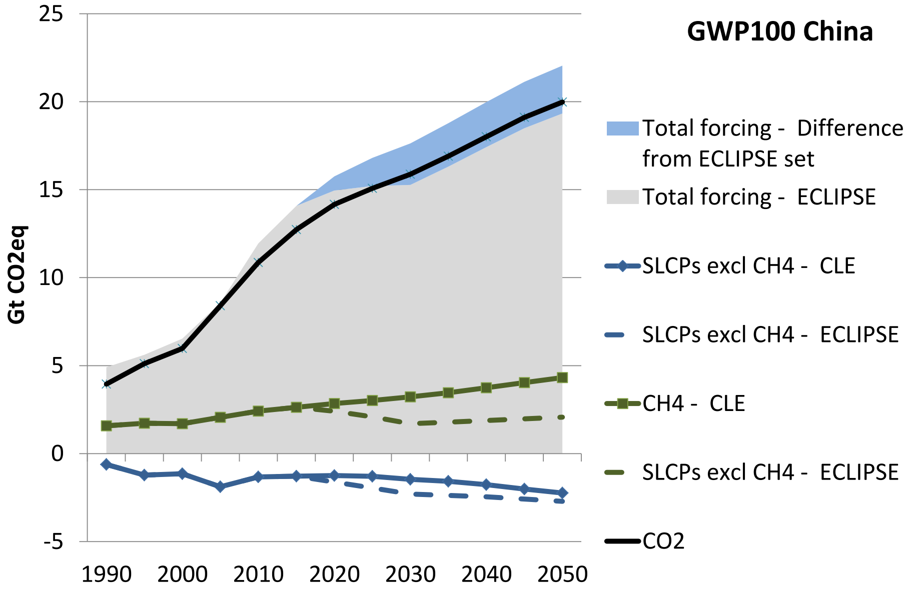

Figure 14: The GWP100 indicator of emissions from China for the current legislation (CLE) baseline and the ECLIPSE scenario with the SLCP measures

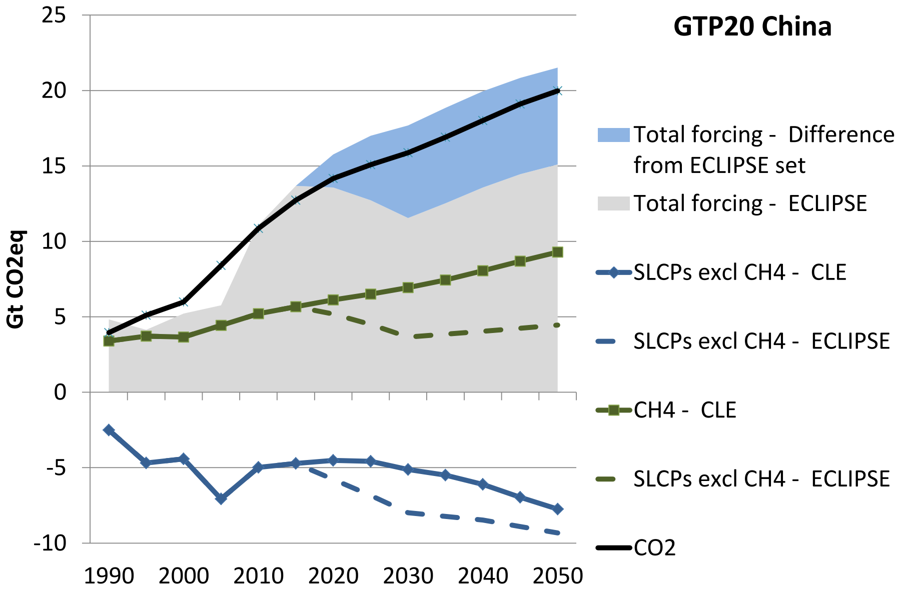

Figure 15: The GTP20 indicator of emissions from China for the current legislation (CLE) baseline and the ECLIPSE scenario with the SLCP measures

2.4.3.4 Rest of the World

Table 6: Emissions for the Baseline Current legislation (CLE) and ECLIPSE scenarios for China (Mt, CO_2 Gt)

		1990	2000	2010	2020	2030	2040	2050
CH_4	CLE	241.9	224.7	251.3	281.2	316.3	356.9	397.9
	ECLIPSE				237.1	159.0	172.2	184.7
SO_2	CLE	60.2	54.1	47.5	47.3	52.3	61.9	69.7
	ECLIPSE				46.7	51.8	61.4	69.2
NO_x	CLE	58.3	62.0	57.6	57.5	59.7	70.3	80.5
	ECLIPSE				48.1	46.1	54.6	62.4
VOC	CLE	72.3	73.0	75.0	77.9	77.8	85.3	92.3
	ECLIPSE				58.7	28.6	31.8	34.8
BC	CLE	4.1	4.2	4.6	4.6	4.7	4.9	5.1
	ECLIPSE				3.0	1.0	1.1	1.1
OC	CLE	8.2	9.0	10.3	10.2	10.5	11.0	11.4
	ECLIPSE				6.6	2.8	2.9	3.0
CO	CLE	333.8	340.1	332.9	341.5	335.2	363.6	389.4
	ECLIPSE				314.4	269.4	165.2	117.1
NH_3	CLE	27.2	32.2	37.3	41.9	46.9	51.1	55.4
	ECLIPSE				41.8	46.5	50.6	54.9
CO_2		11.0	13.1	16.0	19.5	22.7	26.8	30.4

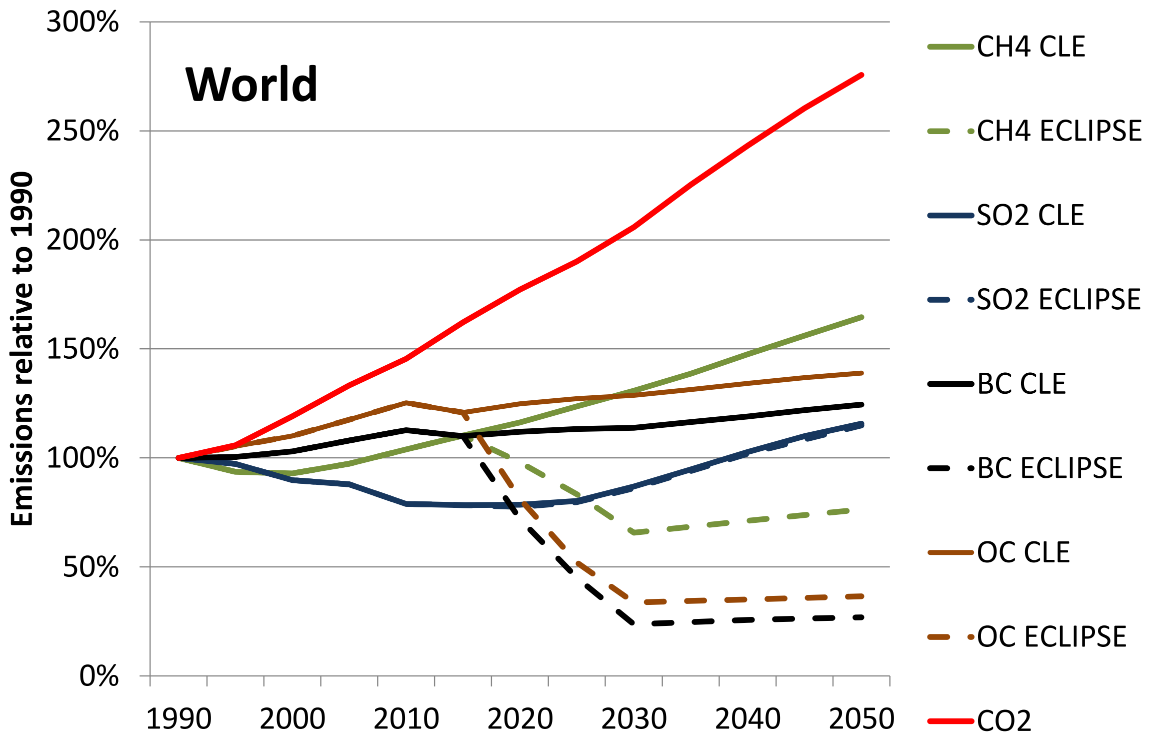

Figure 16: Evolution of emissions of the Baseline Current legislation (CLE) and the ECLIPSE scenarios for the rest of the Worlds, relative to 1990

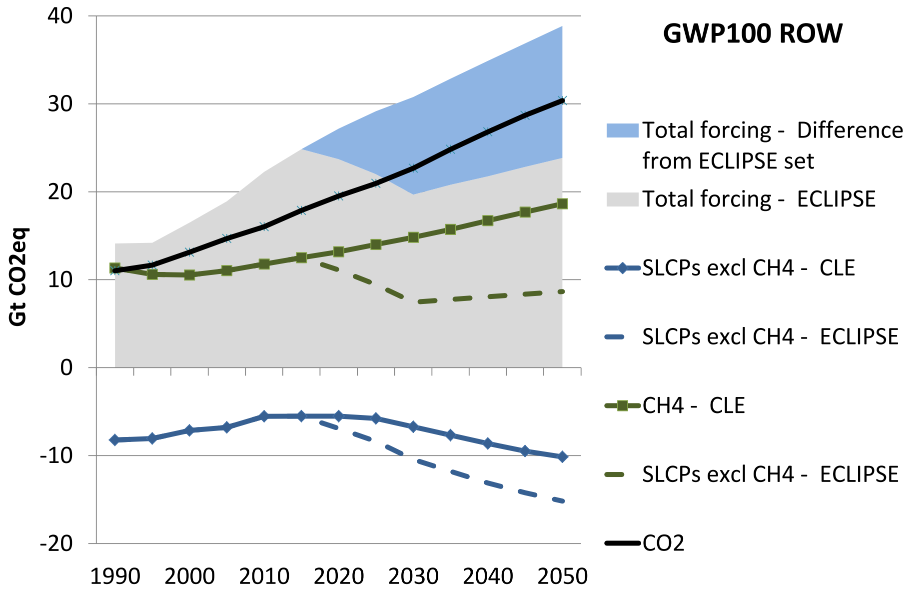

Figure 17: The GWP100 indicator of emissions from other world regions for the current legislation (CLE) baseline and the ECLIPSE scenario with the SLCP measures

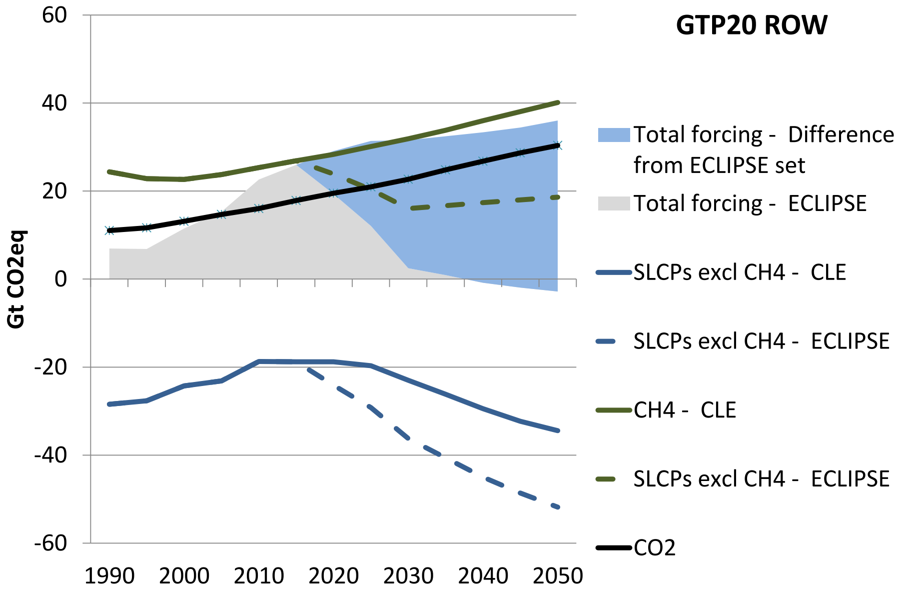

Figure 18: The GTP20 indicator of emissions from other world regions for the current legislation (CLE) baseline and the ECLIPSE scenario with the SLCP measures

2.5 The most effective measures to reduce climate impacts of SLCPs

It is noteworthy that in the analysis above a small sub-set of measures achieves a high share of the reduction potential, while the large majority of the measures result in only very little net benefits. These top 20 measures would deliver approximately 80% of the total potential for GWP100 improvement (or reduce about 63% of the total climate effects of SLCPs)). while implementation of the remaining 240 measures, cumulatively, would be necessary to harvest the remaining 20% (Figure 19).

However, whilst these 20 measures can produce a large share of the climate benefit from a global perspective, they are not the only measures available to policy makers in different regions, nor are they necessarily the most cost-effective measures. However, the selection provides a solid starting point from which to develop effective policy making to reduce SLCPs, and all strategies that aim at significant reductions of SLCP emissions need to include these measures in one or the other way.

It turns out that the ranking of the top measures is rather robust against the choice of metric, especially the sub-set of 20 measures that deliver the largest benefits. There are, however, variations in the ranking within the top 20 measures, with higher priority of BC-related measures for the GTP20 metric, and higher priority for CH_4 measures if GWP100 is taken as the criterion.

2.5.1 Key measures in Europe and China

Within each of the two world regions, i.e., Europe (Figure 19) and China (Figure 20) that have been considered in the analysis, the top 20 measures emerge as rather robust against different climate metrics, although the sequence of individual measures varies somewhat between the GTP20 and GWP100 metrics.

However, the sub-sets of the top 20 measures are not identical for Europe and China. Measures that do not appear in the other region among the top 20 are highlighted in Figure 20 and Figure 19 (see Table 7). Differences can be traced back to different importance of activity rates in the regions (e.g., the large gas producing sector in Russia, or rice paddies in China), or the level to which emission are already controlled in the ‘Current legislation’ case (e.g., Euro 6/Vi with diesel particle filters, which are not yet required in China).

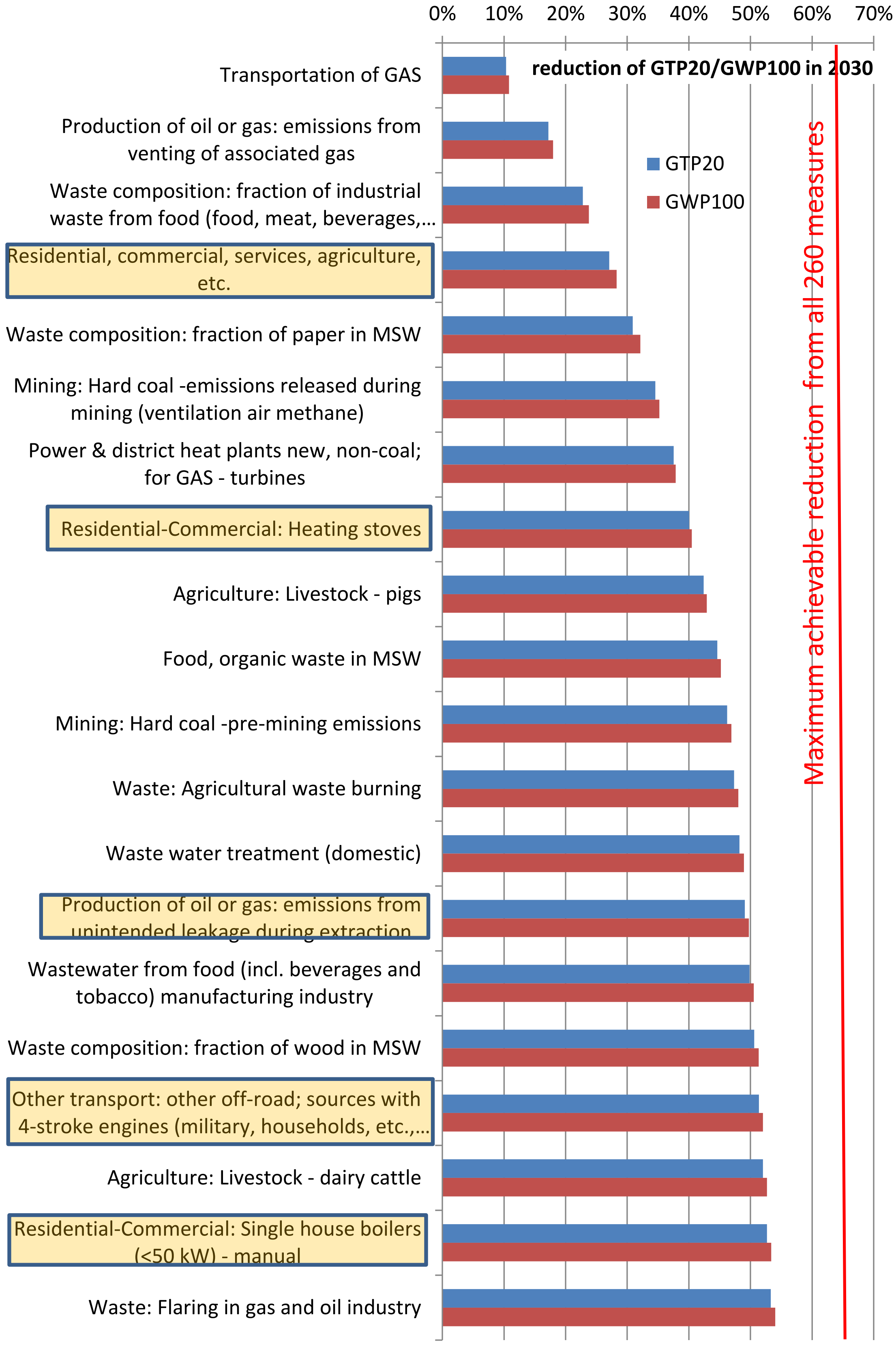

Figure 19: The ‘Top 20’measures to reduce climate impacts of SLCPs in Europe in 2030

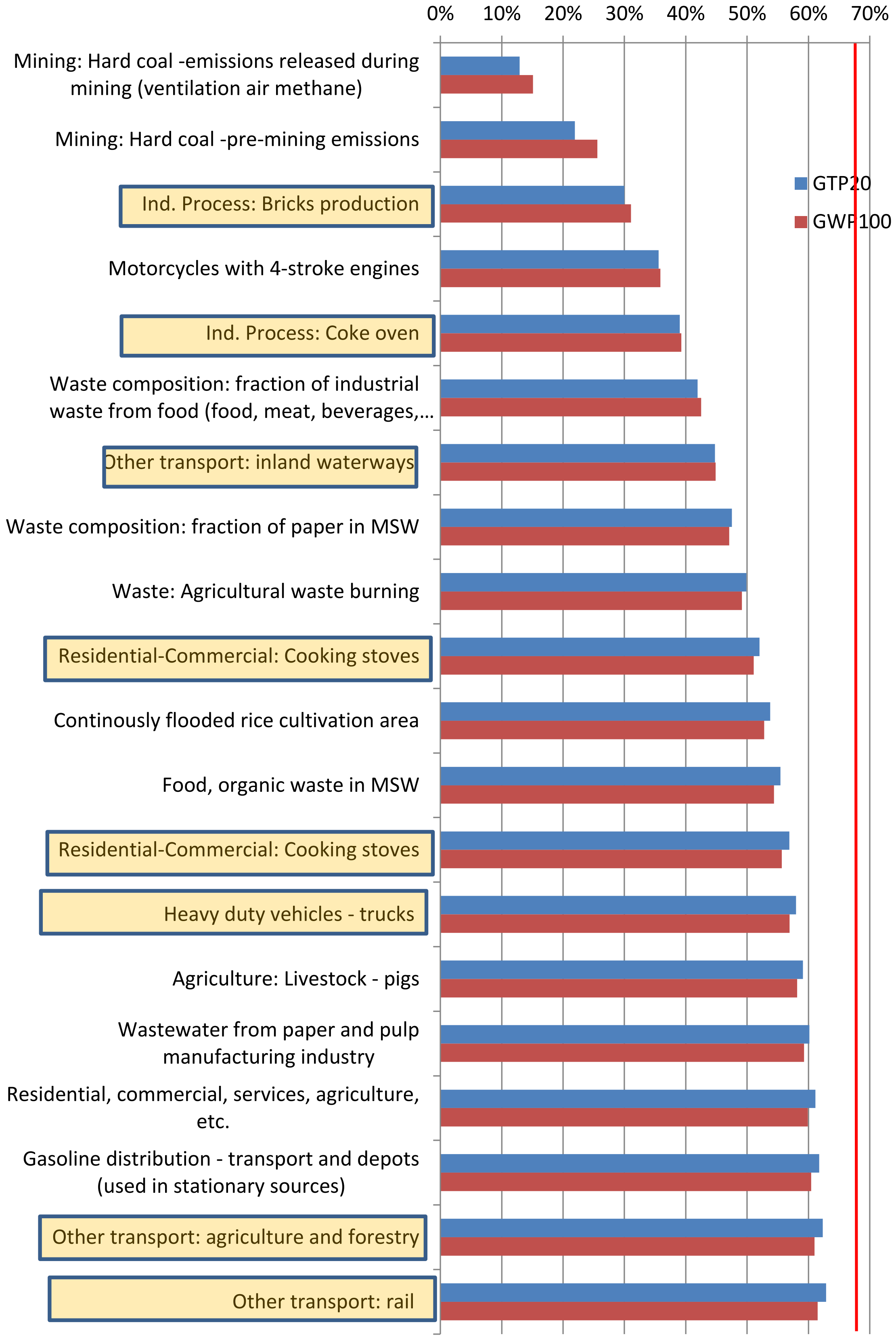

Figure 20: The 'Top 20'measures to reduce climate impacts of SLCPs in China in 2030

Table 7: Top-20 measures in Europe and China

Europe and China	Europe only	China only
Mining: Hard coal -pre-mining emissions	Transportation of natural gas	Industrial processes: bricks production
Mining: Hard coal -emissions released during mining (ventilation air methane)	Oil and gas production – reduced leakages	Industrial process: coke ovens
Residential, commercial, services, agriculture, etc.	Power & district heat plants new, for gas-turbines	DPF for heavy duty vehicles
Residential-commercial: Heating stoves	Residential-commercial: Single house boilers (<50 kW) - manual	Motorcycles with 4-stroke engines
Waste composition: fraction of industrial waste from food (food, meat, beverages, tobacco) industry	Wastewater from food (incl. beverages and tobacco) manufacturing industry	Other transport: inland waterways
Waste composition: reduced fraction of paper in municipal solid waste	Waste water treatment (domestic)	Residential-Commercial: Cooking stoves
Waste: Agricultural waste burning	Reduced emissions from gas flaring	Continuously flooded rice cultivation area
Agriculture: Anaerobic digestion, livestock - pigs		Food, reduced organic waste in MSW
Reduced food and organic waste in municipal solid waste		Wastewater treatment from paper and pulp manufacturing industry
		Replacement of kerosene wick lamps

2.6 Health benefits and contribution to development goals

As discussed in ECLIPSE Deliverable 7.2, the ECLIPSE set of measures, in addition to their climate impacts, also results in significant health benefits. Just for India and China, implementation of these measures could save annually up to 900,000 cases of premature deaths from air pollution in the long run.

In addition to their positive health effects, the selected measures will result in a variety of other benefits that contribute to human development and rank high on national policy agendas. These include:

- increased security in food and energy supply (through reduced tropospheric ozone burden, lower water demand,
- improved occupational health (in coal mines),

- cost savings due to revenues from selling recovered methane from oil and gas production, land fills, anaerobic digestion,
- less ground-water pollution from avoided landfills,
- Reduced water demand from Intermittent flooding of rice paddies,
- Lower CO_2 emissions through more efficient energy use (e.g., brick production)

3 Conclusions

The study has identified 20 measures that could together reduce the GWP100 from short-lived substances by 60%. The main mitigation potential is in developing countries.

The key mitigation potential is associated with methane measures, while the net effects of many BC measures on GWP100 are limited.

The largest mitigation potential is found for operations of large multi-national and national energy companies and municipalities, compared to measures that require investments at poor households in developing countries.

These measures for short-lived substances have important co-benefits on a wide range of development goals, including improved human health from air pollution. However, control of short-lived substances does not resolve all local (air quality) problems, and additional measures might involve trade-offs with climate objectives.

The analysis also clearly demonstrates that non-Kyoto gases do not offer substitutes for CO_2 mitigation aimed at long-term climate targets.

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