Quantification of the climate benefits of the UK achieving WHO-10 by 2030

Report for Clean Air Fund
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Executive summary

The aim of this project is to build on the work carried out by Imperial College, which defined a pathway for achieving the WHO $PM_{2.5}$ guideline value of 10 µgm^{-3} (WHO-10) by 2030, and to now estimate what this pathway would mean in terms of associated greenhouse gas (GHG) emissions.

E1 The Baseline

The key task was to develop a GHG baseline dataset which is comparable to the $PM_{2.5}$ emissions described in the report by Imperial College[1] (*Imperial report* hereafter). For the purpose of this study, we only considered anthropogenic emissions.

The main priority when developing an emission dataset is to have a full set of fuel data and other activity data that is consistent across all pollutants of interest, i.e., GHG and $PM_{2.5}$. Most of the sources shared by both GHGs and $PM_{2.5}$ relate to the burning of fossil fuels, whereas biofuels are not important for GHGs since their combustion does not release fossil carbon. Fortunately for the purposes of estimating GHG emissions, these are largely driven only by the fuel type and the amount of fuel being burned. $PM_{2.5}$ emissions, however, are also driven by the type and quantity of fuel burned, but also depend on how the fuel is being burned (i.e., the combustion technology and/or any abatement technology that might be in place). So in order to estimate GHG emissions it is enough for us to be able to calculate the types and quantities of fuel being burnt, and we do not need to have a full understanding of the appliances being used to burn that fuel.

E1.1 Building the baseline

The underlying 2018 emissions data used by Imperial for their $PM_{2.5}$ assessment are largely based on the UK national atmospheric emission inventory (NAEI), apart from the road transport emissions.
For the purpose of this study, all 2018 GHG and Black Carbon emissions are taken from the 2018 NAEI. Projected 2030 emissions have been derived in line with the Government's Updated Energy and Emissions projections (EEP18) reference scenario (case), published in April 2019[2]. As such the results in this report take account of all policies and measures (PaMs) considered in the EEP18 analysis.

UPDATED ENERGY AND EMISSIONS PROJECTIONS 2018 REPORT*
EEP Policies *The main projection is the "reference case", which is one view of how the UK energy and emissions system could evolve under implemented, adopted and agreed** Government policies if no new policies or changes to existing policies were introduced. Other views of the future are possible and there are significant uncertainties in these projections.*

*https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/794590/updated-energy-and-emissions-projections-2018.pdf
**Agreed policies are at the point where policy-specific analysis has been published (i.e. April 2019) with sufficient detail for inclusion in the Energy and Emissions Projections (EEP). Annex D provides details on how we include policies in the EEP. The polices in the EEP18 are based on the 2009 Low Carbon Transition Plan or later policies adopted and agreed by April 2019.

In summary, the EEP reference scenario projections provide a somewhat conservative view of the future by assuming central assumptions around fuel price, GDP and population growth. It is worth noting that our projected GHG emissions are naturally more uncertain than historic (past) emissions, not least due to the uncertainty around the trends in emissive activities even under a business-as-usual future,

[1] https://www.imperial.ac.uk/school-public-health/environmental-research-group/research/modelling/pathway-to-who/
[2] https://www.gov.uk/government/publications/updated-energy-and-emissions-projections-2018. It should be noted that a more recent publication of UK GHG projections is available, "Energy and emissions projections: Net Zero Strategy baseline".

whereas activity levels in the past are relatively certain. Thus, activity levels tend to change even in absence of new policies as the economy grows or shrinks or as factories, plants or machinery are modified or replaced etc. It is also worth stating that the EEP dataset is developed annually by BEIS to track progress of the UK's GHG emissions against the carbon budgets set in the 2008 Climate Change Act. Thus, the PaMs that are considered when deriving EEP are those that have a significant impact on fuel use and GHG emissions. But these PaMs can also impact on air quality pollutants. Conversely, some PaMs, that impact on air quality pollutants may not be considered by EEP but might still impact on GHGs. Thus, projects such as this study are vital to obtain an overarching view of future emissions across all species and to understand the impacts PaMs have on various species.

E1.1.1 Understanding the relationship between emissions of GHG and particulate matter (PM)

To fully understand and interpret the GHG baseline and the GHG scenario results in the following sections, it is useful to take a step back and examine the overall relationship between emissions of particulate matter (PM), and emissions of GHGs. This relationship very much determines the impact a specific PaM will have on reducing (or even increasing) GHGs and/or PM, and the magnitude of the change in emissions on either or both. PaMs targeting GHG emissions do not necessarily have the same impact on air quality pollutants such as $PM_{2.5}$ and *vice versa*. In fact, certain GHG policies can have the opposite impact on $PM_{2.5}$, e.g. increasing the use of biomass instead of natural gas, say, would decrease GHGs but increase the release of harmful air quality pollutants such as $PM_{2.5}$.

E1.1.1.1 Basics of (anthropogenic) emissions to air

Emissions of all pollutants occur as a result of various activities or processes. Some of these activities (such as fuel combustion) result in emissions of a wide spectrum of pollutants to air, including both PM and GHGs. The GHGs and PM are both formed as a result of the same process – that of combusting a fuel, for example – so there is a possibility that any PaM to address emissions of PM from that type of source will also have an impact on any GHG emissions from that source. However, it matters how that PaM seeks to reduce PM emissions. Taking the example of fuel combustion, there are a wide range of options for reducing PM, including:

1. Reducing the consumption of the fuel i.e. reducing the level of the activity itself;
2. Changing the way the fuel is burnt, for example by using a new 'cleaner' appliance instead of an older type with higher emissions (changing appliances may of course also change fuel consumption as well);
3. Changing the quality of the fuel itself e.g. using kiln-dried wood instead of wet wood or using coal of a certain quality.
4. Use of abatement technologies that can reduce the levels of air pollutants in waste gases before they are released to atmosphere e.g. use of filtration to capture particulate matter.

PaMs targeting the reduction of certain fuels (first option above) will reduce emissions of all pollutants equally – using less fuel means less emissions in total. The remaining options, i.e. options 2 to 4 from the above list, are unlikely to have the same impact on all pollutants and are in fact likely to have less impact (or possibly no impact at all) on GHGs. CO_2 emissions just depend on the quantity of fuel being combusted, so options 2-4 will not impact on the magnitude of CO_2 emissions unless a specific PaM also reduces the quantity of fuel being burnt. In theory, CO_2 emissions can be abated e.g. by carbon capture and storage, but that will not be a PaM for reducing PM emissions. Emissions of CH_4 and N_2O may be changed by options 2 and 3, although emissions may not always be reduced. $PM_{2.5}$ abatement techniques (option 4) are unlikely to affect either pollutant. BC emissions are closely related to $PM_{2.5}$ so all 4 of the listed options would be likely to also reduce emissions of BC.

It is also important to note that the significance of emission sources varies depending on the pollutant considered. Just because a particular activity gives rise to very significant emissions of $PM_{2.5}$ doesn't mean that it also gives rise to very significant emissions of GHGs and in fact many of the more important sources of $PM_{2.5}$ are irrelevant for GHGs. Some general themes are:

- Solid fuels generally give rise to much higher PM emissions than gaseous or liquid fuels do, although liquid fuels such as heavy fuel oil can emit significant PM. In comparison, all fossil fuels, whether solid, liquid or gaseous give rise to similar levels of GHGs per unit of mass burnt.
- Biofuels do not emit fossil carbon but solid biofuels such as wood are very significant sources of PM emissions
- PM emissions also occur from a wide range of non-combustion 'processes' such as construction activities, or handling of dusty materials, and these processes will not emit GHGs.

E1.1.2 GHG baseline emissions for 2018 and 2030

Table E1 summarises the resulting UK GHG baseline emissions for both historic and projected years. Emissions are grouped by SNAP[3] code (**S**elected **N**omenclature for **A**ir **P**ollution), a common nomenclature used to categorise emissions of air quality pollutants. It is worth noting that GHG emissions tend to be summarised by IPCC (CRF) code and not SNAP code. However, for the benefit of comparing GHG and $PM_{2.5}$ emissions we have grouped the GHG emissions by SNAP[4]. The results for 2030 will be different to the emissions quoted in the EEP18 report but this will be due to subtle methodological differences - they are both generated using the same basic data. For comparison we have added the $PM_{2.5}$ emissions as summarised in Table 2 in the Imperial Report.

Table E1: 2018 baseline emissions and 2030 Business as Usual emissions, Mtonnes

SNAP*	GHG total (CO_2 equiv)**		% change in GHG under BAU	$PM_{2.5}$		% change in $PM_{2.5}$
	2018	2030		2018	2030	
1	94.13	50.66	-46%	0.004	0.003	-20%
2	87.43	91.21	4%	0.047	0.029	-39%
3	49.40	40.69	-18%	0.019	0.014	-25%
4	9.31	8.89	-5%	0.008	0.007	-12%
5	5.58	3.71	-33%	0.001	0.000	-60%
6	14.29	14.34	0%	0.001	0.001	-8%
7	112.86	91.29	-19%	0.016	0.011	-29%
8	18.54	18.55	0%	0.006	0.003	-47%
9	23.12	17.42	-25%	0.002	0.002	0%
10	40.84	40.84	0%	0.003	0.003	0%
Total	**455.50**	**377.59**	**-17%**	**0.104**	**0.072**	**-31%**

* 1 Combustion in energy production and transfer; 2 Combustion in commercial, institutions, residential and agricultural sectors; 3 Combustion in industry; 4 Production process; 5 Extraction / distribution of fossil fuels; 6 Solvent use; 7 Road transport; 8 Other transport and machinery; 9 Waste treatment and disposal; 10 Agricultural (excl forests and land use change)
**Include CO_2, CH_4, N_2O, F gases

The 2030 baseline emissions take account of PaMs which have been agreed and/or adopted by April 2019 and are considered in EEP18. The associated emission changes are not considered again for the scenario development. In addition, the Imperial report describes additional adjustments made to some sectors to reflect further PaMs that impact on $PM_{2.5}$ (see Table 4 of Imperial report). As mentioned already, the EEP18 dataset reflects PaMs that impact significantly on GHGs and does not necessarily include PaMs that are important for air quality pollutant emissions. To ensure consistency with Imperial's work, we reviewed the $PM_{2.5}$ adjustments made, and estimated how GHG emissions should also be changed (either increased or decreased emissions). It is important to note that these emission changes are not linked to moving to tighter WHO $PM_{2.5}$ limit values but are the result of updating the baseline

[3] https://en.eustat.eus/documentos/elem_13173/definicion.html
[4] Appendix 1 provides a conversion table for CFR to SNAP code.

data to improve consistency with more up to date data (EEP19[5]) and to include PaMs that are excluded from EEP18.

Table E2 provides an overview of additional GHG emission reductions driven by $PM_{2.5}$ adjustments.

Table E2: 2030 $PM_{2.5}$ emission adjustments

SNAP sector	$PM_{2.5}$ adjustments	Expected CO_2 e saving in 2030
1	Adjustment for new natural gas projection: using EEP19 natural gas figures for power stations instead of EEP18 figures	8 Mtonne CO_2 e
2	Using latest Defra domestic wood burning activity from the 2021 Digest of UK Energy Statistics (DUKES).	0.5 Mtonne CO_2 e
2	Legislation regulating the sale of traditional coal in England - sales of house coal in England were phased out in May 2021, with transition periods available.	1.2 Mtonne CO_2 e

E2 The Scenarios

The Imperial study developed four scenarios, one UK Road Transport only scenario and three London specific scenarios, see table E3.

Table E3: Scenario overview

Scenario	Underlying PaMs and assumptions
UK Road Transport scenario	Committee on Climate Change's Sixth Carbon Budget report[6] (UK CCC BNZP) 2030 baseline emissions based on NAEI 2018[7]
LS1	London Environment Strategy (LES)[8], Port of London Authority's Emission Reduction Roadmap[9] and Air Quality Strategy[10]
LS2	London Environment Strategy (LES), Mayor's $PM_{2.5}$ roadmap document[11]
LS3	LS2 plus 100% reduction to domestic wood burning

The underlying baseline dataset for 2018 and 2030 used for the London scenarios are a subset of the UK baseline dataset. We assumed the same basket of measures to assess the impacts on GHG emissions.

E2.1 UK Road Transport Scenario

The UK scenario, developed by the Imperial College team, is covering Road Transport measures only. Imperial estimated the UK's road transport $PM_{2.5}$ emissions in 2030 using the Sixth Carbon Budget report[12] published by the Climate Change Committee (CCC) in December 2020, and their recommendation on the "Balanced Net Zero Pathway" (BNZP) scenario. Thus, the CCC BNZP was also used to estimate the UK's GHG road transport emissions in 2030 for the UK emissions scenario.

The CCC BNZP under the Sixth Carbon Budget report is built on known mitigation technologies where they exist and try to minimise the use of greenhouse gas removals. Assumptions for the CCC BNZP for

[5] https://www.gov.uk/government/publications/updated-energy-and-emissions-projections-2019
[6] Sixth Carbon Budget - Climate Change Committee (theccc.org.uk)
[7] The CCC Sixth Carbon Budget report is using provisional figures of NAEI 2019, the final figures of NAEI 2018, and CCC's internal analysis as the starting point to develop emission projections. To align with the Imperial report, the NAEI2018 road transport data has been used as baseline data.
[8] https://www.london.gov.uk/sites/default/files/london_environment_strategy_0.pdf
[9] https://server1.pla.co.uk/assets/emissionsroadmapjune2020final.pdf
[10] https://server1.pla.co.uk/assets/airquality2020v1.pdf
[11] https://www.london.gov.uk/sites/default/files/pm2.5_in_london_october19.pdf
[12] Sixth Carbon Budget - Climate Change Committee (theccc.org.uk)

the surface transport sector were derived based on a detailed review of available evidence. This includes previous CCC's analysis, research across all sectors that has been published since the Fifth Carbon Budget, recent market development, new analytical modelling within the CCC, new research on potential decarbonisation options for road freight and extensive stakeholder engagement.

E2.2 London Road transport Scenario

The Imperial College team has assumed the same emission scenario for the three 2030 London road transport scenarios (LS1, LS2, LS3). LS1 is considered to be the business-as-usual scenario and thus is based on the commitments made in the London Environment Strategy (LES) published in May 2018[13]. Since the LES included the two phases of the implementation of the ultra-low emission zone (ULEZ) in London, the same vehicle assumptions have been used in all scenarios. This study applies those vehicle assumptions, as listed in Table 8 in the Imperial report, in the London emission scenarios (LS1, LS2 and LS3) to examine the climate benefits in London in 2030.

E2.3 London Stationary and other transport Scenario

GHG reductions have been calculated for the scenario assumptions as described in the Imperial report (Table 9). That table lists a number of high-level source sectors and presents the emissions in London in 2018 and 2030 for the three London scenarios – LS1, LS2 and LS3. There is some accompanying discussion of these scenario 'measures' but they are not described in detail, and it is sometimes not possible to gain a firm idea of what the scope of source sectors are, and how any emission reductions are brought about. We have analysed the relationship between GHG and $PM_{2.5}$ emissions from each of these sources and estimated an associated GHG emission reduction potential for each measure assuming a best-case scenario in cases where we have no firm information, i.e. our default assumption is to assume the same percentage reduction in GHG emissions as can be achieved for $PM_{2.5}$. As a result, the calculated GHG reductions are quite uncertain, and more likely to over- than under-estimate GHG emissions.

The dataset developed by the Imperial College team also contains one source currently not covered by the NAEI, commercial cooking. This source should only cover $PM_{2.5}$ that is created from the foods being cooked, since $PM_{2.5}$ from the fuels being consumed (i.e., burned) to do that cooking should already be included elsewhere in both the NAEI and Imperial's estimates. These cooking processes will most likely also produce small quantities of GHGs however there are no emission estimates in the NAEI, due to the lack of a suitable methodology. Thus, we cannot estimate GHG reductions for this source. However, it is in any case debateable whether controls on dust nuisance from commercial cooking would have any impact on gaseous GHGs. The controls would take the form of requiring appropriate abatement of the dust, so use of filters, for example, which would be ineffective at reducing emissions of GHGs. Although this is a significant measure in the context of reducing $PM_{2.5}$ emissions, we believe that there will be no reductions in GHGs.

Black carbon reductions have been calculated directly from the $PM_{2.5}$ reductions given in Table 9 of the Imperial report. This is done by calculating an aggregate black carbon to $PM_{2.5}$ ratio for each of the source categories given in that Table, using data from the NAEI. As with GHGs, the NAEI does not contain black carbon estimates for commercial cooking, but we have made some provisional estimates for this study.

E3 Results

UK emissions totals, aggregated for SNAP categories 1-10 are shown in Table E4. Figures are given for 1990, 2018 and the various scenarios for 2030, and the table also includes overall UK reductions in CO_2e, calculated relative to three different baselines: 1990, 2018 and the 2030 BAU scenario.

[13] https://www.london.gov.uk/what-we-do/environment/london-environment-strategy

Table E4: UK GHG emissions and emission reductions

Year	Scenario	GHG total (Mt CO_2 equiv)	% reduction in UK emissions relative to:		
			1990	2018	2030 BAU
1990	-	785	-	-	-
2018	-	455	42%	-	-
2030	BAU	378	52%	17%	-
2030	CCC BNZP	332	58%	27%	12%
2030	CCC BNZP + LS1	329	58%	28%	13%
2030	CCC BNZP + LS2	329	58%	28%	13%
2030	CCC BNZP + LS3	329	58%	28%	13%

Table E5 summarises the total impact of the measures defined in the CCC BNZP, and the LS1, LS2 and LS3 scenarios on overall UK 2030 GHG emissions compared to the 2030 GHG business as usual emissions. The results have been split into stationary and other transport (i.e. shipping, rail and aviation) and road transport sources. Results are expressed as % reductions of the UK 2030 business as usual emissions. Note that the figures for the UK (CCC BNZP) and London scenarios are calculated separately and can be summed, and so the total reduction in all emissions from both scenarios is 13%: 12% from road transport sources under the UK CCC BNZP scenario, and ~1% from non-road transport sources under the London scenarios.

Table E5: 2030 Scenario results (% change in UK CO2e emissions compared with 2030 BAU)

Scenario	CCC BNZP	LS1	LS2	LS3
Measures for road transport	-12%	-	-	-
Measures for stationary and other transport sources	Only affects non-RT	-0.8%	-0.8%	-0.8%

E3.1 Road transport sources (UK and LS1-LS3)

The Balanced Net Zero Pathway delivers a reduction in the UK surface transport emissions of 50% by 2030 which can be achieved if all recommended measures are implemented; for example, phase-out of fossil fuelled passenger vehicles by 2032, significant uptake of zero emission vehicles, demand-side measures in road transport, better efficiency of new conventional vehicles, uptake of PHEVs and rail decarbonisation. In this project, we have assumed that the UK's 2030 road transport emissions are reduced by 50% under the UK Road Transport scenario similarly to the CCC BNZP scenario for the surface transport emissions. The UK BNZP Road Transport scenario delivers a 12% reduction in the total UK emissions by 2030 as shown in Table E5.

In the Imperial report, LS1 was considered to be the business-as-usual scenario for London 2030 emissions and which is based on the commitments made in the London Environment Strategy (LES) as was published on 31 May 2018. However, since the two phases of the Ultra Low Emission Zone (ULEZ) in London were taken into account in the LES, the same vehicle and traffic assumptions were made in the LS2 and LS3 emission scenarios for 2030, as presented in Table 8 of the Imperial report. Therefore, all London's emissions scenarios (LS1, LS2, LS3) do not result in further reductions to the UK 2030 RT GHG emissions as shown in Table E5.

E3.2 Stationary and other transport sources (LS1-LS3)

The impact of the $PM_{2.5}$ measures related to stationary sources and other transport on GHG emissions are small partly because some of the measures focus on technological solutions such as abatement of dust emissions or rely on controlling sources such as biofuels which are trivial sources of GHG emissions. It also reflects the fact that London contributes less than 10% of UK GHG emissions.

Overall emission reductions for GHGs are fairly modest: those achieved under the three London scenarios for stationary sources and other transport are equal to less than 1% of UK emissions when compared with overall 2018 UK baseline. The reductions under the three London scenarios just within London are obviously more significant within London itself (Table E6), although there is little difference between the GHG reductions in each of the three scenarios, which is very different to the situation for $PM_{2.5}$. For that pollutant, the LS2 and LS3 scenarios achieve much higher reductions in London: this is done by reducing $PM_{2.5}$ from sources that are not significant sources of GHGs, thus there is little extra GHG reduction in LS2 and LS3.

Table E6: 2030 scenario reductions relative to 2018 London baseline, Stationary and other transport sources only (Imperial report table 9 & this study for CO_2e)

Pollutant	2030 UK2030+LS1	2030 UK2030+LS2	2030 UK2030+LS3
$PM_{2.5}$	19%	57%	63%
CO_2e	22%	24%	24%

Note that the figures in Table E6 refer only to emissions in London for the sources listed in Imperial's Table 9 (i.e. stationary and other transport sources only), and not all emission sources in London. We use this because it is the only way we can present data on a consistent basis for both pollutants.

The overall reduction in GHGs from these sources is slightly higher than that for $PM_{2.5}$ for LS1 and much lower for LS2 and LS3. As discussed above, this reflects the fact that LS2 and LS3 seek reductions in sources that are significant for $PM_{2.5}$ but insignificant for GHGs. For the LS2 and LS3 scenarios, GHG reductions are about a third of the reduction in $PM_{2.5}$ in LS2 and LS3 (and note that we have had to assume a best-case reduction in GHGs in all three scenarios). This illustrates the point already made that reduction strategies for AQ pollutants don't always reduce GHGs. Measures to reduce CO_2 emissions would have to target the amount of fuel being burned in the first place rather than focusing on treatment of the exhaust gas. In addition, some important sources of $PM_{2.5}$ are not sources of GHGs so strategies aimed at reducing emissions from, say, commercial cooking or construction or Part B processes will not have any significant impact on GHGs. The detailed methodology how the PM2.5 impacts have been translated int GHG impact can be found in section 4.3.

E4 Discussion

Key outcomes of the analysis

The analysis indicates that current and proposed government policies related to net zero and air pollution, based on EEP18, CCC BNZP and LS1 will drive greenhouse gas emissions down by 28% by 2030 from 2018 levels, while simultaneously achieving the WHO-10 standard for $PM_{2.5}$ across the majority of the UK. Additional measures in London (LS2 to LS3 scenarios) designed to achieve the WHO-10 standard across London were estimated to generate less than 1% reduction in national GHG emissions from 2018 levels.

This study aimed to estimate the GHG emissions benefits of achieving WHO-10 by 2030, building on the analysis carried out by Imperial College. It also provides an understanding of the challenges in quantifying these co-benefits, highlighting what data are most important, and what is less essential. For example, detailed information on the underlying assumptions about fuel consumption and other activity, and assumptions regarding the nature of PaMs are both important for understanding the potential for

GHG emission reductions associated with reducing $PM_{2.5}$. Uncertainties regarding the underlying data and assumptions result in some uncertainty in the results, but this study still provides valuable information on the associated greenhouse gas (GHG) impacts of achieving the WHO $PM_{2.5}$ guideline value of 10 μgm^{-3}.

More broadly the key messages from the co-benefits analysis process are:

- It is possible to calculate the climate benefits associated with $PM_{2.5}$ reductions.
- To do that requires information on the assumptions and data used to estimate the $PM_{2.5}$ emissions and reductions, and gaps in that information adversely affect the quality of any estimates of climate benefits.
- In particular, it is vital to understand the fine detail of emissions, to be able to estimate the fuel consumption and other activity data that underpin the $PM_{2.5}$ estimates, and to understand the full nature of the PaMs that are assumed to reduce the $PM_{2.5}$ emissions.
- Both $PM_{2.5}$ and GHG inventories contain many of the same emission sources, but there are also plenty of sources that are only relevant for $PM_{2.5}$ or only relevant for GHGs, so some PaMs can address sources of one pollutant but have no impact on the other. Even for shared emission sources, there are huge variations in the relative significance. For example, all fossil fuels when burnt emit roughly similar quantities of GHG per tonne of fuel, whereas natural gas will produce far less $PM_{2.5}$ than will be produced by coal or heavy fuel oil. Biomass combustion can produce significant $PM_{2.5}$ emissions but will produce no fossil CO_2 at all. So PaMs that seek to address significant sources of $PM_{2.5}$ may not be addressing significant sources of GHGs. In London and the UK, for example, combustion of natural gas is a major source of GHG emissions but a minor source for $PM_{2.5}$. Thus, strategies to significantly reduce overall emissions of $PM_{2.5}$ may not reduce GHGs that much.
- When estimating co-benefits, it is crucial that there is consistency between the estimates made for different pollutants. This means that common assumptions are needed regarding the sources present and the levels of activity for each source. We have been able to estimate GHG emissions and GHG emission reductions only because we have sufficient information to understand the basis of the $PM_{2.5}$ inventory in the Imperial report. Our understanding is not complete, and further detail might have resulted in slightly different results.
- PaMs can work in different ways and not all PaMs that reduce $PM_{2.5}$ will necessarily also reduce GHG emissions (and *vice versa*). Some PaMs rely on prohibiting or otherwise reducing the level of an emissive activity e.g. banning the use of a particular fuel, and these PaMs will reduce all emissions from that particular source. Others rely on technologies or change aspects of a source (such as the quality of the fuel), and these have different impacts on different pollutants. We found it difficult to assess these differing impacts and therefore used a best-case default: that if PaMs were able to impact on GHGs as well as $PM_{2.5}$, that the percentage reduction would be the same for both. In other words, we characterised PaMs as either totally ineffectual at reducing GHGs or being equally effective for both GHGs and $PM_{2.5}$. This was mostly because we had insufficient information on the PaMs assumed by Imperial, but it also reflects a lack of a good dataset on co-benefits. Uncertainty regarding the effectiveness of PaMs to reduce emissions of GHGs is perhaps the most significant source of uncertainty in our estimates for gaseous GHGs.
- PaMs that try to decarbonise the road transport sector by phasing out fossil fuelled vehicles and improving the fuel efficiency of the remaining conventional vehicles can tackle just as much $PM_{2.5}$ as GHGs emissions, reiterating the point made previously that PaMs with a clear objective of reducing the consumption of the fossil fuels will have a similar impact on both air quality and GHG pollutants.

- Reductions have also been estimated for black carbon. Here, because black carbon is part of the $PM_{2.5}$ emission, it is much more certain that any PaM that reduces $PM_{2.5}$ will also reduce black carbon, probably by a very similar extent regardless of the type of PaM. But the assumptions used in the UK NAEI for the percentage of black carbon in $PM_{2.5}$ emissions from each source are quite uncertain and this is perhaps the biggest source of uncertainty for our results for this pollutant.
- Our work is based on data sources which have since been superseded, for example the BEIS Energy and Emission Projections and TfL GHG projections. Thus, our results show the GHG co-benefits for a certain point in time. More up to date datasets can lead to different results.

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1 Introduction

The aim of this project is to build on the work carried out for Clean Air Fund (CAF) by Imperial College to define a pathway for achieving the WHO $PM_{2.5}$ guideline value of 10 µgm^{-3} (WHO-10) by 2030, and to now estimate what this pathway would mean in terms of greenhouse gas (GHG) benefits. The base scenario used by Imperial comprised DEFRAs Business as Usual (BAU) forecast, plus adjustments based on the Climate Change Committee's 6th Carbon Budget and a current policy scenario for London (LS1). The scenario estimated that the WHO-10 value would be largely achieved across the country with the exception of London and so two further London focused scenarios were estimated (LS2 and LS3) to achieve compliance in London. The analysis has been carried out at both the national level and for London (as a subset) to estimate the co-benefits.

The objectives of this project are to:

- Quantify the climate benefits of the UK achieving WHO-10 by 2030. Quantify the greenhouse gas emission reductions associated with the set of policies identified in Imperial's report 'Pathway to WHO: achieving clean air in the UK' (hereafter referred to as the 'Imperial report'). The climate impact will be estimated split between expected greenhouse gas (GHG) emissions (from existing climate action based on the committee on climate change 6th carbon budget) and what additional benefit will be achieved from additional measures to ensure WHO-10 by 2030.
- Provide evidence of the climate impacts of AQ action in the UK for messaging in the public consultation process and parliamentary debate on the UK's new $PM_{2.5}$ target. The evidence generated will be disseminated by CAF and provided to the air quality field and other partners to use in the public consultation process and parliamentary debate.
- Develop a proof of concept for generating evidence of AQ-climate synergies at a national scale, to quantify climate impacts of AQ targets and AQ action.

1.1 $PM_{2.5}$ and GHG emission sources

Before discussing the approach in detail, it is perhaps useful to examine the relationship between emissions of particulate matter (PM), and emissions of GHGs. This relationship determines if PaMs designed to tackle PM will impact on GHGs, and vice versa.

Emissions of all pollutants occur as a result of various activities or processes. Some of these activities (such as fuel combustion) result in emissions of a wide spectrum of air pollutants, including both PM and GHGs. The GHGs and PM are both formed as a result of the same process – that of combusting a fuel, for example – so there is a possibility that any PaM to address emissions of PM from that type of source will also have an impact on any GHG emissions from the source. However, it matters how that PaM seeks to reduce PM emissions.

Taking the example of fuel combustion, there are a wide range of options for reducing PM, including:

1. Reducing the consumption of the fuel i.e. reducing the level of the activity itself (for example electrification of the vehicle fleet);
2. Changing the way the fuel is burnt, for example by using a new 'cleaner' appliance instead of an older type with higher emissions (changing appliances may of course also change fuel consumption as well);
1. Changing the quality of the fuel itself e.g. using kiln-dried wood instead of wet wood, or using coal of a certain quality.
2. Use of abatement technologies that can reduce the levels of air pollutants in waste gases before they are released to atmosphere e.g. use of filtration to capture particulate matter.

The first option above will reduce emissions of all pollutants equally – using less fuel means less emissions across the board. The remaining options though are unlikely to have the same impact on all pollutants and are in fact likely to have less impact (or possibly no impact at all) on GHGs. CO_2 emissions just depend on the quantity of fuel being combusted, so options 2-4 will not impact on the magnitude of CO_2 emissions unless the measure also reduces the quantity of fuel being burnt. For example, a new cleaner gas boiler might emit less $PM_{2.5}$ than an old boiler, but it might also be a bit more efficient than the older appliance, so that less gas needs to be burnt. But fitting, say, a filter, in order to capture PM emissions is unlikely to have any significant impact on fuel consumption and therefore, CO_2. The other gaseous GHGs (methane and nitrous oxide) and Black Carbon (see section **Error! Reference source not found.**) are somewhat like $PM_{2.5}$ and other air quality pollutants in that emission rates are dependent on the technology and fuel quality as well. So, emissions of these GHGs could well be affected by options 2 and 3 listed above (although not necessarily always reduced). Abatement techniques for $PM_{2.5}$ are unlikely to have any impact on methane and nitrous oxide.

From the above, it is clear that, in order to assess the co-benefits of PaMs, it is vital to understand the exact nature of those PaMs. Ideally, one should be able to understand how each PaM will impact on the level of activity, as well as the level of emission. This is arguably the single most important requirement for analysing the climate benefits of air quality reductions or *vice versa*.

It is also important to note that the significance of emission sources varies depending on what air pollutant is being considered. Just because a particular activity gives rise to very significant emissions of $PM_{2.5}$ doesn't mean that it also gives rise to very significant emissions of GHGs and in fact many of the more important sources of $PM_{2.5}$ are irrelevant for GHGs. Some general themes are:

- Solid fuels generally give rise to much higher PM emissions than gaseous or liquid fuels do, although liquid fuels such as heavy fuel oil can emit significant PM. In comparison, all fossil fuels, whether solid, liquid or gaseous give rise to similar levels of GHGs per unit of mass burnt.
- Biofuels do not emit fossil carbon but solid biofuels such as wood are very significant sources of PM emissions.
- PM emissions also occur from a wide range of non-combustion 'processes' such as construction activities, or handling of dusty materials, and these processes will not emit GHGs.

Thus, some of the sources that make a major contribution to $PM_{2.5}$ emissions make minimal or no contribution to GHG emissions and PaMs that address these sources cannot therefore have any significant impact in reducing GHG emissions. The differences in contributions can be illustrated for fuels by comparing the ratio of GHG emission (in tonnes CO_2e) with $PM_{2.5}$ emissions (in tonnes) for different fuel types burnt by industry:

Fuel	CO_2e : $PM_{2.5}$ Ratio
Wood	14
Coal	540
Fuel Oil	2270
Burning oil	3600
Natural Gas	87,300

In other words, if enough wood is burnt to emit 1 tonne of $PM_{2.5}$, this would only result in about 14 tonnes CO_2e, whereas burning enough gas to emit 1 tonne of $PM_{2.5}$ would result in nearly 90,000 tonnes of CO_2e. Combustion of natural gas is not generally seen as an important source of $PM_{2.5}$ but it is a major source of GHGs and any PaMs that seek to reduce gas combustion will be likely to significantly reduce GHGs as well.

1.2 PM2.5 and Black Carbon emission sources

Unlike the greenhouse gases discussed in Section 1.1, black carbon emissions are closely related to $PM_{2.5}$ emissions, being essentially a proportion of those $PM_{2.5}$ emissions. Because of this close relationship between the pollutants, any policy or measure that seeks to reduce $PM_{2.5}$ from a specific source will also likely reduce black carbon from that source, for example road transport exhaust emissions and dust emitted from construction activities. Unlike for $PM_{2.5}$ and greenhouse gases, this doesn't depend much on the exact nature of the policy or measure - regardless of whether a measure works by eliminating an activity, or by abating $PM_{2.5}$ through the use of technology, that measure should also reduce black carbon. Abatement and other technological measures may not have the exact same impact on $PM_{2.5}$ and black carbon i.e. the percentage reductions might not be identical, but we expect that differences will be fairly small. For the purposes of this work, and because we do not have data on the efficiencies of measures for black carbon, we will assume that the same percentage reduction can be assumed for black carbon as is achieved for $PM_{2.5}$.

Black carbon makes up a proportion of $PM_{2.5}$ emissions from sources, but that proportion varies widely from one type of source to another. Black carbon is essentially soot i.e. carbonaceous particulate matter formed from incomplete combustion of carbon-containing fuels such as fossil fuels or biofuels. Emissions can also occur from industrial processes that involve combustion or from high-temperature treatment of materials, and there are also some non-combustion sources in the UK inventory including tyre-wear. In the NAEI, emissions of black carbon for each source are estimated by assuming a fixed percentage of $PM_{2.5}$ is black carbon. This fixed percentage varies by source and is lowest for industrial processes involving heat (e.g. kilns producing glass, lime & bricks, electric arc furnaces, chemicals manufacture): for these types of process, the assumption is that $PM_{2.5}$ is <2% black carbon, and often <1%. Assumed levels of black carbon in $PM_{2.5}$ emissions for the most commonly used types of fuels are shown in Table 8 (as ranges – the exact figure depends on the emission source).

Table 1: Assumed levels of black carbon in $PM_{2.5}$ emissions for various fuel types

Fuel type	$PM_{2.5}$ adjustments
Natural gas	2.5% to 4%
Coal	2% to 10%
Biomass	10% to 30%
Oils used in industry	30% to 70%
Oils used in transport	12% to 60%

The assumptions used in the NAEI are quite uncertain, but they do indicate that measures to tackle emissions of $PM_{2.5}$ from petroleum-based fuels and from biomass are also likely to be important for reducing emissions of black carbon.

2 Task 1 – Scenario alignment

The key task for the baseline alignment is to develop a GHG baseline dataset which is comparable to the $PM_{2.5}$ emissions described in the Imperial report. Some of the emission sources that emit $PM_{2.5}$ (such as combustion of fossil fuels) will also produce emissions of GHGs, and so we have to produce a GHG baseline that uses consistent assumptions about those shared emission sources. However, some sources of $PM_{2.5}$ are sources only of dust and emit no GHGs (for example construction activities) and there are also sources of GHGs that do not create $PM_{2.5}$ (for example, the various sources of F gases). For the sake of completeness, we have included the GHG-only sources in our GHG dataset, but these sources will not be affected by measures to achieve WHO-10, so do not need to be considered further. Similarly, there will be some measures to achieve WHO-10 which have no impact on GHGs, since they address sources that only emit particulate matter.

The main priority when developing a GHG dataset is to develop a full set of fuel data that are consistent with both the GHG and $PM_{2.5}$ baseline dataset. Most of the sources that are shared by both GHGs and $PM_{2.5}$ relate to the burning of fossil fuels, therefore if we generate a set of fuel consumption estimates consistent with the $PM_{2.5}$ baseline, this can then be used to estimate GHG emissions. GHG emissions are mostly driven by the fuel type and the amount of fuel burned whereas $PM_{2.5}$ emissions are partly driven by the type and quantity of fuel burned, but also driven by how the fuel is being burned (i.e., the combustion technology and any abatement in place). We therefore do not have to understand the full detail of the $PM_{2.5}$ baseline dataset – what technologies are assumed, for example – instead we just need to have a basic inventory of fuels burned. The Imperial report does not give fuel consumption and other activity data consistent with the $PM_{2.5}$ baseline data, and indeed some of the emissions data are derived from air monitoring data and inverse modelling, rather than from the use of activity data and emission factors. So instead, we have had to create an activity dataset that could be expected to be closely consistent with the $PM_{2.5}$ figures reported in the Imperial report. We can do this because we know that the Imperial work started from the 2018 'version' of the UK National Atmospheric Emission Inventory[14] (NAEI), and so we can start with the activity data held in the 2018 version of the NAEI database, and the activity data that we calculated in 2020 for the associated emission projections, which were based on the 2018 version of BEIS' Energy and emissions projections (EEP) forecasts (hereafter referred to as EEP2018). These NAEI activity data/projections should be broadly consistent with the emission estimates summarised in the Imperial report. The Imperial team did make some adjustments to the NAEI data but, to a large extent, these adjustments can be ignored because most of them essentially related to adjusting the $PM_{2.5}$ emission factors (EF) and not the underlying activity (i.e. fuel) data. For example, the Imperial College work used alternative road traffic emission estimates, but we can assume that their estimates will still assume the same use of petrol and diesel as in the NAEI. This is certainly true for the historic 2018 baseline since consumption of petrol and diesel in that year is available in the Digest of UK Energy Statistics (DUKES) and not in doubt. On the other hand, it is possible that Imperial's estimates for 2030 might assume a slightly different consumption of road fuels. However, even if this is true, it is likely to be a trivial difference and the impact on GHG emissions will be small. Imperial did make changes in two areas that would have affected the underlying activity data:

- More recent projections were used for natural gas consumed at power stations i.e., they deviated from the projected NAEI data for 2030 for this source. We have assumed that they instead used the 2019 version of BEIS' Energy and emissions projections forecasts (hereafter referred to as EEP2019) and so have made a similar change to our GHG dataset. The change in the projected 2030 activity data is relatively trivial.
- More recent data were used for wood burnt in the residential sector. BEIS have recently revised down their estimates for this fuel, see DUKES 2021[15], by about 70% compared with the numbers used in the 2018 NAEI (see DUKES 2019[16]). This is a significant change for $PM_{2.5}$ since residential combustion of wood is a key source of $PM_{2.5}$ emissions. But wood is a biofuel and so burning it does not lead to any reportable emissions of CO_2. Methane and nitrous oxide will be emitted but these emissions are trivial. Nonetheless, we have adjusted our GHG dataset to be consistent with this adjustment.

The reporting of emissions to the UNFCCC (as part of the Kyoto Protocol) and UNECE (as part of the Gothenburg Protocol) also differs between $PM_{2.5}$ and GHG pollutants. Some sources that would be included in national totals for air quality pollutants such as $PM_{2.5}$ are excluded from national totals for GHGs and *vice versa.* For the purposes of this work, we have reported GHG emissions using the same SNAP[17] sector used on the Imperial report for $PM_{2.5}$. This does mean that the GHG emissions will not necessarily match emissions reported elsewhere. Appendix 1 provides a mapping table of SNAP sector, used to summarise the $PM_{2.5}$ emissions, and IPPC codes used to summarise GHG emissions.

2.1 UK 2018 and 2030 GHG baseline

2.1.1 UK Baseline alignment

The UK 2018 emissions and 2030 $PM_{2.5}$ business as usual emissions[18] scenarios, developed by Imperial College, start from the 2018 UK NAEI and DEFRAs 2030 Business as Usual (BAU) forecast. Table 2 in the Imperial report provided an overview of the UK emission estimates for both 2018 and 2030 at SNAP level. The report further explains where the $PM_{2.5}$ data deviate from the NAEI 2018. To

[14] https://naei.beis.gov.uk/
[15] https://www.gov.uk/government/statistics/digest-of-uk-energy-statistics-dukes-2021
[16] https://www.gov.uk/government/statistics/digest-of-uk-energy-statistics-dukes-2019
[17] https://en.eustat.eus/documentos/elem_13173/definicion.html
[18] As stated in Table 2 of the technical report issues by Imperial "Pathway to WHO: achieving clean air in the UK. Modelling air quality costs and benefits."

understand the final fuel mix feeding into the $PM_{2.5}$ emission estimates described in the Imperial report, we compared the $PM_{2.5}$ emissions in the Imperial report with the detailed raw data in the 2018 NAEI. Table 2 summarises known differences between the Imperial $PM_{2.5}$ dataset, the 2018 NAEI detailed data as well as the assumptions we drew for developing a comparable fuel dataset for the GHG baseline.

Table 2: Adjustments in the Imperial $PM_{2.5}$ 2018 baseline scenario

Year	Imperial $PM_{2.5}$ emissions	NAEI $PM_{2.5}$ emissions	Assumptions feeding into GHG baseline
2018	Road Transport emissions are derived using Imperial's' UK emissions tool to generate annual emissions for NO_X, NO_2, $PM_{2.5}$ and PM_{10}, road by road	Road Transport emissions are based on vkm provided by DfT and/or fuel used as given in DUKES	Use the fuel estimates in the NAEI 2019 in line with CCC BNZP report
2018	Include Biogenic emissions	Excludes Biogenic emissions	Excludes Biogenic emissions
2018	Revises wood consumption figures (assumed to be consistent with DUKES 2021)	Wood consumption figures from DUKES 2019.	Replaced wood consumption figures with values consistent with DUKES 2021
2030 (Stationary & other non RT)	Based on NAEI projections using NAEI18 and EEP18 but with adjustments based on EEP19	NAEI18 and EEP18	Activity data from NAEI $PM_{2.5}$ projections, adjusted to EEP19 where needed to align with Imperial's method, and assuming no change in GHG factors from 2018
2030 (RT)	Based on CCC's estimates of vehicle kilometre from the BNZP scenario, COPERT 5.4 emission factors and projected Euro standards for different vehicle types from NAEI18 projections.	NAEI18 and EEP18	Based on CCC Sixth Carbon Budget report and EEP19 forecasts.

In addition to these known differences, we observed generally small differences in the $PM_{2.5}$ emissions reported by Imperial and those taken from the 2018 NAEI, these differences occurring for most SNAP codes. We were not able to identify the reason for these differences, but they were sufficiently trivial to convince us that:

a) there was a close relationship between Imperial's emission estimates and those in the 2018 NAEI;
b) the underlying NAEI activity data therefore provided a solid starting point for generating GHG emissions data for this project.

Table 4 in the Imperial report lists additional adjustments applied to DEFRAs 2030 BAU forecast. Two of these adjustments have an impact on GHG emissions and as such need to be considered when developing a comparable 2030 GHG baseline. These relate to gas-fired power stations and residential coal use.

DEFRAs 2030 BAU forecast are based on the NAEI 2018 projections and so should be consistent with the EEP18[19] set of BEIS projections (Reference Scenario). The Imperial report indicates that more

[19] https://www.gov.uk/government/publications/updated-energy-and-emissions-projections-2018

recent EEP projections were used for natural gas consumption at power stations. This suggests that the EEP19[20] set was used (although it could also mean the subsequent Net Zero Scenario version). We have therefore modified our NAEI 2018 projections so that they are now consistent with the EEP19 projections for this particular emission source, although this makes relatively little difference to $PM_{2.5}$ (and GHGs).

Legislation regulating the sale of traditional coal in England – the Air Quality (Domestic Solid Fuel Standards) Regulations 2020 (England) – will ban the sale of house coal in 2023. EEP18 does not take account of this. Therefore, we have adjusted the NAEI 2030 figures and assumed that coal consumers in England switch to smokeless fuels and petroleum coke instead of house coal in 2030. This is somewhat worst-case from the perspective of GHGs since some consumers might actually switch to wood instead, however this assumption is consistent with more recent NAEI projections. Note that these Regulations will also prohibit the sale of wet wood as well, with the assumption being that consumers will buy dry wood instead. This will have minimal or no impact on GHG emissions since the measure only involves the replacement of one biofuel with another one with the same or similar GHG emissions. It is actually possible that methane and nitrous oxide emission rates from burning dry wood might be slightly different to emissions from burning wet wood but there are no emission factors to indicate what difference there might be, so this measure has not been considered further.

Most adjustments mentioned in the Imperial report will have little or no impact on GHG emissions, for example:

3. Phase out of red diesel: going back to regular diesel
    a. No impact on GHG emissions since red diesel is the same as regular diesel with the addition of a red colour additive. There is no associated GHG emission change expected from this change.
4. Controls on medium combustion plant (MCPs) and high-NO_X generators (HNG)
    a. We assume no impact on GHG emissions since this adjustment concerns the regulation of MCPs and HNG and the subsequent need by operators of these plant to meet emission limit values (ELVs) for NO_X, which will be done primarily by technological means i.e. using abatement or changing to less emissive technologies. Some technological changes can of course have an impact on fuel use – for example, an operator might conceivably change from one type of combustion plant to another in order to ensure compliance with MCP controls, and that might then change the operator's fuel consumption. But we expect that the changes in fuel consumption (which would affect GHGs) for some operators would be very small compared to the overall change in NO_X emissions across all operators. And since it would anyway be extremely difficult to estimate changes in fuel consumption with any certainty, any effect has been ignored.

2.1.2 GHG UK 2018 and 2030 Baseline Emissions

Table 3 and Table 4 show the resulting 2018 emissions and 2030 GHG business as usual emissions for the UK. The total emissions are not identical to the GHG emissions published under EEP18 or EEP19 since the data in this report are based on the NAEI using a mixture of EEP version, whereas the EEP figures are derived by BEIS using a somewhat different method to that of the NAEI. Further details of modifications to the 2030 baseline are given in section 2.1.3.

[20] https://www.gov.uk/government/publications/updated-energy-and-emissions-projections-2019

Table 3: UK 2018 emissions, Mtonnes CO_2 equivalent, Black Carbon in ktonne

SNAP*	CO_2	CH_4	N_2O	F gases	*CO_2 equiv***	Black Carbon
1	93.07	0.32	0.74	0.00	94.13	0.13
2	86.62	0.67	0.14	0.00	87.43	4.56
3	49.12	0.11	0.17	0.00	49.40	4.22
4	8.79	0.05	0.26	0.22	9.31	0.05
5	0.60	4.97	0.00	0.00	5.58	0.30
6	0.08	0.00	0.60	13.61	14.29	0.00
7	111.67	0.09	1.10	0.00	112.86	2.76
8	18.29	0.04	0.20	0.00	18.54	3.81
9	3.91	18.42	0.78	0.00	23.12	0.94
10	1.27	25.37	14.20	0.00	40.84	0.00
Total	**373.43**	**50.05**	**18.19**	**13.83**	**455.50**	**16.78**

* 1 Combustion in energy production and transfer; 2 Combustion in commercial, institutions, residential and agricultural sectors; 3 Combustion in industry; 4 Production process; 5 Extraction / distribution of fossil fuels; 6 Solvent use; 7 Road transport; 8 Other transport and machinery; 9 Waste treatment and disposal; 10 Agricultural (excludes forests and land use change)
**Includes CO_2, CH_4, N_2O, F gases

Table 4: UK 2030 business as usual emissions, MtonnesCO_2 equivalent, Black Carbon in ktonne

SNAP*	CO_2	CH_4	N_2O	F gases	*CO_2 equiv***	Black Carbon
1	49.77	0.30	0.60	0.00	50.66	0.10
2	90.41	0.67	0.13	0.00	91.21	5.00
3	40.41	0.11	0.17	0.00	40.69	4.55
4	8.42	0.04	0.22	0.22	8.89	0.04
5	0.31	3.40	0.00	0.00	3.71	0.30
6	0.09	0.00	0.64	13.61	14.34	0.00
7	90.15	0.08	1.06	0.00	91.29	1.87
8	18.31	0.04	0.20	0.00	18.55	3.48
9	1.77	14.85	0.80	0.00	17.42	0.88
10	1.27	25.37	14.20	0.00	40.84	0.00
Total	**300.89**	**44.86**	**18.02**	**13.83**	**377.59**	**16.22**

* 1 Combustion in energy production and transfer; 2 Combustion in commercial, institutions, residential and agricultural sectors; 3 Combustion in industry; 4 Production process; 5 Extraction / distribution of fossil fuels; 6 Solvent use; 7 Road transport; 8 Other transport and machinery; 9 Waste treatment and disposal; 10 Agricultural (excludes forests and land use change)
**Includes CO_2, CH_4, N_2O, F gases

2.1.3 GHG UK 2030 Baseline Adjustments

The 2030 baseline GHG emissions rely on data from EEP and therefore take account of policies and measures which have been implemented and/or adopted to date and which impact on fuel consumption. Emissions of CH_4 and N_2O in particular might also be reduced by using technology to abate emissions, but this is unlikely to contribute to significant reductions to GHGs between 2018 and 2030 and cannot in any case be modelled by the simple method we have used to generate our 2030 GHG estimates.

The energy projections in EEP will, as well as reflecting policies and measures (PaMs), also reflect other factors – whether the economy is expected to grow or shrink or, say, consumer choices to switch from one fuel to another. So, the change between the 2018 and 2030 GHG emission estimates shown in Tables 2 and 3 represent the net impact of all of those PaMs and other trends and influences. Some information on the emission changes driven by policies is given in the EEP reports[21] published by BEIS. Section 4.1.2 discusses some of the main changes between 2018 and 2030 but it is not possible to quantify the impact of individual PaMs in our GHG emission projections due to the use of EEP data that only indicates the overall change in energy consumption.

The Imperial report describes additional adjustments to reflect further PaMs that may impact on $PM_{2.5}$ (table 4 Imperial report). In other words, these are mostly PaMs that, rather than affecting fuel consumption (and therefore GHGs), will use technology to reduce $PM_{2.5}$ emissions. The EEP data sets are developed to understand energy use and GHG emissions and so do not reflect all PaMs that would impact on air emissions. For consistency we reviewed the $PM_{2.5}$ adjustments and investigated whether these would change emissions of GHGs (either increase or decrease emissions).

Table 5 provides an overview of GHG emission changes driven by $PM_{2.5}$ adjustments. It is important to note that these emission savings are not linked to moving to tighter WHO $PM_{2.5}$ limit values but are purely based on the fact that more up to date datasets have been used in comparison to EEP18. They are already accounted for in Table 4 as part of the 2030 baseline emissions.

Table 5: 2030 $PM_{2.5}$ baseline adjustments

SNAP sector	$PM_{2.5}$ adjustments	Expected CO_2 equiv saving in 2030
1	Adjustment for new natural gas projection: data using the later EEP19 natural gas figures instead of EEP18 nature gas figures for power stations	8 Mtonnes CO_2e
2	Defra new domestic wood burning activity for wet wood in line with the latest wood figures published in the 2021 Digest of UK Energy Statistics (DUKES).	0.5 Mtonnes CO_2e
2	Legislation regulating the sale of wet wood and traditional coal in England - The sales of house coal and wet wood in England was phased out in May 2021, with transition periods available.	1.2 Mtonnes CO_2e

2.2 Developing the London 2018 and 2030 GHG baseline emission

2.2.1 London Baseline alignment

The 2018 $PM_{2.5}$ baseline data for London are based on the London Atmospheric Emissions Inventory (LAEI2016[22] and LAEI2019[23]). The 2030 London $PM_{2.5}$ baseline projections were developed by Imperial together with TfL. At present no 2030 London GHG projections are publicly available.

For the purpose of this assessment, the GHG 2018 and 2030 baseline emissions for London are taken from Defra's Air Quality Scenario Modelling Tool (SMT, not publicly available). The 2018 SMT emissions are equal to the NAEI 2018 and the 2030 business as usual emissions are based on EEP18 consistent with the underlying datasets assumed for the UK GHG assessment.

[21] https://www.gov.uk/government/publications/updated-energy-and-emissions-projections-2019 and https://www.gov.uk/government/publications/updated-energy-and-emissions-projections-2018
[22] https://data.london.gov.uk/dataset/london-atmospheric-emissions-inventory--laei--2016
[23] https://data.london.gov.uk/dataset/london-atmospheric-emissions-inventory--laei--2019

3 Task 2 – Implementation of the scenarios

The Imperial report describes the measures assumed under the CCC BNZP (RT only), LS1, LS2 and LS3 scenarios. We assumed the same basket of measures to assess the impacts on GHG emissions. Table 6 summarises the total impact of these additional measures on overall 2030 UK GHG emissions compared to the 2030 GHG baseline. The results have been split into stationary and other transport (i.e. shipping, rail and aviation) and road transport sources.

The impact of the $PM_{2.5}$ measures related to stationary and other transport sources on GHG emissions is very small because the measures themselves tend to focus on abatement of dust emissions or other technological changes, or address biofuels which are very minor sources of GHGs. Only a few of the measures seek to reduce or eliminate sources entirely, which would be needed to reduce GHG emissions significantly, as shown in section 3.3.

Table 6: 2030 Scenario results (% change in UK CO2e emissions compared with 2030 BAU)

Scenario	CCC BNZP	LS1	LS2	LS3
Measures for road transport	-12%	-	-	-
Measures for stationary sources and other transport	Only affects non-RT	-0.8%	-0.8%	-0.8%

Overall, UK emissions for the various 2030 scenarios, aggregated across SNAP categories 1-10, are shown in Table 7, together with reductions relative to three different baselines (1990, 2018 & 2030 BAU).

Table 7: UK GHG emissions and emission reductions

Year	Scenario	GHG total (Mt CO_2 equiv)	% reduction in UK emissions relative to:		
			1990	2018	2030 BAU
1990	-	785	-	-	-
2018	-	455	42%	-	-
2030	BAU	378	52%	17%	-
2030	CCC BNZP	332	58%	27%	12%
2030	CCC BNZP + LS1	329	58%	28%	13%
2030	CCC BNZP + LS2	329	58%	28%	13%
2030	CCC BNZP + LS3	329	58%	28%	13%

The emissions totals are also shown in Figure 1, but broken down by pollutant.

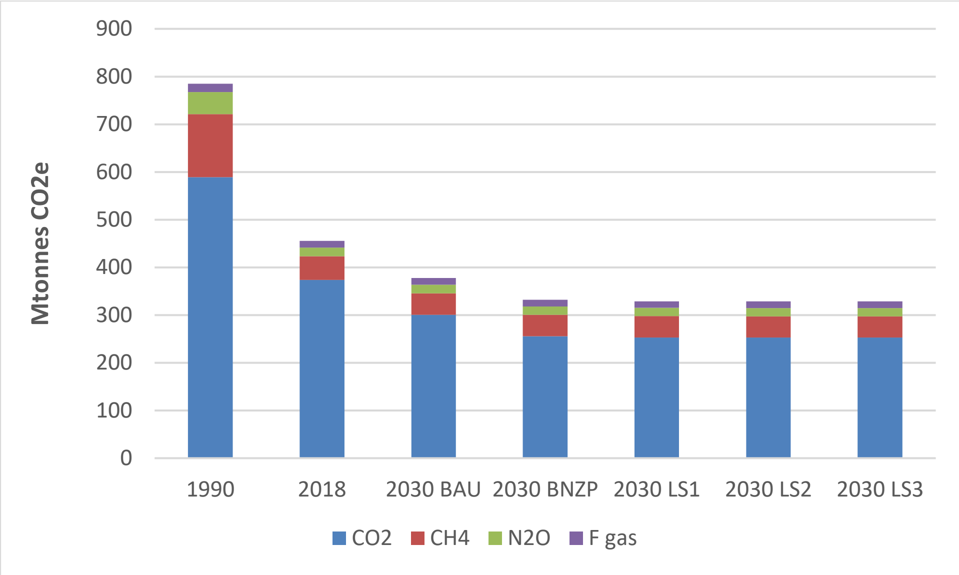

Figure 1: UK GHG emissions by pollutant (Mtonnes CO_2 equivalent)

3.1 GHG UK 2030 Road transport measures

Imperial estimated the UK's road transport $PM_{2.5}$ emissions in 2030 using the Sixth Carbon Budget report[24] published by the Climate Change Committee (CCC) in December 2020. Thus, the CCC report was also used to estimate the UK's GHG road transport emissions in 2030.

The "Balanced Net Zero Pathway" (BNZP) and four other "exploratory" scenarios were developed in the CCC report to explore alternative pathways to deliver emissions reductions across all sectors and showcase the pace at which GHG emissions reductions vary between sectors. CCC identified the BNZP as the recommended pathway for the UK to deliver Net Zero by 2050. Emissions under those decarbonisation scenarios were compared against a baseline scenario which represents the growth in emissions if no further climate mitigation action is taken beyond firm and funded policies. For that baseline scenario, the Government's forecasts on energy demand, emissions, and GDP were used from the EEP19[25] and complemented by CCC's internal analysis. The EEP19 "Reference Scenario" dataset covers currently funded low-carbon policies but doesn't take into account unfunded policies or strategies or any additional uptake of low-carbon technologies beyond today. CCC's analysis on emissions scenarios used the Government's forecasts and supplemented them by additional evidence on the cost and technology uptake rates for each sector.

The decarbonisation scenarios under the Sixth Carbon Budget report are built on known mitigation technologies where they exist and try to minimise the use of greenhouse gas removals. Assumptions for the decarbonisation pathways for the surface transport sector were derived based on a detailed review of available evidence. This includes previous CCC's analysis (i.e. CCC's first report in 2008 and advice on carbon budgets since then), research across all sectors that has been published since the Fifth Carbon Budget, recent market development and trends, new analytical modelling within the CCC, new research on potential decarbonisation options for road freight and extensive stakeholder engagement.

In the Sixth Carbon Budget report, the historical emissions are derived from the provisional figures of NAEI 2019, the final figures of NAEI 2018, and CCC's internal analysis. The categories of the NAEI

[24] Sixth Carbon Budget - Climate Change Committee (theccc.org.uk)
[25] Updated energy and emissions projections: 2019 - GOV.UK (www.gov.uk)

have been re-mapped onto the CCC's sectors of emissions, i.e. CCC's surface transport sector includes emissions from road transport vehicles, railways and railways stationary combustion, aircraft support vehicles, lubricant consumption and urea carbon emissions from road vehicle engines, and emissions from vehicles used in accidental fires. As surface transport is currently the UK's largest GHG-emitting source, implementing the BNZP scenario will require the deployment of low carbon technologies, low carbon fuels, efficiency improvements for petrol and diesel vehicles, behaviour change to reduce travel demand and shift journeys to other low or no carbon emissive modes of transport.

The Balanced Net Zero Pathway delivers a 50% reduction in the surface transport emissions by 2030 which can be achieved if the recommended solutions are implemented; phase-out of fossil fuelled passenger vehicles by 2032, significant uptake of zero emission vehicles, demand-side measures in road transport, better efficiency of new conventional vehicles, uptake of PHEVs and rail decarbonisation. In this project, we have assumed that the UK's 2030 road transport emissions are reduced by 50% under the UK Road Transport scenario similarly to the CCC BNZP scenario for the surface transport emissions.

3.2 GHG London 2030 Road transport measures

Imperial has assumed three emission scenarios (LS1, LS2, LS3) for the London road transport emissions in 2030. LS1 is considered to be the business as usual scenario and is based on the commitments made in the London Environment Strategy (LES) published in May 2018[26]. Since the LES included the two phases of the implementation of the ultra-low emission zone (ULEZ) in London, the same vehicle assumptions have been considered in LS2 and LS3 scenarios. This project applies the same vehicle and traffic assumptions as in the Imperial report to examine the climate benefits in London in 2030. Those assumptions are listed in Table 8 in the Imperial report. The input data (fleet and vkm forecasts for 2030 under all emissions scenarios) for the modelling assessment of the London road transport emissions has been provided by TfL and Imperial in May 2022, accordingly.

3.3 GHG London 2030 Stationary and other transport measures

GHG reductions have been calculated for the scenario assumptions given in Table 9 of the Imperial report. This table lists a number of high-level source sectors and presents the emissions in London in 2018 and then in 2030 for the three London scenarios – LS1, LS2 and LS3. There is some accompanying discussion of these scenario 'measures' but they are not described in detail, and it is sometimes not possible to gain a firm idea of what the scope of source sectors are, and how any emission reductions are brought about. As a result, the calculated GHG reductions are quite uncertain. The sources listed in Imperial's report are discussed below.

Commercial cooking

This is a $PM_{2.5}$ source that Imperial College add relative to the NAEI (the NAEI does not include the source due to the lack of a suitable method). The source should only cover $PM_{2.5}$ that is created from the foods being cooked, since $PM_{2.5}$ from the fuels being consumed (i.e. burned) will already be included elsewhere in inventories. Those cooking processes will most likely also produce small quantities of GHGs however there are no emission estimates in the NAEI. It is also debateable whether controls on dust nuisance from commercial cooking would have any impact on gaseous GHGs. Those controls would take the form of requiring appropriate abatement of the dust, so use of filters, for example, which would be ineffective at reducing emissions of GHGs. Although this is a significant measure in the context of reducing $PM_{2.5}$ emissions, there are no reductions in GHGs for LS1- LS3.

[26] https://www.london.gov.uk/what-we-do/environment/london-environment-strategy

Domestic wood burning

The Imperial report indicate that emissions from this source can be reduced to zero in scenario LS3, although the accompanying text discusses actions such as "***an improved testing regime, better information at the point of sale using appropriate technology/fuels for smoke control zones, and new powers for the Mayor to set tighter emission standards for wood burning stoves sold in London (for example, the eco-design standard).***" For the purposes of national GHG emission reporting, domestic wood combustion only leads to emissions of methane and nitrous oxide since emissions of CO_2 are biological in origin and therefore not reported. It is unclear to us to what extent the measures described in the Imperial report will also impact on methane and nitrous oxide. The reductions in $PM_{2.5}$ quoted in the Imperial report for LS1 & LS2 may be the result of improving the population of domestic appliances (through better testing and use of 'appropriate technology') and changing the population of domestic appliances could also affect the potential to emit GHGs. But reducing emissions to zero, as indicted in in LS3, could only be achieved by reducing the use of wood to zero. Therefore, emissions of GHGs would also be reduced to zero in LS3. Changes in GHG emissions for LS1 and LS2 are far less certain, and emissions could conceivably even increase if there are changes in domestic appliances (we do not have the emission factors to be able to draw any conclusion). However, we have assumed that the very significant reductions in $PM_{2.5}$ in LS2 in particular do suggest a reduction in the use of wood fuel so we have estimated GHG reductions for LS1 and LS2 assuming that these scenarios are achieved wholly by reducing the consumption of wood, rather than by improving the emission characteristics of domestic appliances. Our GHG reduction estimates for LS1 and LS2 are therefore 'best-case' but note that GHG emissions from this source are relatively trivial and so this conservative approach has only very limited impact on the overall reduction figures.

Construction dust

Emissions of $PM_{2.5}$ from construction activities are largely fugitive in nature and occur due to the suspension of fine material (soil, cement, plaster, brick dust etc.) by wind. There are no GHG emissions associated with this source under any scenario and in any case, the Imperial reported estimated very little change in $PM_{2.5}$ emissions for this source.

Construction NRMM / Industrial NRMM

Emissions of $PM_{2.5}$ from non-road mobile machinery will be reduced through the action of progressively tighter emission limits imposed over time via EU Directives. The Mayor has "***issued guidance to create an NRMM Low Emission Zone through planning conditions with minimum emission standards, based on the European engine "stages". The NRMM Low Emission Zone will include progressively tightening standards, with the current proposals as follows: Stage IV throughout London by 2025 and Stage V throughout London by 2030"*** (Imperial report). In other words, improved engine design and/or tailpipe abatement of dust emissions will reduce $PM_{2.5}$ emissions from NRMM in London. Improved engine design could conceivably also reduce fuel consumption slightly and as a result reduce GHG emissions, but tailpipe abatement would not, and so it is questionable whether the measures to reduce $PM_{2.5}$ will have any impact on GHGs at all under LS1 , LS2 and LS3. We have assumed zero impact.

Domestic gas

The Imperial report states that various initiatives and measures are suggested to decrease $PM_{2.5}$ from natural gas use in the domestic sector: ***"the Mayor's 'Energy for Londoners' programme will support the transition from old inefficient gas boilers to ultra-low NO_X gas boilers and alternatives, such as heat pumps. The Mayor will evaluate the boiler scrappage initiative scheme and the London Boiler Cashback and Better Boilers schemes. This will help inform the development of future initiatives to provide more efficient and low NO_X boiler replacements. Through the Energy for Londoners programme, the Mayor's energy efficiency programmes will also help to remove inefficient heating systems that contribute to poor air quality***." These measures include options that will reduce NO_X (such as the use of ultra-low NO_X boilers) and options that are aimed at replacing gas boilers with alternatives such as heat pumps. Thus, there is a combination of better technology/abatement plus fuel reduction. Better technology/abatement would not necessarily change GHG emissions, however Imperial's report only explicitly mentions NO_X reducing options. $PM_{2.5}$ emissions from natural gas boilers occur at such low levels that it would not be feasible to use abatement or better design to reduce them further. Therefore, we have assumed that the reductions in $PM_{2.5}$ given in Imperial's report can only be achieved by reducing gas consumption (as opposed to the somewhat larger reductions given for NO_X which will be achieved by both abatement and reducing fuel consumption). Thus, the reductions in $PM_{2.5}$ can be used to infer the reductions that are achievable for GHGs under LS1 , LS2 and LS3.

Domestic oil/coal

The Imperial report says that "***oil and coal emissions will be set to zero.***" The only way to achieve zero emissions from oil and coal combustion would be to no longer burn these fuels. In other words, use of oil and coal will reduce to zero by 2030, either through action by the Major or by consumers choosing alternatives over time. Since the use of these fuels will reduce, there will be a corresponding reduction in emissions of GHGs as well under LS1 , LS2 and LS3.

Commercial gas

Various initiatives and measures are suggested to decrease $PM_{2.5}$ from natural gas use in the commercial sector as stated in the Imperial report: "***The Mayor will work with government to seek reductions in emissions from large scale generators producing power for commercial buildings in London. The Mayor will work with BEIS and Defra to seek market reforms and discourage the use of emergency generators in the STOR (Short Term Operating Reserve) and capacity markets. The Mayor will encourage Defra to apply more robust standards, and give the Mayor the powers to regulate this sector in London. The Mayor will also work with the retrofit industry and generator owners to develop and install effective retrofit solutions for existing generators as soon as possible. Where applicable, retrofit for emergency generators could be supported by the Mayor's retrofit programmes.***" This suggests a mix of measures that lead to adoption of better technology, adoption of abatement, and also replacement or removal of combustion plants altogether. As with domestic gas, reductions in $PM_{2.5}$ are only likely to be achieved by reducing the use of gas, and the similar percentage reductions that Imperial quote for both NO_X and $PM_{2.5}$ suggest that this is the dominant mechanism within the overall strategy for this sector. Since gas consumption decreases, GHG emissions will do so as well, and reductions can be calculated using the same trend as seen for $PM_{2.5}$ under LS1 , LS2 and LS3.

Imperial do not give any detailed description of what they include in the 'commercial' sector. As such we have chosen to interpret it as including all industrial-scale combustion plants, regardless of whether that is operated within power stations, industry, or within the public, commercial or agricultural sectors. That scope is potentially much wider than Imperial intended, however NAEI estimates of $PM_{2.5}$ for this wide scope are actually marginally smaller than the figures given in Table 9 of Imperial's report, so we believe this wide scope is justified.

Commercial oil & coal

The Imperial report does not give any information specifically on oil and coal, and instead includes it in the text reproduced above in the discussion for commercial gas. The NO_X and $PM_{2.5}$ reductions for LS1 are quite different, suggesting that for LS1 at least, there are improvements in equipment and/or abatement that impact on these different pollutants to different degrees. But emissions are set to zero for LS2 and LS3, so it is clear that in those scenarios, consumption of coal and oil stops completely. Since we do not know how much of the LS1 reduction in $PM_{2.5}$ originates from abatement or plant improvements, and how much results from reductions in fuel use, we have assumed a best case i.e., that all reductions result from lower use of these fuels and that emissions of GHGs will therefore also reduce to the same extent. GHG emissions from this sector are relatively trivial so although this assumption is best-case, it has only very limited impact on the overall reduction figures.

Imperial do not give any detailed description of what they include in the 'commercial' sector. We have chosen to interpret it as including all industrial-scale combustion plant, regardless of whether that is operated within power stations, industry, or within the public, commercial or agricultural sectors. That scope is potentially much wider than Imperial intended, however NAEI estimates of $PM_{2.5}$ for this wide scope are actually very much smaller than the figures given in Table 9 of Imperial's report, so we believe this wide scope is justified.

Industrial Part A & Part B processes

As with some of the other categories, it is not clear what scope has been considered in the Imperial report for this source. Many combustion plants are regulated as Part A or Part B processes, but we assume that the intention here was only to include non-combustion sources. In any case, the Imperial report assumes the same emissions both in 2018 and in the three scenarios for 2030 and so we do not need to consider this source further under LS1 , LS2 and LS3.

Rail

Rail emissions are calculated by Imperial by taking account of "***the full electrification of all services to and from Kings Cross (except for Grand Central services) and to and from Paddington; and the replacement of Voyager and Meridian trains serving Euston and St Pancras, respectively*** (see Imperial report). Voyager and Meridian trains are diesel powered, and so we interpret the scenarios for the rail sector as being reductions in $PM_{2.5}$ and NO_X that are largely achieved by the reduction in the use of diesel by this sector. Imperial actually predict a larger reduction in $PM_{2.5}$ than they do for NO_X, so it is also likely that the $PM_{2.5}$ reductions are at least partially due to less emissive diesel usage, perhaps in newer train types. Even the NO_X emission reductions may be partially from diesel usage with lower emissions. However, since we do not know how much of the reduction is related to lower diesel usage, we will assume a best case and that the NO_X reduction is entirely due to reduced fuel usage and that GHG emissions can be assumed to reduce to the same extent under LS1 , LS2 and LS3.

Shipping

The Imperial report assumes a 40% reduction in NO_X and $PM_{2.5}$ emissions between 2016 and 2030, based on the Port of London Authority's Emission Reduction Roadmap report. This report suggests that a combination of technologies can be used to reduce emissions including:

- exhaust clean-up (which will reduce air quality pollutants but not CO_2);
- use of low-carbon fuels (which will reduce CO_2)
- electric or hydrogen fuel cell drives (which would eliminate GHGs)

It is not clear to us what balance of options is envisaged to achieve a 40% reduction, but a best-case assumption would be that this is entirely achieved by reducing fossil fuel use. Use of biofuels would not necessarily reduce emissions of CH_4 or N_2O but would eliminate emissions of CO_2, which would be more significant than emissions of the other GHGs from fossil fuels in any case. Thus options such as use of low-carbon fuels, or alternative propulsion systems could be assumed to reduce GHG emissions roughly equally to reductions in air quality emissions.

Imperial's report includes two categories for shipping – a main category and a smaller category for small river-craft and canal boats. Imperial assume no change in the emissions from the smaller vessels and so the 40% reduction only relates to the main shipping category. The SMT dataset which we use to estimate GHG emissions and emission reductions only includes emissions from categories which seem to only match Imperial's smaller craft category. We have therefore had to generate an estimate for GHGs from larger shipping using UK ratios for GHG and $PM_{2.5}$ emissions from shipping, and the $PM_{2.5}$ emissions reported in Imperial's Table 9 for London. We have then assumed that these GHG emissions reduce in the three 2030 scenarios (LS1 , LS2 and LS3) to the same extent as $PM_{2.5}$ emissions.

Aviation

The Imperial report states that there are "***no new airport infrastructure developments nor any increases in capacity beyond existing caps on aircraft movements. Specifically, the projections assumed that there is no 3rd runway at Heathrow.***" Imperial consider that emissions of $PM_{2.5}$ will decrease somewhat as a result of "***differences relating to activity data projection, changes to the aircraft emissions brought about by the modernisation of the fleet and changes to ground vehicle fleet included newer vehicles, with tighter emissions standards, replacing older ones***." In other words, reductions due to less activity (and therefore less GHG emissions) and reductions due to changes in fleets (which may or may not affect GHGs in the same way). As with many other sectors, we are unable to be certain about how the $PM_{2.5}$ scenarios (LS1 , LS2 and LS3) impact on GHGs and therefore can only assume a best case that GHGs reduce equally to $PM_{2.5.}$

Agriculture

The Imperial report indicate a small reduction in $PM_{2.5}$ emissions from agriculture but do not provide any further detail. Agricultural emissions of dust are associated with animal manures and agricultural soils, and these sources and the sources of GHGs are sufficiently different that one cannot just assume that measures to reduce $PM_{2.5}$ emissions will also reduce GHGs. Agricultural emissions in London are also relatively trivial and we have assumed that the most defensible approach given the absence of information in the Imperial report, and the differences in air quality and greenhouse gas emission sources, is to assume no reductions in GHG emissions from this source category under LS1 , LS2 and LS3.

Accidental fires

The Imperial report assumes a small reduction in emissions from this source. This could only be achieved by reducing the potential for fires to start or to develop, so perhaps measures such as increasing use of smoke detectors or use of more fire-resistant materials. If fewer accidental fires occur, then GHG emissions will be reduced as well. However, note that NAEI figures only include CH_4 emissions: CO_2 and N_2O would be released as well but there is no methodology for estimating these pollutants in the NAEI and so they have not been considered under LS1 , LS2 and LS3. Emissions of CH_4 are assumed to decrease by the same percentage as $PM_{2.5}$, and this would be reasonable for CO_2 and N_2O as well if those pollutants were estimated.

Small-scale waste burning

Imperial estimate that $PM_{2.5}$ emissions from this source (and commercial cooking) can be reduced by "***using new powers to require appropriate abatement of significant combustion related sources of $PM_{2.5}$ by strengthening local authority enforcement powers and conferring the ability to create zero emission zones where no combustion is allowed on certain, time limited occasions.***" Abatement does not seem to be a relevant option for small-scale waste burning so that part of the quoted statement above is assumed to refer only to commercial cooking. Zero emission zones where no combustion is allowed could be used to reduce emissions from waste burning (such as garden bonfires) and since this measure relies upon reducing the quantity of waste burnt, it will have an equal impact in reducing GHG emissions. However, GHG emissions are not estimated for this source in the NAEI, due to a lack of suitable method and so they have not been considered under LS1 , LS2 and LS3. It is also likely that most waste would be garden waste, and so would not be a source of fossil CO_2.

Waste processes

Imperial list three types of waste process (sewage treatment, landfills and waste-transfer stations) but assume that air quality emissions from all three types of process stay constant from 2018 onwards. Therefore, we can assume that there are also no reductions in GHG emissions under LS1, LS2 and LS3.

Garden/household NRMM

Imperial assume no change in $PM_{2.5}$ emissions from 2018 onwards and thus there is no potential for GHG emission reductions either under LS1, LS2 and LS3.

3.4 Black carbon reductions

Black carbon reductions have been calculated directly from the $PM_{2.5}$ reductions given in table 9 in the Imperial report, also shown in Table 8 below. This is done by calculating an aggregate Black Carbon to $PM_{2.5}$ ratio for each of the source categories given in that table, using data from the NAEI. It should be noted that:

- Since the NAEI does not include the 'commercial cooking' source given in Table 9, it is not possible to derive a Black Carbon to $PM_{2.5}$ ratio for that source, and therefore we cannot estimate black carbon reductions for that source.
- Not all sources of $PM_{2.5}$ are considered in the NAEI to also be sources of black carbon. So, for example, construction activities and spray coating processes are sources of $PM_{2.5}$ only. Any reduction in dust from these sources would not have any co-benefit in terms of black carbon reductions.
- We have had to use aggregate Black Carbon to $PM_{2.5}$ ratios in the analysis, since we do not have sufficient detail in the Imperial College report to do otherwise. While this is not ideal, it is unlikely to introduce much uncertainty since Black Carbon to $PM_{2.5}$ ratios are generally fairly uniform for the various NAEI sub-sources that we believe fit within each of the broad source categories given in Table 9, and the broad categories do differentiate well between sources with relatively high black carbon to $PM_{2.5}$ ratios, and those where those are low. So, for example, all of the sub-sources within "domestic other fuels (oil & coal)" have Black Carbon to $PM_{2.5}$ ratios of about 0.1, whereas the sub-sources within "domestic gas" have Black Carbon to $PM_{2.5}$ ratios of about 0.03. Only for the category "commercial other fuels (oil & coal)" is there a large range of values, since Black Carbon to $PM_{2.5}$ ratios are about 0.05 for coal and >0.5 for fuel oil. We calculate an average ratio for that sector of about 0.1, which will be too low if the sector in London is actually dominated by fuel oil (which is very unlikely).

Table 8: UK Black Carbon emission reductions for stationary sources and other transport

Measure Name	Scenario reduction in % (Table 9 Imperial Report)			BC reductions, tonnes		
	LS1	LS2	LS3	LS1	LS2	LS3
Commercial cooking	13%	75%	75%	0	0	0
Domestic wood burning	13%	75%	100%	7.74	46.24	61.62
Construction Dust	2%	2%	2%	0	0	0
Construction NRMM	0%	0%	0%	0	0	0
Industrial NRMM	0%	0%	0%	0	0	0
Domestic Gas	18%	18%	18%	1.94	1.94	1.94
Commercial Gas	33%	33%	33%	0.74	0.74	0.74
Domestic oil and coal	59%	100%	100%	6.18	10.47	10.47
Commercial oil and coal	23%	100%	100%	20.13	88.00	88.00
Industrial Part A	0%	0%	0%	0	0	0

Measure Name	Scenario reduction in % (Table 9 Imperial Report)			BC reductions, tonnes		
	LS1	LS2	LS3	LS1	LS2	LS3
Industrial Part B	0%	0%	0%	0	0	0
Rail	65%	65%	65%	9.75	9.75	9.75
Shipping	38%	38%	38%	2.91	2.91	2.91
Aviation - Heathrow	22%	22%	22%	1.8	1.8	1.8
Agriculture	0%	0%	0%	0	0	0
Accidental Fires	6%	6%	6%	1.68	1.68	1.68
Smallscale waste burning	0%	50%	50%	0	19.53	19.53
Waste STW	0%	0%	0%	0	0	0
Landfill	0%	0%	0%	0	0	0
Waste Transfer Stations	0%	0%	0%	0	0	0
Shipping, Canal & Small River	0%	0%	0%	0	0	0
Garden NRMM	0%	0%	0%	0	0	0

4 Task 3 – Results analysis

4.1 UK GHG Changes 2018-2030

Section 2.1.2 summarises the UK estimates for 2018 and 2030 and Table 3 and Table 4 show how baseline emissions (by SNAP code) change over the period. Those changes will reflect PaMs but will also reflect underlying trends – economic growth or decline, developments in technology and choices over fuels being used. It would be extremely difficult to unpick the individual impacts of each of the various PaMs and other factors since the 2030 figures are based on energy projections which give the net impact of all of those factors together.

4.1.1 GHG UK 2030 Baseline Adjustments Road Transport

For the road transport emissions, the main changes between 2018 and 2030 business as usual emissions, as shown in Table 3 and Table 4, are related to:

- requiring only Euro 6 vehicles by 2030,
- the uptake of low carbon vehicles (electric and hybrids),
- fuel efficiency policies for cars/vans/HGVs on fuel efficiency targets and uptake of ultra-low emission vehicles,
- the Renewable Transport Fuel Obligation,
- Local Sustainable Transport Fund to promote public transport and low carbon means of transport,
- DfT's traffic forecasts based on the National Transport Model runs in January 2020, and
- adoption of different versions of the COPERT[27] emission factors.

The CCC Sixth Carbon Budget report recommends an ambitious UK scenario for reaching Net Zero by 2050 for all sectors; 50% emissions reduction in the UK's 2030 emissions from surface transport sources. The Imperial study adopted the BNZP scenario for estimating the highest reduction in the UK's $PM_{2.5}$ emissions to reach WHO-10 by 2030. We have also followed the recommended BNZP scenario to estimate how much the UK GHG road transport emissions could be reduced by 2030 if ambitious measures are implemented; phase-out of fossil fuelled vehicles by 2032, significant uptake of ZEVs, more fuel-efficient vehicles in the remaining conventional vehicles, and behaviour change to reduce travel demand.

4.1.2 UK GHG Changes 2018-2030 for other sources

The main changes between 2018 and 2030 business as usual emissions for the stationary and non-transport sources are:

- Coal is eliminated as a fuel at power stations, reducing CO_2e by 14.8 Mtonnes between 2018 and 2030. This is due to the closure of the UK's remaining few coal-fired power stations.
- Quantities of natural gas used at power stations also decline markedly, reducing CO_2e by 28.7 Mtonnes between 2018 and 2030.
- Quantities of municipal waste burnt with energy recovery increase, however, and emissions from this source increase by 4.0 Mtonnes CO_2e.
- North Sea production of oil and gas is expected to decline and use of fuels decreases, so emissions fall by 2.0 Mtonnes CO_2e. Emissions from flares on North Sea platforms fall by 2.4 Mtonnes CO_2e.
- Coal and natural gas decline as fuels used by the industrial, commercial, public and agricultural sectors and emissions reduce by 1.7 and 4.9 Mtonnes CO_2e respectively.

[27] https://www.emisia.com/utilities/copert/

- Consumption of road transport fuels also decreases and emissions from these fuels decrease by 18.9 Mtonnes CO_2e.
- Natural gas consumption by the residential sector increases and CO_2e emissions rise by 4.1 Mtonnes.
- Leakage of methane from the natural gas distribution network is reduced by 1 Mtonne CO_2e
- Emissions of methane from landfills decrease by 3.3 Mtonnes CO_2e, due to a decrease in quantities of biodegradable waste sent to landfill

All of these changes relate to changes in activities e.g. reduced GHGs due to reductions in the consumption of fuels or reductions in the quantities of waste landfilled etc. This reflects the way the 2030 projections were produced. We don't routinely produce emission projections for GHGs and so had to generate figures using broad assumptions. Essentially, we assumed that GHG emission factors remained unchanged between 2018 and 2030, and that emissions changed only in line with changes in activity levels. However, this is mostly a reasonable assumption, and emission factors for CO_2 at least are unlikely to change much over time for each source. Emission factors for methane and nitrous oxide from some sources (such as landfills or gas leakage) could change over time but it has not been possible to reflect that in the figures in Table 4. However, it is unlikely that changes in emission factors would substantially change the overall picture – changes in GHGs occur mainly as the result of changes in activity. In the future, this may change, for example if carbon capture and storage is used to 'abate' CO_2 but it is currently true for the UK.

4.2 GHG Reductions associated with the London Scenarios for road transport

Table 9 below presents the information from Table 8 in the Imperial report about the traffic and vehicle assumptions used under the London scenarios (LS1, LS2 & LS3). The GHG emissions reductions are related to the assumed reduction in the vehicle km, the assumed fleet composition, and the different proportion of zero/low carbon vehicles in London in 2030.

Table 9: Table 8 in Imperial's report on vehicle assumptions used in the London Scenarios[28]

Category	Future forecast	Comment
Vehicle km	-5% by 2030	CCC UK vehicle growth +5%
Buses	By 2030: 77.4% Electric, 8.4% Hybrid Electric	Phase-out of diesel buses, and purchase of only hybrid and zero emission double decker buses from 2018, with the entire fleet becoming zero carbon by 2037 at the latest
Taxis	Fleet Zero emissions capable by 2033 with 19% diesel, 71% plug in hybrids and 10% electric remaining in 2030	No longer licensing new diesel taxis from 2018 and supporting the sector to upgrade to cleaner "zero-emission capable" vehicles
Cars	60%, 50% and 49% electric in Central, Inner and Outer London respectively in 2030	The equivalent figure from the CCC across the UK is 40%
LGV	32.5% electric in 2030	CCC's UK-wide estimate is 42%
Coaches	In 2030 are projected to be 26% electric (74% will still be diesel)	Bus and coach figures are more optimistic in London than the 17.3% UK electric vehicle figure forecast by the CCC

[28] https://www.imperial.ac.uk/school-public-health/environmental-research-group/research/modelling/pathway-to-who/

Rigid and Articulated HGVs	In 2030 6% and 10% electric respectively, with the remainder still diesel	CCC UK figures are 3% and 5% respectively
Motorcycles	27% electric by 2030, and 73% petrol vehicles.	CCC UK projection of 26% EMCs

4.3 GHG Reductions associated with the London Scenarios for other sources

The sectors where we predict GHG reductions between 2018 and the 2030 scenarios are listed in **Table 10**, together with the air quality pollutant reductions that are used to estimate those reductions.

Table 10: Sources with potential GHG reductions

Source	AQ pollutant	AQ pollutant reductions (LS1/2/3)	How certain that GHG emissions also reduce proportionately
Domestic wood	$PM_{2.5}$	13% / 75% / 100%	Low
Domestic gas	$PM_{2.5}$	18% (all scenarios)	High
Commercial gas	$PM_{2.5}$	33% (all scenarios)	High
Domestic oil/coal	$PM_{2.5}$	59% / 100% / 100%	High (LS2/LS3), low (LS1)
Commercial oil/coal	$PM_{2.5}$	23% / 100% / 100%	High (LS2/LS3), low (LS1)
Rail	NO_X	49% (all scenarios)	Low
Shipping	$PM_{2.5}$	38% (all scenarios)	Low
Aviation	$PM_{2.5}$	22% (all scenarios)	Low
Accidental fires	$PM_{2.5}$	6% (all scenarios)	High

The table shows that we are confident in our assumptions regarding GHG reductions in about 4 cases (covering domestic & commercial use of gas, oil and coal) but are much less certain for other sources. This is because $PM_{2.5}$ and NO_X can be reduced through a variety of strategies and only some of those strategies will impact on GHG emissions. Since we do not fully understand the mix of strategies that are assumed in the Imperial report, we cannot always predict the impact on GHG emissions with any certainty. Only where the strategy to reduce the air quality pollutants relies on reducing the underlying activity (i.e. fuel burned), can we be certain that GHG emissions will also be reduced. Thus, measures that prohibit activities or which tend to reduce the level of activity will reduce emissions of all pollutants equally. However, for most of the sectors listed in Table 10: , there are alternative strategies such as fitting abatement, or modifying technologies so that they emit less of the air quality pollutant. In these cases, there is no certainty that GHG emissions will be affected at all.

Because we do not always know exactly how the $PM_{2.5}$ and NO_x emissions are being reduced, we have to make assumptions. We could either take a worst-case view and assume that $PM_{2.5}$ and NO_x emission reductions are all achieved by (A) abatement or other strategies that have no impact on GHGs, or we can adopt a best-case view and assume that (B) the same % reduction is achieved for GHGs as is achieved for $PM_{2.5}$ or NO_x. Or we could adopt some arbitrary intermediate position. We have chosen to assume (B), a best-case and as such the emission reductions we estimate are more likely to overestimate than underestimate. However, those sources with the greatest uncertainty in the GHG reduction figures are generally also sources with relatively small GHG emissions, and so the potential overestimation of GHG reductions for those sources is not expected to change the overall reduction much.

Combustion of natural gas (by all sectors) is the key source for GHG emissions, so it is the assumptions for that fuel that matter most. Abatement of $PM_{2.5}$ from gas combustion is not likely: emission rates are very low and regulators generally would not require operators of gas-fired plant to address PM emission rates. It seems reasonable to assume that reductions in $PM_{2.5}$ emissions from gas combustion must be achieved predominantly by reducing the use of gas – either with more fuel-efficient equipment, or by replacing gas combustion with another form of energy/heat production. Thus, the assumption that % $PM_{2.5}$ reduction is the same as the % GHG reduction seems justified for this source.

Overall emission reductions for GHGs are modest: the reductions achieved for stationary sources and other transport are equal to less than 1% of UK emissions. Since the measures in question relate only to London, one would of course expect that any reduction would be fairly small when compared with UK totals, but the reduction for GHGs is about three times smaller than the reduction in $PM_{2.5}$ (despite us assuming a best-case reduction in GHGs). This illustrates the point already made that reduction strategies for AQ pollutants don't always reduce GHGs. In addition, some important sources of $PM_{2.5}$ are not sources of GHGs so strategies aimed at reducing emissions from, say, commercial cooking, construction or Part B processes will not have any significant impact on GHGs.

Finally, even where different sources emit both AQ pollutants and GHGs, they don't all emit the two groups of pollutants in the same ratio. For example, GHGs are emitted when all fossil fuels are burnt and, broadly speaking, the quantities of GHGs released are similar in magnitude regardless of whether one is burning a unit of natural gas, oil or coal. But the $PM_{2.5}$ emissions are very different, being much higher for coal and other solid fuels than for gases and light oils. Biofuels, particularly solid and liquid ones, result in $PM_{2.5}$ but don't create fossil CO_2 emissions. So, while controls on biomass, coal, and oils might help bring large reductions in overall $PM_{2.5}$ emissions, those measures don't necessarily result in equally large reductions in overall CO_2 emissions. Combustion of natural gas and, to a lesser extent, petroleum-based fuels used for transport are collectively responsible for the majority of UK fuel-related GHG emissions, so it is those sources that need to be addressed to achieve large reductions in GHGs. But these sources are not quite as significant when considering $PM_{2.5}$ emissions and can also be hard to reduce, as can be seen in the fairly small reductions suggested for domestic gas and commercial gas in the London scenarios. These modest reductions are nonetheless the most important measures for reducing GHGs in London for non-road transport source and contribute about 90% of the reduction in GHGs for each of the three London scenarios.

Table 11 summarises the overall emission reduction for CO_2, CH_4 and N_2O (expressed as CO_2e) achieved in the three London scenarios for the stationary and other transport sources.

Table 11: Non-transport Source Emission Reductions in London for LS1, LS2, LS3 compared with 2018 baseline figures

Scenario	Reduction, Mtonne CO_2e
LS1	2.91
LS2	3.11
LS3	3.12

4.4 Black Carbon Reductions associated with the London Scenarios

The sectors where we predict black carbon reductions between 2018 and the 2030 scenarios are listed in Table 12, together with the air quality pollutant reductions that are used to estimate those reductions.

Table 12: Sources with potential black carbon reductions

Source	AQ pollutant	AQ pollutant reductions (LS1/2/3)	How certain that black carbon emissions also reduce proportionately
Domestic wood	$PM_{2.5}$	13% / 75% / 100%	High
Domestic gas	$PM_{2.5}$	18% (all scenarios)	High
Commercial gas	$PM_{2.5}$	33% (all scenarios)	High
Domestic oil/coal	$PM_{2.5}$	59% / 100% / 100%	High
Commercial oil/coal	$PM_{2.5}$	23% / 100% / 100%	High
Rail	$PM_{2.5}$	65% (all scenarios)	High
Shipping	$PM_{2.5}$	38% (all scenarios)	High
Aviation	$PM_{2.5}$	22% (all scenarios)	High
Accidental fires	$PM_{2.5}$	6% (all scenarios)	High
Small-scale waste burning	$PM_{2.5}$	0% / 50% / 50%	High

The table shows that we are relatively confident in our assumptions regarding black carbon reductions. All PaMs that reduce $PM_{2.5}$ from sources would be likely to also reduce black carbon from those same sources, regardless of how those PaMs achieved the $PM_{2.5}$ reductions. As with gaseous GHGs, PaMs that sought to reduce activities (such as reducing or banning the use of certain fuels) would achieve the same percentage reduction in black carbon from a given source, as would be achieved for $PM_{2.5}$. For PaMs that involve using technology to reduce or abate emissions from a source, the percentage reduction might be different for each pollutant, with some technologies maybe being better at reducing $PM_{2.5}$ than black carbon or *vice versa*. However, we think any differences will be relatively small and, since we have no alternative information, we assume that all PaMs have an equal impact in reducing both $PM_{2.5}$ and black carbon. The total black carbon reductions relative to 2018 for all of the sectors shown in Table 12 are 53 tonnes or 0.4% (LS1), 183 tonnes or 1.3% (LS2) and 198 tonnes or 1.4% (LS3).

The main uncertainty for black carbon reductions relates to the ‘commercial cooking’ source. This is a $PM_{2.5}$ source that Imperial included in their inventory for London, but which does not appear in the NAEI, due to the lack of a suitable estimation method. This source would almost certainly create black carbon emissions as well but, because we have no NAEI data, we cannot estimate black carbon emissions with any certainty. However, the NAEI uses only a relatively small number of assumed black carbon to $PM_{2.5}$ ratios in order to generate black carbon emissions from $PM_{2.5}$ emissions. We tentatively suggest that assumptions used for sources in the NAEI such as oil combustion and small-scale waste combustion might be most suitable for commercial cooking, and this would imply a high black carbon to $PM_{2.5}$ ratio of about 0.5. The Imperial report gives PM emissions from commercial cooking of 548 tonnes in 2018, reducing to 479 tonnes in the LS1 scenario for 2030 and 137 tonnes in both the LS2 and LS3 scenario. A black carbon to $PM_{2.5}$ ratio of 0.5 would imply that emissions of black carbon from commercial cooking were about 274 tonnes in 2018 but will decrease to 240 tonnes in the LS1 scenario and 69 tonnes in the LS2/LS3 scenarios, so a reduction of 34 tonnes in LS1 (so a further 0.3% reduction) and 205 tonnes in LS2/LS3 (further 1.5% reduction). These figures are highly uncertain but suggest that controls on commercial cooking could make a particularly significant contribution to reducing black carbon emissions, compared with the sectors listed in Table 8.

The black carbon emissions reductions associated with the London scenarios cannot be estimated because detailed road transport $PM_{2.5}$ emissions are not presented in the Imperial report. Black carbon is estimated as a fraction of the exhaust $PM_{2.5}$ emissions for different vehicle technologies. However, we assume that all PaMs have an equal impact in reducing both $PM_{2.5}$ and black carbon emissions.

4.5 Uncertainties

The numbers generated by this study are uncertain. This derives from many sources, but including:

- Uncertainty in the 2030 UK projections for GHGs. The 2030 UK figures have been prepared expressly for this study and are based on broad assumptions. They assume that GHG emission factors remain at the same level as in 2018, which is not certain, at least for some sources of CH_4 and N_2O where technological changes over time might lead to marginally different factors in 2030. Uncertainty in the 2030 UK GHG figure is likely to be slightly asymmetric in that our approach is more likely to be conservative: in other words, where emission factors do change, they are more likely to decrease than increase, so by keeping factors constant, we are more likely to over- than to under-estimate.
- Uncertainty in the 2030 estimates for GHGs in London. The SMT distributions are all based on the NAEI by-source geospatial distribution grids[29].
- Uncertainty in the nature of PaMs used to achieve $PM_{2.5}$ reductions in the London scenarios. Not all PaMs will also lead to GHG reductions – those PaMs that seek to eliminate a source will reduce GHGs from a source by the same extent as $PM_{2.5}$ is reduced, but other PaMs may have no impact on GHGs at all. Because we do not have full details of the types of PaMs assumed in the Imperial report, we have adopted a 'best-case' approach where we generally assume that the same percentage reductions can be achieved for GHGs as for $PM_{2.5}$ unless the Imperial report gives sufficient information to indicate that is not possible. Therefore, we are likely to over-estimate the reductions in GHGs for London. This is perhaps the key uncertainty but it is also worth noting that we have a high level of confidence in our figures for many of the key GHG sources. In other words, the sectors where we are most uncertain about the potential for GHG reductions are also sectors with relatively small GHG emissions in London.

In addition to these uncertainties, it is also important to note that both the Imperial study and this study use datasets that have been superseded. The NAEI is updated annually, and the latest published version is the 2020 NAEI, whereas the work detailed here, and that done by Imperial, use the 2018 NAEI. Each version of the NAEI uses a different version of the UK energy statistics (DUKES), which is updated each year. Similarly, both sets of work rely on a combination of EEP18 and EEEP19, whereas BEIS have produced a later, interim, set of results (EEP NZS). The SMT results used for London's 2030 GHG emissions rely on the NAEI18 and EEP18. If analyses were updated to use the latest versions of both the NAEI and EEP, we would generate slightly different numbers. The complexities of both the NAEI and EEP and the many changes that occur for each successive version of each mean that it is impossible to predict exactly how different those numbers would be. Some indication though of the potential for change can be obtained through by noting two issues:

- The figures for domestic use of wood fuels in recent years were reduced by up to about 70% between the 2020 version of DUKES and the 2021 edition. This change had a major impact on the UK $PM_{2.5}$ UK inventory and was the main reason for a roughly 20% reduction in the UK emission total. It actually had little impact on GHGs since wood is a minor source of CH_4 and N_2O only but is indicative of the scale of changes that can occasionally occur between versions of the NAEI.
- Neither EEP18 nor EEP19 took any account of the Covid pandemic. EEP18 was released before the start of the pandemic (April 2019), whereas EEP19 was produced in the early months of the pandemic (December 2020) and did not model the impact. It is unclear how much impact the pandemic would have on energy consumption in 2030, but it serves to make the point that

[29] More information on the NAEI UK Spatial Emissions Methodology can be found at https://uk-air.defra.gov.uk/assets/documents/reports/cat09/2107291052_UK_Spatial_Emissions_Methodology_for_NAEI_2019_v1.pdf

successive versions of the EEP projections can be developed in very different situations, with perhaps very different predictions for economic growth etc.

Having mentioned all of these uncertainties and issues, they are unlikely to affect the overall messages: any reductions in $PM_{2.5}$, either in London or elsewhere in the UK, are likely to bring co-benefits in terms of reductions in GHG emissions, but those reductions will be a lot more modest than the reductions achieved for $PM_{2.5}$. Reductions in $PM_{2.5}$ emissions in London to achieve WHO-10 will likely only achieve a ~1% reduction in UK GHGs, both because PaMs to reduce $PM_{2.5}$ emissions will not always affect GHG emissions, and because London contributes less than 10% of the UK's GHG emissions.

Appendices

Appendix 1: IPCC to SNAP mapping

Appendix 1 – IPCC to SNAP mapping

IPCC	SNAP
1A1a_Public_Electricity&Heat_Production	101
	201
	10101
	10102
	10104
	10105
	20105
1A1b_Petroleum_Refining	103
1A1ci_Manufacture_of_Solid_Fuels-coke	104
	10406
1A1cii_Other_Energy_Industries	1
	104
	105
1A2a_Manufacturing_Industry&Construction:I&S	301
	30203
	30301
1A2a_Manufacturing_Industry&Construction:Non-Ferrous Metals	30307
	30308
	30309
	30310
1A2b_Non-Ferrous_Metals	301
1A2c_Chemicals	301
	30322
1A2d_Pulp_Paper_Print	301
1A2e_Food_drink_tobacco	301
1A2f_Manufacturing_Industry&Construction:Other	3
	301
	30311
	30312
	30319
	30320
	40619
1A2fii_Manufacturing_Industry&Construction:Off-road	808
1A3aii_Civil_Aviation_Domestic	80501
	80503
1A3b_Road_Transportation	7
	704
	706
	70101
	70102
	70103
	70201
	70202

IPCC	SNAP
	70203
	70301
	70302
	70303
	70501
	70502
	70503
1A3c_Railways	80203
1A3di_International_Marine	0
1A3dii_National_Navigation	8
	80301
	80302
	80303
	80304
	80402
1A3e_Other_Transportation	810
1A4a_Commercial/Institutional	2
	201
1A4bi_Residential	202
1A4bii_Residential:Off-road	809
1A4ci_Agriculture/Forestry/Fishing:Stationary	203
1A4cii_Agriculture/Forestry/Fishing:Off-road	806
1A4ciii_Fishing	80403
1A5b_Other:Mobile	801
1B1a_Post-Mining_Activities	50103
1B1a_Surface_Mines	50101
1B1a_Underground_Mines	50102
1B1b_Solid_Fuel_Transformation	10406
	10407
	20205
	40201
	40204
1B1c_Closed_Coal_Mines	50102
1B2a_Oil_Exploration	50202
1B2a_Oil_Production	502
1B2a_Oil_Transport	50202
	50401
1B2a_Refining/Storage	40101
	40104
	50201
	50401
1B2av_Distribution_of_Oil_Products	505
	50501
	50502
	50503

IPCC	SNAP
1B2b_Distribution	50603
1B2b_Gas_Exploration	50202
1B2b_Gas_Production	502
	50401
1B2b_Transmission	50603
1B2bi_Natural_Gas_Production	50302
1B2c_Flaring_Gas	90206
1B2ci_Venting_Gas	50202
1B2ci_Venting_Oil	50202
1B2cii_Flaring_Oil	90203
	90206
2A1_Cement_Production	40612
2A2_Lime_Production	40618
2A3_Limestone_&_Dolomite_Use	4
	40202
	40618
2A5_Asphalt_Roofing	40610
2A6_Road_Paving_with_Asphalt	40611
2A7	40600
2A7_(construction)	40618
2A7_(Fletton_Bricks)	30319
2A7_(glass)	30314
	30315
	30316
	30317
2A7_(mining)	40616
2A7_Glass_Production	40618
	40619
2A7_Other:Asphalt_Manufacture	40611
2B1_Ammonia_Production	40403
2B2_Nitric_Acid_Production	40402
2B3_Adipic_Acid_Production	40521
2B5_Carbon from NEU of products	90202
2B5_Chemical_Industry_Other	6
	405
	40401
	40405
	40409
	40410
	40413
	40416
	40501
	40505
	40516
	40520

IPCC	SNAP
	40522
	40525
	40527
	100601
2B6_Titanium_Dioxide_Production	40410
2B7_Soda_Ash_Production	40619
2C1_Iron&Steel	40202
	40206
	40207
	40208
	40209
	40210
2C3_Aluminium_Production	30322
	40301
2C4_Cover_gas_used_in_Al_and_Mg_foundries	40304
2C4_SF6_Used_in_Aluminium_and_Magnesium_Foundries	40304
2C5_Other	403
	30304
	30307
	30309
	40305
2C6_Zinc_Production	30304
2D1_Pulp_and_Paper	40601
2D2_Food_and_Drink	406
	40605
	40606
	40607
	40608
2E1_Production_of_Halocarbons_and_Sulphur_Hexafluoride	40801
2E2_Production_of_Halocarbons_and_Sulphur_Hexafluoride	40802
2F1_Refrigeration_and_Air_Conditioning_Equipment	60502
2F2_Foam_Blowing	60504
2F3_Fire_Extinguishers	60505
2F4_Aerosols	60501
	60506
2F5_Solvents	60204
	60508
2F9_Other	60508
2F9_Other_(one_component_foams)	60500
2F9_Other_(semiconductors_electrical_sporting_goods)	60203
	60507
2H1_Pulp_and_Paper	406
3_Solvent_and_Other_Product_Use	60403
3A_Paint_Application	60101
	60102

IPCC	SNAP
	60103
	60104
	60105
	60106
	60107
	60108
	60109
	60406
3B_Degreasing&Dry_Cleaning	60201
	60202
3C_Chemical_Products,manufacture&processing	4
	60304
	60305
	60307
	60308
	60309
	60311
	60312
	60313
3C_Degreasing&Dry_Cleaning	60313
3D_Solvent_and_Other_Product_Use_Other	60403
	60404
	60405
	60406
	60408
	60412
4A10_Enteric_Fermentation_Deer	100415
4A1a_Enteric_Fermentation_Dairy	100401
4A1b_Enteric_Fermentation_Non-Dairy	100402
4A3_Enteric_Fermentation_Sheep	100403
4A4_Enteric_Fermentation_Goats	100407
4A6_Enteric_Fermentation_Horses	100405
4A8_Enteric_Fermentation_Swine	1004
4B10_Manure_Management_Deer	100515
4B12_Liquid_Systems	1005
4B13_Solid_Storage_and_Drylot	1005
4B14_Other	1005
4B1a_Manure_Management_Dairy	100501
4B1b_Manure_Management_Non-Dairy	100502
4B3_Manure_Management_Sheep	100505
4B4_Manure_Management_Goats	100511
4B6_Manure_Management_Horses	100506
4B8_Manure_Management_Swine	1005
	100504
4B9_Manure_Management_Poultry	100507

IPCC	SNAP
	100508
	100509
4D_Agricultural_Soils	1001
	1002
	91005
4F1_Field_Burning_of_Agricultural_Residues	100301
4F5_Field_Burning_of_Agricultural_Residues	100301
5A	0
	11
5A_Forest Land (Biomass Burning - wildfires)	11
5A_Forest Land (Drainage of soils)	11
5A1_Forest Land Remaining Forest Land	1122
5A2_Land Converted to Forest Land	1122
5B	0
	11
5B_Cropland (Biomass Burning - controlled)	11
5B_Cropland (Biomass Burning - wildfires)	11
5B1_Cropland Remaining Cropland	0
5B2_Land Converted to Cropland	0
5B2_N2O emissions from disturbance associated with land-use conversion to cropland	11
5C_Grassland (Biomass burning - controlled)	11
5C_Grassland (Biomass Burning - wildfires)	11
5C1_Grassland Remaining Grassland	0
5C2_Land converted to grassland	0
5D1_Land converted to settlements	999
5D1_Wetlands remaining wetlands	0
5D2_Land converted to wetlands	0
	11
	999
5D2_Non-CO2 emissions from drainage of soils and wetlands	0
5E	0
	11
5E_Settlements (Biomass burning - controlled)	11
5E_Settlements (Drainage of soils)	0
5E1_Settlements remaining settlements	0
5E2_Land converted to settlements	11
	999
5G_Other (Harvested wood)	0
5G_Other (OT and CD)	0
6A1_Managed_Waste_Disposal_on_Land	90401
6B1_Industrial_Wastewater_Handling	91002
6B2_Wastewater_Handling	91002
6C_Waste_Incineration	902
	90201
	90202

IPCC	SNAP
	90205
	90207
	90901
	90902
	91102
6D_Waste_Incineration	91006
	100907
Aviation_Bunkers	0
	80502

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