Review of Reporting Systems for National Black Carbon Emissions Inventories: EU Action on Black Carbon in the Arctic - Technical Report 2

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Black smoke from burning of associated gas, Leonid Ikan / Shutterstock

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Preface

This report presents the results of the EU Action on Black Carbon in the Arctic's Review of Reporting Systems for National Black Carbon Emissions Inventories.

The EU Action on Black Carbon in the Arctic is an initiative sponsored by the European Union to contribute to the development of collective responses to reduce black carbon emissions in the Arctic and to reinforce international cooperation to protect the Arctic environment. It provides and communicates knowledge about sources and emissions of black carbon and supports relevant international policy processes:

- Supporting processes aimed at setting clear commitments and/or targets for reducing black carbon emissions from major sources (gas flaring, domestic heating, transport, open burning and maritime shipping).
- Enhancing international cooperation on black carbon policy in the Arctic region – with a special focus on supporting the work of the Arctic Council and Convention on Long-range Transboundary Air Pollution and other national, regional and international initiatives, and building strong collaboration with EU strategic partners.

This technical report reviews the status of black carbon emissions reporting, with special emphasis on reporting systems applied under the United Nations Economic Commission for Europe (UN ECE) Convention on Long-range Transboundary Air Pollution and the Arctic Council, with the aims of identifying gaps and proposing measures to fill these gaps. Results of this work will be communicated to relevant bodies under these and other international organizations engaged in work to document emissions of black carbon affecting the Arctic.

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Executive summary

Black carbon has emerged as an important climate-forcer and a pollutant impacting human health. Recognising the significance of this pollutant, international policy action on reducing black carbon emissions has started to take shape over the past decade.

The 2012 amendment of the Gothenburg Protocol to the United Nations Economic Commission for Europe (UNECE) Convention on Long-range Transboundary Air Pollution (CLRTAP) and the subsequent revision of the EU National Emission Ceilings Directive encourage Parties/Member States to prioritise emissions reductions of particulate matter in source sectors "known to emit high amounts of black carbon".

In the Arctic context, black carbon has been identified as a significant driver of Arctic warming. Introduction of proven mitigation technologies would have nearterm benefits in reducing warming, both within the Arctic and globally. Under the *Enhanced Black Carbon and Methane Emissions Reductions: An Arctic Council Framework for Action*, the eight Arctic Council Member States adopted an aspirational collective goal in 2017 to collectively reduce black carbon emissions by 25–33% below 2013 levels by 2025.

Within the scope of the United Nations Framework Convention on Climate Change (UNFCCC), a small number of countries included emissions reduction targets for black carbon within their Nationally Determined Contributions (NDCs) under the Paris Agreement.

Critical to the success of action to reduce black emissions are well developed emissions inventory and reporting systems. Emissions inventories and systems that facilitate and ensure reporting of inventory data provide both a baseline for developing emissions reduction targets and a transparent gauge for monitoring individual and collective progress toward meeting those targets. This technical report reviews the systems currently in place for reporting national black carbon emissions inventories, focussing on reporting of emissions from sectors of Arctic relevance.

There are currently three international fora where official national inventory estimates of black carbon are reported to a central body: UNECE-CLRTAP, the EU's NEC Directive, and the Arctic Council Framework on Enhanced Black Carbon and Methane Emissions Reductions. Where countries belong and report to two or three of the above fora (e.g., the Scandinavian EU- and Arctic Council Member States), generally the same emissions data are reported (mostly those data submitted to CLRTAP using the CLRTAP reporting template). In all three fora, the reporting of national black carbon emissions data is not mandatory, but rather encouraged. Despite the absence of a mandatory reporting obligation, a relatively high level of reporting has been achieved in recent years. As of 2018, 41 of the 51 CLRTAP Parties, 26 of 28 EU Member States, and all eight Arctic Council Member States (plus 10 of 13 Observer States) submitted estimates for national total black emissions to some extent during recent reporting cycles. This level of voluntary reporting demonstrates that a large number of countries within CLRTAP, the Arctic Council, and the EU, view black carbon emissions to be a significant climate and human health issue, and an area where action to reduce emissions is warranted. It also indicates that workable emissions reporting materials (reporting templates, inventory methodological guidelines) exist and that these can be employed by many countries, albeit with considerable scope for improvements.

While the observed level of reporting is encouraging, this review conducted under the auspices of the EU Action on Black Carbon in the Arctic highlights a number of critical deficiencies in the current reporting systems. Starting with the recommended inventory methods in the 2016 EMEP/EEA Guidebook, it is apparent that emission coefficients (black carbon emission factors / fractions of particulate matter with an aerodynamic diameter <2.5 µm – $PM_{2.5}$) are lacking, particularly for *Higher Tier* methods (i.e., methods that support more comprehensive and detailed emissions categorisation). Furthermore, the emission coefficients currently provided in guidance documents are typically associated with high relative uncertainties. Another issue to emerge was that of incompleteness in- and inconsistency between the reported national black carbon emissions inventories. While national circumstances dictate which emission sources are relevant, the review revealed a significant variation in the number of source sectors reported, both between the countries but also over the time series of certain countries. Focusing on five priority source sectors (residential combustion, gas flaring, maritime shipping, open burning of agricultural residues, road transport), it was also apparent that *Lower Tier* inventory methods were being applied to a large extent. Finally, despite many countries submitting black carbon inventory data (albeit to varying extents), it should also be noted that those countries which have not yet reported black carbon emissions constitute a considerable gap in the respective emissions reporting systems. Nine countries have not yet submitted black carbon emissions estimates to CLRTAP (Albania, Austria, Bosnia and Herzegovina, Liechtenstein, Luxembourg, Macedonia, Montenegro, Turkey, Ukraine) and three have not yet reported black carbon emissions to the Arctic Council (China, India, Singapore). Russia, which reported black carbon emissions to the Arctic Council in 2015, has yet to provide black carbon inventory data to CLRTAP. In terms of monitoring the emissions of black carbon directly impacting the Arctic, the absence of routine reporting by the Russian Federation represents a particularly significant gap.

Emissions reporting systems are thus in need of further improvement. In evaluating needs for improvement, the EU Action on Black Carbon in the Arctic review identified the following priority areas:

1. Improvements in the available black carbon inventory methods and a subsequent revision of the EMEP/EEA Guidebook to include more *Higher Tier* black carbon inventory methods.
2. Establishment of mandatory reporting under CLRTAP.

3. Continued and enhanced cooperation between scientists developing independent black carbon emissions datasets and the national inventory experts compiling official black carbon inventories.

4. Enhanced cooperation between CLRTAP and the Arctic Council to expand and harmonise black carbon emissions reporting by countries whose black carbon emissions impact the Arctic.

The following text elaborates on these priority areas.

Future revisions of the 2016 EMEP/EEA Guidebook should look to further develop methods for estimating black carbon emissions, focusing in particular on increasing the extent to which relevant black carbon source sectors are provided with *Higher Tier* emission coefficients. To support this work, further experimental research is likely to be required to derive new emission factors and black carbon fractions and to reduce uncertainties in these parameters. The Intergovernmental Panel on Climate Change (IPCC) Task Force on National Greenhouse Gas Inventories could be crucial in this process, particularly in terms of inventory guidelines with expanded geographical scope. However, before embarking on a comprehensive update and expansion of the current methodologies, a reassessment of the validity of the current methods using black carbon fractions of $PM_{2.5}$ should be considered. Such an improvement in methodologies would provide countries within and beyond CLRTAP, the Arctic Council, and the European Union with the tools needed to develop and/or improve their own black carbon emissions inventories.

However, improving the available inventory methodologies alone will not secure voluntarily reporting of black carbon by those countries that do not currently prepare national inventories. Neither will it secure that those countries that do compile inventories take the steps to upgrade their inventories by collecting the activity data required for implementing *Higher Tier* inventory methods. This report argues that substantial improvements in reporting under CLRTAP can only be expected once the reporting of black carbon emissions becomes mandatory. Implementing this step, which was included in the most recent proposed updates and revisions to the long-term strategy for CLRTAP, would not only legally oblige the Parties to report their black carbon emissions, but would also mean that the emissions estimates would be subject to rigorous independent inventory review by the Convention's Centre for Emissions Inventories and Projections (CEIP). These so-called Stage 3 reviews, which focus on mandatory pollutants only, can identify and where necessary request action on sectors in the inventories, where for example emissions estimates are not available or should have been estimated with *Higher Tier* methods. These reviews are a vital part of the quality assurance process that is part of any comprehensive emissions reporting system intended to support international action. Making reporting of black carbon emissions mandatory under CLRTAP is therefore considered a critical step in improving the completeness and consistency of the current CLRTAP reporting systems. This would have considerable benefit for the European Union and Arctic Council whose reporting systems are essentially based on the same data, methods and reporting mechanisms. According to proposals made by the CLRTAP policy review group, a transition to mandatory black carbon emissions reporting could be implemented via an update of the 2012 Gothenburg Protocol Amendment. This report strongly supports such action; however, the report furthermore argues that implementing mandatory black carbon emissions reporting could be accelerated through an updated or new Executive Body Decision on *Reporting of Emissions and Projections Data under the Convention and its Protocols in Force*. Effecting mandatory black carbon emissions reporting through an Executive Body Decision would furthermore mean that the reporting obligation would apply to all 51 CLRTAP Parties and not just Parties to the Gothenburg Protocol.

It should be stressed that even if mandatory black carbon emissions reporting under CLRTAP were to be implemented, a number of inherent limitations will remain, particularly when viewing the systems' adequacy for monitoring black carbon emissions that are contributing to regional warming in the Arctic. This report therefore highlights the importance of independent black carbon emissions inventories, as well as enhanced cooperation between multilateral environmental agreements.

Independent inventories of black carbon emissions offer valuable estimates for comparing with officially reported inventories. Such inventories, often achieved with different but generally comparable methodologies and/or data on activity levels and emission factors, help establish confidence in officially reported inventories. Variation between estimates indicates the scale of uncertainties in the methods used, and also helps to improve emission calculations when the reasons for discrepancies can be identified and understood. Enhancing the dialogue between those responsible for preparing national inventories and independent international inventory experts is therefore highly recommended. Furthermore, these emissions estimates are essential to filling national and/or sectoral gaps in the official reporting systems. The limited geographical scope of the EMEP grid and the current incomplete reporting of gridded black carbon emissions under CLRTAP both highlight the importance of spatially-disaggregated emissions estimates from independent inventories, particularly with respect to emissions from high-latitude gas flaring and shipping in Arctic waters.

Finally, with hopes that black carbon emissions reporting would become established under the UNFCCC Paris Agreement somewhat dashed by the agreed *Paris Rulebook* that emerged from the recent 24th Conference of the Parties in Katowice, Poland, the onus remains very much on the CLRTAP-Arctic Council-EU Nexus. Further cooperation between CLRTAP and the Arctic Council in particular could broker a geographically expanded and harmonised reporting system for monitoring black carbon emissions that impact the Arctic. Despite being Parties to CLRTAP, the United States and Canada are not obliged to follow the reporting Guidelines and thus do not have to report their emissions data in the same format and at the same source sector resolution as the other 49 Parties to CLRTAP. Furthermore, restricted to the current 51 Parties, the Convention does not cover other northern hemisphere countries whose black carbon emissions significantly impact the Arctic. In this respect, enhanced collaboration between CLRTAP and the Arctic Council could be key in harmonising an expanded system that also includes high emitting Arctic Council Observer States outside CLRTAP. Canada's reporting under CLRTAP is largely consistent with that expected of the EMEP countries; however, Canada is currently considering steps to further harmonise their black carbon emissions reporting by submitting the black carbon data in the CLRTAP reporting template rather than as a separate data file. This small but significant technical adjustment was discussed at an EU-Canada stakeholder meeting involving Canadian inventory representatives and experts from the EU Action on Black Carbon in Arctic. Such dialogue at a higher level through the Arctic Council may be an option to encourage harmonised black carbon emissions reporting to CLRTAP by the United States, whose emissions are currently reported using a more aggregated source sector split. Indeed the Arctic Council may provide a suitable forum to encourage Russia to report black carbon emissions to CLRTAP – Russia is yet to report these emissions to CLRTAP, despite having reported national total- and source sector black carbon emissions estimates to the Arctic Council. Furthermore, the Arctic Council could also represent a platform to engage non-CLRTAP Artic Council Observer States, including India and China, to prepare black carbon inventories and report these in a manner consistent with that of other countries reporting under CLRTAP and the Arctic Council Framework. Opening up reporting mechanisms for voluntary submissions from countries external to the CLRTAP-Arctic Council-EU scope could be further considered in this connection and could possibly be facilitated through the Clean Air and Climate Coalition (CCAC). These working recommendations will be explored further during the course of this EU Action on Black Carbon in the Arctic and elaborated in an upcoming *Roadmap for International Cooperation on Black Carbon*.

1. Introduction

Black carbon, defined by Bond et al. (2013) as a distinct type of carbonaceous material, formed only in flames during the combustion of carbon-based fuels, has emerged over the past decade as potentially one of the most important anthropogenic air pollutants. It is distinguished from other forms of carbon in atmospheric particulate matter, such as organic carbon, by its strong absorption of visible light, aggregate morphology, insolubility in water / common organic solvents, and that it is refractory (vaporisation temperature ~4000 K). Due to these distinct physical properties and its potential toxicity (Janssen et al., 2012) black carbon is significant in terms of both climate change and air quality. Given its absorption spectrum in the visible range, black carbon warms the atmosphere directly by absorbing solar radiation and indirectly by accelerating snow/ice melt when deposited (Bond et al., 2013). According to recent estimates, the direct radiative forcing effect of black carbon emissions during the industrial era may have been of a similar magnitude to that of methane (CH_4) emissions (Bond et al., 2013; Wang et al., 2016). Meanwhile, in terms of human health, recent epidemiological studies suggest that certain pulmonary and cardiovascular conditions are more strongly associated with exposure to black carbon than to aggregate particulate matter (e.g., Baumgartner et al., 2014).

Given the relatively recent emergence of scientific literature on black carbon as a short-lived climate forcer (SLCF) and a pollutant affecting human health, international policy action on reducing black carbon emissions is at an early stage. Under the United Nations Economic Commission for Europe (UNECE) Convention on Long-range Transboundary Air Pollution (UNECE, 1979), the 1999 Gothenburg Protocol to Abate Acidification, Eutrophication and Ground-level Ozone (UNECE, 1999) was amended in 2012 (UNECE, 2012) to, *inter alia*, *encourage* Parties to prioritise reductions in emissions of particulate matter with a diameter equal to or below 2.5 µm ($PM_{2.5}$) in the source sectors where black carbon contents of $PM_{2.5}$ are significant. However, the 2012 Amendment is yet to enter into force (upon ratification by two-thirds of the Protocol Parties), and even upon entering into force does not commit the signatory Parties to the Protocol to explicit reduction targets for black carbon emissions. The Amendment was of additional relevance for European Union (EU) Member States, because much of the Amendment's content on black carbon was included in the revised EU National Emission Ceilings (NEC) Directive 2016/2284. Although this Directive is in force, again the EU Member States are not committed to explicit reduction targets for black carbon emissions. Within the scope of the United Nations Framework Convention on Climate Change (UNFCCC, 1992) and the Paris Agreement to limit the global temperature increase well below 2°C above pre-industrial levels (UNFCCC, 2015), some countries have gone beyond greenhouse gases and included additional emissions reduction targets for black carbon within their Nationally Determined Contributions (NDCs). According to a 2016 report by the Climate and Clean Air Coalition (CCAC), Chile, Mexico and Nigeria submitted Intended Nationally Determined Contributions (INDCs) which included explicit mention of mitigation action on black carbon emissions (CCAC, 2016). These INDCs were converted to NDCs as Chile, Mexico and Nigeria formally joined the Paris Agreement by submitting their respective instrument of ratification, acceptance, approval or accession. Canada also refers to taking action to reduce black carbon in its revised NDC (see NDC Registry[1]). However, despite the flexibility afforded by the Paris Agreement, it remains unclear whether the Parties will ultimately be allowed to account for reductions in black carbon emissions in their respective NDCs. To date, the only formal international action on black carbon with explicit, though not legally binding, reduction targets, is the Arctic Council's 2015 adopted framework *Enhanced Black Carbon and Methane Emissions Reductions: An Arctic Council Framework for Action* (Arctic Council, 2015). Under this framework, the eight Arctic Council Member States agreed to an aspirational collective goal in 2017 to collectively reduce black carbon emissions by 25–33% below 2013 levels by 2025 (Arctic Council, 2017).

The Arctic Council Framework represents a milestone moment and it is hoped that this framework may stimulate further international cooperation on black carbon beyond the Arctic. Within this context, the technical report here, which reviews reporting systems for black carbon emissions inventories, provides a timely and valuable contribution. Well-developed emissions inventories and reporting systems are fundamental to air pollution abatement. Emissions inventories and systems that facilitate and ensure reporting of inventory data provide both a baseline for developing emissions reduction targets and a transparent gauge for monitoring individual and collective progress toward those targets. This technical report reviews the inventory and reporting systems currently in place for black carbon emissions. The review is structured into three sections. The first (Chapter 2) provides an overview of the international frameworks within which national inventory estimates of black carbon emissions are reported. This focuses principally on the UNECE CLRTAP (Section 2.1) and the Arctic Council Framework (Section 2.2), but also reports on relevant developments within other international framework fora such as the European Union and the UNFCCC (Section 2.3). The second part of the review (Chapter 3) then details the current level of black carbon emissions reporting by Parties to the UNECE CLRTAP (Section 3.1) and the Arctic Council Framework (Section 3.2). This chapter includes a summary of the level of reporting of black carbon emissions estimates to the Arctic Council; however, the focus of this part of the review is the level of reporting under CLRTAP given that the data reported here are mostly the same as those reported by Arctic Council Member States under the Framework on Enhanced Black Carbon and Methane Emissions Reductions and/or by EU Member States under the National Emission Ceilings Directive. Here the report details which Parties are reporting

[1] https://www4.unfccc.int/sites/NDCStaging/Pages/All.aspx

estimates of national total black carbon emissions and which are reporting emissions estimates for five priority source sectors: residential combustion, gas flaring, international shipping, open burning of agricultural residues, and road transport. For these source sectors, the review also details which methods are being applied by the reporting Parties. The final part of the chapter on reporting status (Section 3.3) compares national total and sector-level black carbon emissions estimates reported by selected countries to the UNECE Convention and/or Arctic Council with corresponding estimates from independent emissions inventory datasets developed by the international scientific community.

The final part of the review (Chapter 4) summarizes and provides perspectives on the international landscape for reporting black carbon emissions. In particular, it recapitulates the main limitations of the current international frameworks for monitoring black carbon emissions and provides recommendations on how these systems could be improved.

2. Overview of international frameworks for reporting inventory estimates of national black carbon emissions

2.1 UNECE CLRTAP

2.1.1 Overview of CLRTAP and reporting obligations of Parties

The signing of the 1979 Geneva Convention on Long-range Transboundary Air Pollution, henceforth abbreviated as CLRTAP, was a landmark moment in international environmental policy. Bringing together 33 nations under the auspices of the UNECE, CLRTAP established the first international treaty to address regional air pollution and its crossborder impacts. While CLRTAP arguably constituted a loose framework agreement between its Parties, it nonetheless established general principles and an institutional framework for international cooperation on tackling air pollution. Indeed from these foundations, CLRTAP has since been transformed from an initial working agreement tackling sulphur dioxide emissions and effects of acid deposition, to a multi-protocol treaty establishing legally binding emissions reduction targets for a number of pollutants impacting both ecosystems and human health. For more details on the history of CLRTAP, the reader is referred to the UNECE's official website[2] and the review papers by Byrne (2017) and Reis et al. (2012).

A key principle of CLRTAP, laid out in the original 1979 agreement (UNECE, 1979), is the *Exchange of Information* under Article 8. Specifically, under Article 8, paragraph (a), the Parties committed themselves to exchange available information including data on national emissions, the details of which (which pollutants, submission intervals etc.) were *to be agreed upon*. Due to the varying ratification status of the different Protocols and their amendments[3], the obligations for reporting emissions data vary between the 51 Parties that have so far ratified CLRTAP (Figure 2.1). Nonetheless, a set of minimum reporting obligations have been set in Decisions by the Convention's Executive Body. The current minimum reporting obligations are outlined in Annex I of Decision 2013/4 (UNECE, 2013a). According to this document, which took effect on 1 January 2015, all Parties to CLRTAP are obliged, *inter alia*, to submit annual national total emissions by 15 February for the calendar year that is two years prior to the reporting year for the following pollutants:

- Sulphur oxides (SO_X)
- Nitrogen oxides (NO_X)
- Ammonia (NH_3)
- Non-methane volatile organic compounds (NMVOCs)
- Carbon monoxide
- Particulate matter (referring in particular to $PM_{2.5}$ and PM_{10})
- Heavy metals (in particular cadmium, lead, mercury)
- Persistent organic pollutants (in particular hexachlorobenzene, polychlorinated biphenyls, dioxins/furans, polycyclic aromatic hydrocarbons)

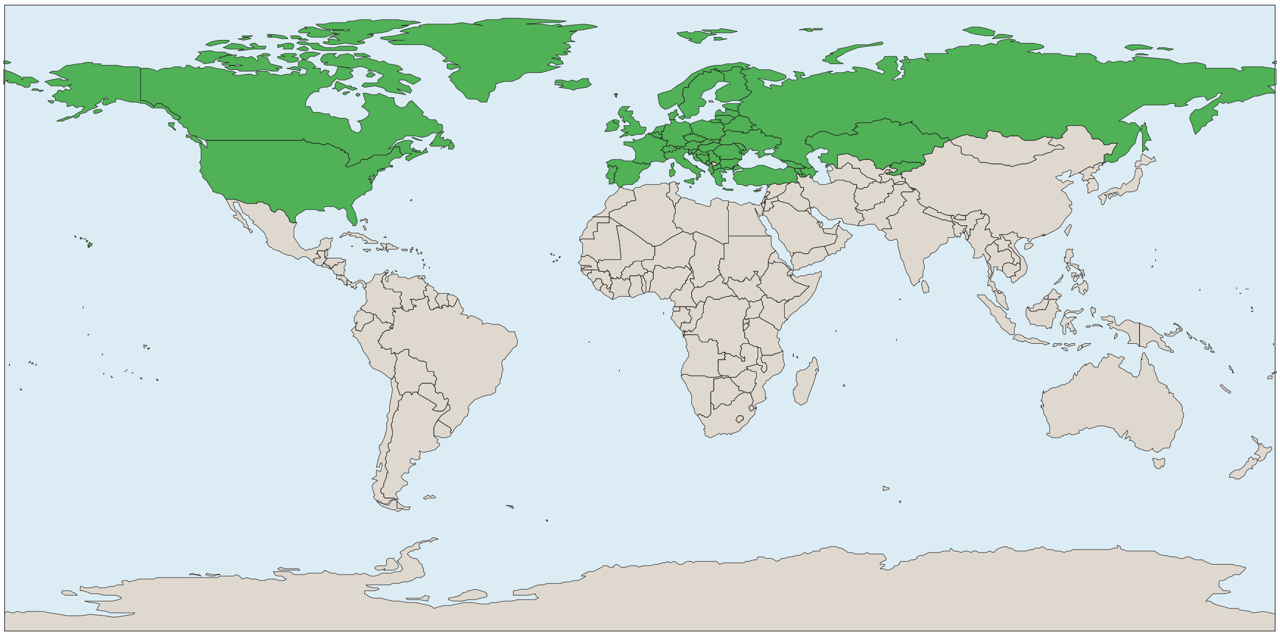

Figure 2.1 Geographical scope of the UNECE Convention on Long-range Transboundary Air Pollution (CLRTAP).

[2] https://www.unece.org/env/lrtap/welcome.html
[3] https://www.unece.org/env/lrtap/status/lrtap_s.html

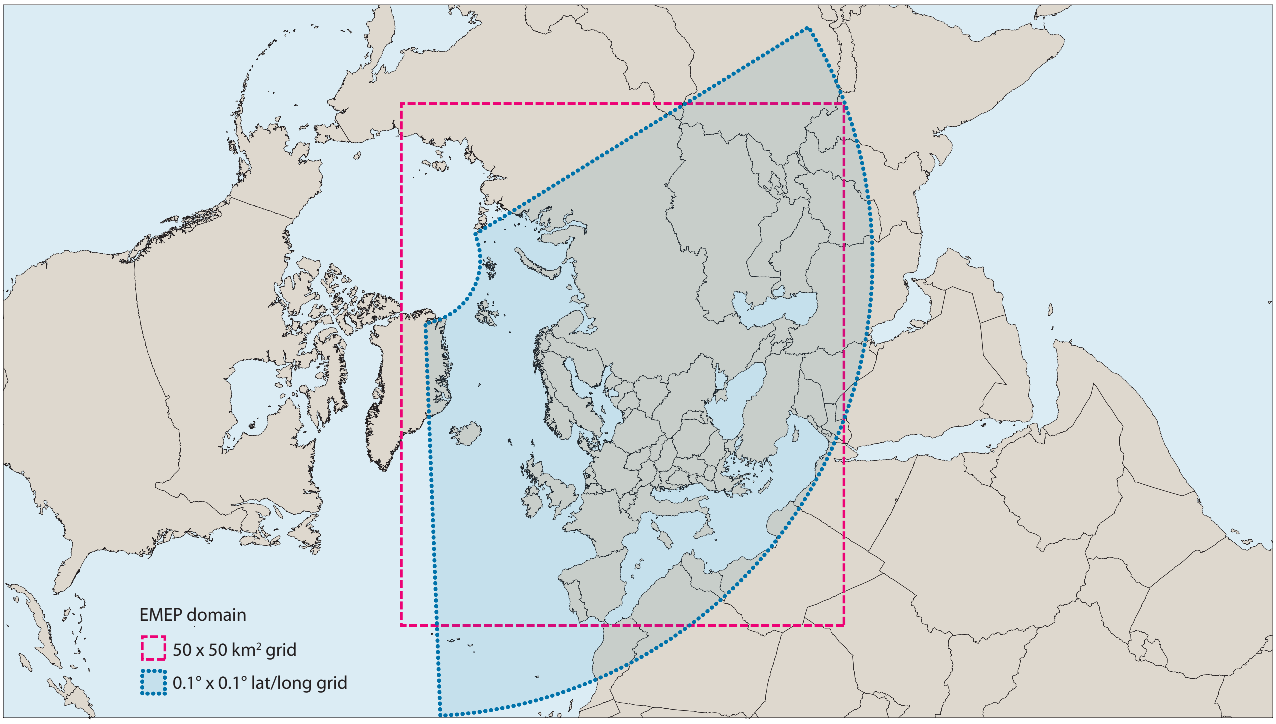

Figure 2.2 Geographical scope of EMEP. The new EMEP domain (0.1° × 0.1°) extends between 30°N and 82°N and between 30°W and 90°E. The previous EMEP domain (50 × 50 km) is also shown.

The Parties are obliged to submit their data to the Centre of Emissions Inventories and Projections (CEIP), which is the body under the European Monitoring and Evaluation Programme (EMEP) responsible for collecting, archiving and reviewing the submitted emissions data.

According to Decision 2013/4 and the parallel Decision 2013/3 (UNECE, 2013b), the Parties are also obliged to follow the most recent version of the *Guidelines for Reporting Emissions and Projections Data under the Convention on Long-range Transboundary Air Pollution* (UNECE, 2015) when compiling and submitting their emissions inventory data. These Guidelines (and the Annexes therein) detail specific requirements for the submission of inventory data such as: the source sector level (so-called Nomenclature for Reporting 'NFR' categories) at which submissions should be calculated; the templates and formats in which the data should be submitted; and the structure and content of the Informative Inventory Report that shall be included in the submission. The Guidelines also stipulate that Parties shall as a minimum use the methodologies in the latest version of the *EMEP/EEA air pollutant emission inventory guidebook*. The latest version of the Guidebook is from 2016 (EEA, 2016) and describes at a source sector level consistent with the reporting requirements, the inventory methods and emission factors the Parties shall employ if superior national methods are unavailable. The Guidebook also includes decision trees that Parties shall follow when selecting inventory methods.

It is important to highlight that despite CLRTAP-wide adoption of the Guidelines via Decision 2013/4 not all Parties are required to follow them. As explained in Chapter IV of the Guidelines, the Guidelines apply only to Parties within the geographical scope of EMEP, as defined in the 1984 Protocol on Longterm Financing of EMEP (UNECE, 1984) (Figure 2.2). The United States and Canada, which both lie outside and do not overlap with the EMEP domain, are thus only invited to follow the Guidelines and the Guidebook when compiling and submitting their emissions inventory data. Both countries have nonetheless developed rigorous emissions inventory systems; however, the degree to which the reporting of their emissions is harmonised with that described in the Guidelines (addressed in Section 3.1.2) is left to the discretion of the two countries.

2.1.2 Black carbon and CLRTAP

2.1.2.1 Developments leading to the inclusion of black carbon reporting

Since the reporting cycles subsequent to the adoption of Executive Body Decision 2002/10 (UNECE, 2002), Parties to CLRTAP have been obliged to submit emissions data for particulate matter. However, unlike other pollutants such as SO_X, NO_X and NMVOCs, particulate matter was not anchored in any of CLRTAP's protocols until the 1999 Gothenburg Protocol to Abate Acidification, Eutrophication and Ground-level Ozone was amended in 2012 (UNECE, 2012). Although the amended protocol is yet to enter into force[4], the 2012 amendment marks a significant development for CLRTAP in terms of particulate matter and black carbon. In addition to defining renewed emissions reductions for SO_X, NO_X, NH_3 and NMVOCs for 2020, the amendment sets out 2020 emissions reduction commitments for $PM_{2.5}$ (base year 2005). Furthermore, the amendment *encourages* Parties to prioritise $PM_{2.5}$ reductions in the source sectors where black carbon contents of $PM_{2.5}$ are significant, and to compile and submit inventory estimates of past and projected national black carbon emissions.

Several developments subsequently followed which have aimed at facilitating the reporting of black carbon emissions by the Parties to CLRTAP. In Decision 2013/4 (UNECE, 2013a), where listing the mandatory pollutants to be reported under

[4] https://treaties.un.org/Pages/ViewDetails.aspx?src=TREATY&mtdsg_no=XXVII-1-k&chapter=27&clang=_en

Article 8, paragraph (a) of the Convention, the text lists black carbon as a pollutant to be reported if a Party considers it appropriate. Meanwhile, the updated Guidelines encourage Parties to report black carbon emissions and furthermore provide a working definition of what black carbon is – carbonaceous particulate matter that absorbs light. As for the other pollutants, the Guidelines also refer Parties to the EMEP/EEA Guidebook, which was updated in 2013 (EEA, 2013) to include methods and emission factors for estimating black carbon emissions. With this official encouragement for compiling and submitting inventory emission estimates for black carbon, the subsequent 2014 update of the Guidelines included an alteration of the emissions reporting template (Annex I), which since the 2015 reporting year has allowed Parties to submit their black carbon emissions estimates to CEIP together with emissions estimates for the other pollutants (see Appendix A1 to this report, Figure A1.1).

Recent developments within the Convention indicate that reporting of black carbon emissions could become mandatory in the future. In 2016, an *ad hoc* policy review group of experts was established by CLRTAP's Executive Body to provide recommendations on how the Convention should take action in light of the 2016 scientific assessment of the Convention, *Towards Cleaner Air: Scientific Assessment Report 2016* (Maas and Grennfelt, 2016). Among the policy review group of experts' findings and suggestions was the recommendation that "…the Convention work on (an) improved definition(s) of black carbon for emissions reporting and for ambient air and effects monitoring purposes, and that reporting of national black carbon emissions inventories should be mandatory once the improved definition for reporting is agreed…" (UNECE, 2017). The policy review group was subsequently tasked with elaborating (in consultation with the Bureau of the Executive Body) a draft revised long-term strategy for the Convention which sets out a vision for the Convention for the period 2020–2030. The draft strategy as proposed by the policy review group states under Chapter *D Strategic priorities of the Convention* (paragraph 51, page 10) that an update of the Gothenburg Protocol (if deemed necessary following the Protocol's entry into force) "…could include the introduction of mandatory emissions reporting; emission reduction commitments; further measures to reduce black carbon emissions…" (UNECE, 2018a). At the Executive Body's thirty-eighth session held 10–14 December 2018 in Geneva, the Executive Body considered and adjusted this version and subsequently adopted the new long-term strategy in Decision 2018/5. This longterm strategy, which is found in the Annex of the advance version of Decision 2018/5 (UNECE, 2018b), does not explicitly include the proposal quoted above, and instead recommends that a review of the amended Gothenburg Protocol, which will determine whether an update of the Protocol is necessary, "... should take into account, as appropriate, the priorities identified in the present strategy, as well as the recommendations in the policy review group report (ECE/EB.AIR/WG.5/2017/3) and the findings of the 2016 scientific assessment report…".

It should be noted that an update of the Gothenburg Protocol is likely only to effect mandatory black carbon emissions reporting in the medium- to long term. Going down this route can only commence once the 2012 Amendment enters into force and would subsequently necessitate a sequence of events, each of which requires a substantial period of time: a formal review of the Protocol, a period of preparation and discussion of draft amendments, adoption of the new amendment, and finally the time required for enough Parties to ratify the new amendment for its entry into force. Furthermore, this obligation would then only apply to Parties to the Protocol rather than all 51 Parties to the Convention. Nonetheless, a move to make reporting of black carbon emissions mandatory would represent a significant step. In addition to providing a legal basis for the reporting, the change in reporting status from voluntary to mandatory would be significant in terms of the independent review of the data. Currently, reported black carbon emissions inventories do not undergo the rigorous independent review to which the emissions of mandatory pollutants are subject. Black carbon emissions are evaluated within the Stage 1 and Stage 2 reviews which document, *inter alia*, whether black carbon was reported by the different parties, outliers in emissions time series, and the extent to which the emissions estimates have been revised (see annual CEIP review reports; such as CEIP, 2018). However, black carbon emissions data are not examined at Stage 3 level, where independent sector experts critically review the data and inventory methodologies applied, and contact Parties for comment/clarification.

2.1.2.2 Methodological recommendations for estimating emissions

As per the most recent Guidelines (UNECE, 2015), Parties are recommended to follow the methodologies set out in the latest EMEP/EEA Guidebook, which is currently the version updated in 2016 (EEA, 2016). The Guidebook is structured in two parts: A and B. Part A provides general guidance on compiling emissions inventories, with the chapters covering issues such as data collection, methodological choice, uncertainties, inventory management, and quality assurance/quality control. Part B on the other hand is a collection of chapters/subchapters describing for each source sector/sub-sector, respectively, the recommended and available methodologies for estimating emissions of air pollutants under CLRTAP and other international agreements (e.g., reporting under the UNFCCC, reporting to the European Union). It is thus in the chapters of Part B, that the specific source sector methods for estimating emissions of black carbon can be found.

As described in the introduction to the EMEP/EEA Guidebook (Part A, chapter 1), the methods available for each source sector are categorised into three tiers reflecting the complexity of the method. Tier 1 methods are the most basic, where the emissions (E) of a given pollutant (x) are calculated from a simple linear equation, where national activity data (AD; such as energy statistics, production statistics) are multiplied by pollutant specific emission factors (EF_x) describing the quantity of the pollutant emitted per unit activity.

$$E_x = AD \times EF_x$$

Tier 2 methods employ the same equation; however, the two tiers differ in the degree of stratification in the activity data and emission factors. For instance, while Tier 1 methods may employ aggregated national activity statistics and global emission factors for a given source, a Tier 2 method may use a country-specific emission factor. Furthermore, Tier 2 methods may stratify the activity data into subactivities and multiply the statistics for each subactivity by respective emissions factors specific to the subactivity. Tier 3 methods go beyond the simple functions of aggregated or stratified national activity statistics and typically constitute the use of, for example, facility level emissions data from the industrial and energy sectors or sophisticated process-based models adapted for the country's conditions.

According to the EMEP/EEA Guidebook, it is considered good practise to use *Higher Tier* methods (Tier 2 or Tier 3) for key categories (i.e., a source category significantly influencing a Party's total emissions), unless necessary resource requirements are prohibitive. Nonetheless, for each chapter in Part B of the Guidebook, a decision tree is provided to help select the most appropriate methods for estimating emissions from each source sector given the country's circumstances (such as availability of required activity data). While a country's circumstances may render Tier 3 methods the most appropriate for certain source sectors according to the decision trees, details on these sophisticated methods and models are beyond the scope of the Guidebook. As such, Part B generally only provides references to the Tier 3 methods available. The Guidebook does however provide details for the Tier 1 and Tier 2 methods. For these, the chapters in Part B describe for each source sector which activity data should be used and provide corresponding Tier 1 and Tier 2 emission factors for each pollutant. In the case of Tier 2 methods, the Guidebook does not provide country-specific emission factors but rather the stratified emission factors for the methods using sub-activity data.

In contrast to the other pollutants, the EMEP/EEA Guidebook mostly recommends that black carbon emissions are calculated as a percentage of particulate matter emissions. The Guidebook also assumes that *elemental carbon* and black carbon are one and the same. Generally, although not always, black carbon factors are given as a dimensionless proportion of $PM_{2.5}$ emissions (F_{BC}) rather than an emission factor *per se* (EF_{BC}). As such, the inventory equation for black carbon emissions typically takes the form:

$$E_{BC} = AD \times EF_{PM2.5} \times F_{BC}$$

As part of this review, an examination was made of the extent to which black carbon fractions or emission factors, henceforth grouped together under the term *black carbon emission coefficients*, are given in the EMEP/EEA Guidebook. Each subchapter in Part B describing the methods for individual source sectors was checked for the presence of Tier 1 and Tier 2 black carbon emission coefficients. As Tables 2.1 to 2.5

Table 2.1 Availability of Tier 1 and Tier 2 black carbon emission coefficients in the 2016 EMEP/EEA Guidebook (EEA, 2016) chapters and subchapters describing source-specific inventory methodologies for estimating air pollutant emissions from the sector *Energy*. Bold indicates the chapters and subchapters describing inventory methodologies for the five priority source sectors in this review.

Chapter/subchapter	Tier 1	Tier 2
1.A Combustion		
1.A.1 Energy industries		
1.A.1.a Public electricity and heat production	green	green
1.A.1.b Petroleum refining	green	green
1.A.1.c Manufacture of solid fuels and other energy industries	red	green
1.A.2 Manufacturing industries and construction	green	red
1.A.3.a Aviation	green	green
1.A.3.b.i-iv Exhaust emissions from road transport	green	green
1.A.3.b.v Gasoline evaporation	-	-
1.A.3.b.vi-vii Road vehicle tyre and brake wear, road surface wear	green	red
1.A.3.c Railways	green	red
1.A.3.d Navigation (shipping)	green	green
1.A.3.e.i Pipeline transport	-	-
1.A.4 Small combustion	green	green
1.A.4 Other non-road mobile sources and machinery	green	green
1.B Fugitive emissions from fuels		
1.B.1.a Fugitive emissions from solid fuels: Coal mining and handling	red	red
1.B.1.b Fugitive emissions from solid fuels: Solid fuel transformation	green	red
1.B.1.c Other fugitive emissions from solid fuels	-	-
1.B.2.a.i & 1.B.2.b Fugitive emissions: Exploration, production and transport of oil and natural gas	-	-
1.B.2.a.iv Fugitive emissions oil: Refining and storage	red	green
1.B.2.a.v Distribution of oil products	-	-
1.B.2.c Venting and flaring	green	red
1.B.2.d Other fugitive emissions from energy production	red	red

Coloured cells show data available (green) and not available (red). A dash indicates that the respective sector is not a source of black carbon.

Table 2.2 Availability of Tier 1 and Tier 2 black carbon emission coefficients in the 2016 EMEP/EEA Guidebook (EEA, 2016) chapters and subchapters describing source-specific inventory methodologies for estimating air pollutant emissions from the sector *Industrial Processes and Product Use*.

Chapter/subchapter	Tier 1	Tier 2
2.A Mineral products		
2.A.1 Cement production	green	red
2.A.2 Lime production	green	red
2.A.3 Glass production	green	green
2.A.5.a Quarrying and mining of minerals other than coal	red	red
2.A.5.b Construction and demolition	-	-
2.A.5.c Storage, handling and transport of mineral products	-	-
2.A.6 Other mineral products	-	-
2.B Chemical industry	green	green
2.B.1 Ammonia production	red	red
2.B.2 Nitric acid production	red	red
2.B.3 Adipic acid production	red	red
2.B.5 Carbide production	red	red
2.B.10.a Other chemical industry	red	green
2.B.10.b Storage, handling, transport of chemical products	-	-
2.B.7 Soda ash production	red	red
2.C Metal production		
2.C.1 Iron and steel production	green	green
2.C.2 Ferroalloys production	green	red
2.C.3 Aluminium production	green	red
2.C.4 Magnesium production	red	red
2.C.5 Lead production	red	red
2.C.6 Zinc production	red	red
2.C.7.a Copper production	green	red
2.C.7.b Nickel production	red	red
2.C.7.c Other metal production	red	red
2.C.7.d Storage, handling and transport of metal products	-	-
2.D Solvent and product use		
2.D.3.a Domestic solvent use including fungicides	-	-
2.D.3.b Road paving with asphalt	green	red
2.D.3.c Asphalt roofing	green	red
2.D.3.d Coating applications	-	-
2.D.3.e Degreasing	-	-
2.D.3.f Dry cleaning	-	-
2.D.3.g Chemical products	red	red
2.D.3.h Printing	red	red
2.D.3.i, 2G Other solvent and product use	red	green
2.H Other industry production		
2.H.1 Pulp and paper industry	green	red
2.H.2 Food and beverages industry	red	red
2.H.3 Other industrial processes	-	-
2.I Wood processing	red	red
2.J Production of POPs	red	red
2.K Consumption of POPs and heavy metals	-	-
2.L Other production, consumption, storage, transportation or handling of bulk products	-	-

Coloured cells show data available (green) and not available (red). A dash indicates that the respective sector is not a source of black carbon.

Table 2.3 Availability of Tier 1 and Tier 2 black carbon emission coefficients in the 2016 EMEP/EEA Guidebook (EEA, 2016) chapters and subchapters describing source-specific inventory methodologies for estimating air pollutant emissions from the sector *Agriculture*. Bold indicates the chapters and subchapters describing inventory methodologies for the five priority source sectors in this review.

Chapter/subchapter	Tier 1	Tier 2
3.B Manure management	-	-
3.D Crop production and agricultural soils	-	-
3.D.f, 3.I Agriculture other including use of pesticides	-	-
3.F Field burning of agricultural wastes	(green)	(green)

Coloured cells show data available (green) and not available (red). A dash indicates that the respective sector is not a source of black carbon.

Table 2.4 Availability of Tier 1 and Tier 2 black carbon emission coefficients in the 2016 EMEP/EEA Guidebook (EEA, 2016) chapters and subchapters describing source-specific inventory methodologies for estimating air pollutant emissions from the sector *Waste*.

Chapter/subchapter	Tier 1	Tier 2
5.A Biological treatment of waste: Solid waste disposal on land	-	-
5.B.1 Biological treatment of waste: Composting	(red)	(red)
5.B.2 Biological treatment of waste: Anaerobic digestion at biogas facilities	(red)	(red)
5.C.1.a Municipal waste incineration	(green)	(red)
5.C.1.b Industrial waste incineration including hazardous waste and sewage sludge	(green)	(red)
5.C.1.b.iii Clinical waste incineration	(green)	(red)
5.C.1.b.v Cremation	(red)	(red)
5.C.2 Open burning of waste	(green)	(green)
5.D Wastewater handling	(red)	(red)
5.E Other waste	(red)	(red)

Coloured cells show data available (green) and not available (red). A dash indicates that the respective sector is not a source of black carbon.

Table 2.5 Availability of Tier 1 and Tier 2 black carbon emission coefficients in the 2016 EMEP/EEA Guidebook (EEA, 2016) chapters and subchapters describing source-specific inventory methodologies for estimating air pollutant emissions the sector *Other and Natural Sources*.

Chapter/subchapter	Tier 1	Tier 2
6.A Other sources	-	-
11.A Volcanoes	-	-
11.B Forest fires	(green)	(red)
11.C Other natural sources	-	-

Coloured cells show data available (green) and not available (red). A dash indicates that the respective sector is not a source of black carbon.

report, some source sectors are lacking black carbon emission coefficients in the Guidebook. Of course, some (marked with a dash in the tables) are assumed not to emit black carbon. The sectors *1.A.3.b.v Gasoline evaporation* and *2.D.3.d Coating applications* are only relevant in terms of NMVOCs, while particulate matter emitted from sectors such as *3.D Crop production and agricultural soils* and *2.A.5.c Storage, handling and transport of mineral products* is assumed to contain no black carbon. Nonetheless, of the 56 subchapters corresponding to source sectors which should theoretically produce black carbon emissions, only 29 currently provide Tier 1 black carbon emission coefficients, while just 16 provide Tier 2 emission coefficients. The biggest gap in black carbon emission coefficients occurs in the sector *Industrial Processes and Product Use (IPPU)*, where Tier 1 emission coefficients are available for only 11 of a potential 29 source sectors (Table 2.2). More than half the source sectors in the sector *Waste* (5/9) are also lacking Tier 1 emission coefficients (Table 2.4). The lack of Tier 2 emission coefficients is even more pronounced: Tier 2 emission coefficients are available for just 5 of 29 and 1 of 9 potential source sectors for *IPPU* and *Waste*, respectively. The sector *Energy* is in contrast better covered in terms of black carbon emission coefficients (Table 2.1). Although Tier 2 emission coefficients are available for almost 50% of the *Energy* source sectors, Tier 1 emission coefficients are provided for 12 of the 16 potential *Energy* source sectors emitting black carbon. For *Agriculture*, Tier 1 and Tier 2 emission coefficients are provided for the one relevant source sector emitting black carbon, *3.F Field burning of agricultural wastes* (Table 2.3). Finally, a Tier 1 emission factor is provided for the only relevant natural source sector *11.B Forest fires* (Table 2.5).

Despite the variable extent to which black carbon emission coefficients are available for the different source sectors, it should be noted that those sectors which contribute most significantly to global total emissions appear to be well covered by the EMEP/EEA Guidebook. For instance, while emission coefficients, in particular Tier 2 coefficients, were found to be lacking for many sources within *IPPU* and *Waste*, these sectors as a whole were estimated to contribute only 6.3% and 1.3%, respectively, to global total anthropogenic black carbon emissions in 2010 (Klimont et al., 2017). According to the same study, the residential combustion and road transport source sectors on the other hand constituted 57.3% and 18.5% of the global total anthropogenic black carbon emissions in

2010 and for these source sectors Tier 1 and Tier 2 emission coefficients are provided in the Guidebook (Part B subchapters *1.A.4 Small combustion* and *1.A.3.b.i-iv Exhaust emissions from road transport*). In fact, for the priority source sectors upon which the EU Action on Black Carbon in the Arctic and this technical report is focused (residential combustion, gas flaring, shipping, open agricultural burning, road transport) the Guidebook provides Tier 1 and Tier 2 methods for all source sectors except gas flaring, for which only a Tier 1 method is described.

The following sections describe the Tier 1 and Tier 2 (if available) methods recommended by the latest EMEP/EEA Guidebook (EEA, 2016) for estimating national black carbon emissions from the five priority source sectors.

2.1.2.2.1 **Residential combustion**

The recommended methods for estimating black carbon emissions from residential combustion are provided in subchapter *1.A.4 Small combustion* in Part B of the 2016 EMEP/EEA Guidebook.

According to subchapter 1.A.4, pollutant emissions from residential combustion consider those emissions arising from small stationary combustion installations for heating and cooking in residential applications. Emissions from residential combustion may be differentiated from non-residential combustion (small combustion installations applied in stationary institutional/commercial plants or stationary plants applied in agriculture/forestry/aquaculture) emissions based on the heating capacity of the individual combustion appliances – residential appliances are typically considered to be <50 kWth. Nonetheless, the primary criterion for differentiation is use (i.e., combustion for heating and cooking in living spaces).

The activity data considered for calculating these emissions are national fuel consumption statistics expressed as total heat produced by the combustion of the given fuel (GJ, net calorific basis). Using these statistics, $PM_{2.5}$ emissions are calculated by multiplying by respective $PM_{2.5}$ emission factors (g GJ^{-1}) with black carbon emissions derived by multiplying the $PM_{2.5}$ emissions by corresponding black carbon fractions (% of $PM_{2.5}$).

Tier 1 methods/emission coefficients for residential combustion differentiate only between the following four fuel types: hard coal and brown coal (includes coking coal, other bituminous coal, sub-bituminous coal, coke, manufactured 'patent' fuel, lignite, oil shale, manufactured 'patent' fuel, and peat); gaseous fuels (includes natural gas, natural gas liquids, liquefied petroleum gas, gas works gas, coke oven gas, and blast furnace gas); liquid fuels (includes residual fuel oil, refinery feedstock, petroleum coke, Orimulsion, bitumen, gas oil, kerosene, naphtha, and shale oil); and biomass (includes wood, wood pellets, charcoal, vegetable [agricultural] waste).

In the absence of national statistics on the respective fuel split for residential combustion, the subchapter refers the reader to statistics provided by international bodies such as Eurostat and the International Energy Agency (IEA).

Tier 2 emission coefficients are also provided which differentiate between fuel type and type of combustion technology, for example, stove type and boiler type. Apart from a differentiation between wood and wood pellets, the fuel split is at the same aggregated level as in Tier 1. However, in contrast to Tier 1, the emission coefficients for Tier 2 differentiate between the following technology types (<50 kWth): open fireplaces; partly closed / closed fireplaces; conventional stoves; conventional boilers; high-efficiency stoves; advanced/ecolabelled stoves and boilers; and pellet stoves and boilers.

The ability to apply Tier 2 methods depends on whether the fuel can be split between technology/appliance types. In the absence of national estimates, the subchapter provides default splits which can be applied, for example average EU splits or the country-specific splits assumed in the IIASA GAINS model (Amann et al., 2011). It is however recommended that country-specific information on fuel and technology splits be used when applying Tier 2 methods and the subchapter does provide guidance on how such information could be sourced or estimated via proxy/surrogate data. The subchapter also provides guidance on the type of information required for further fuel- and technology-type disaggregation at Tier 3 level. Finally, Appendix E of subchapter 1.A.4 provides a literature review of black carbon methodologies for small combustion from 2012. This details the literature emission coefficients plus information of country and fuel- and technology type used to calculate the aggregated Tier 1 and Tier 2 emission factors. This information may be helpful to inventory experts looking to develop Tier 2/3 methods appropriate for their country's circumstances.

Tables containing the Tier 1 and Tier 2 $PM_{2.5}$ emissions factors and black carbon fractions for residential combustion are provided in Appendix A1 to this report (Tables A1.1 and A1.2).

2.1.2.2.2 **Gas flaring**

The recommended methods for estimating black carbon emissions from gas flaring are provided in subchapter *1.B.2.c Venting and flaring* in Part B of the 2016 EMEP/EEA Guidebook.

According to subchapter 1.B.2.c, pollutant emissions from gas flaring consider those emissions arising from venting and flaring during the processes of extracting and refining oil and gas. Flaring (i.e., the combustion of waste/by-product gas) is performed at extraction and refining facilities due to limited process/transport capacities and/or the need to maintain a continuous gas flow and gas pressure within the piping system.

In the absence of facility-emissions estimates (Tier 3), the activity data considered for calculating these emissions are annual national statistics for total gas throughput converted to Mg or total heating values of the flare gas (GJ). Using these statistics, $PM_{2.5}$ emissions are calculated by multiplying the activity statistics by respective $PM_{2.5}$ emission factors (kg Mg^{-1} or g GJ^{-1}). Black carbon emissions are subsequently derived by multiplying the $PM_{2.5}$ emissions by corresponding black carbon fractions (% of $PM_{2.5}$).

Tier 1 methods (see Appendix A1 to this report, Table A1.3) for gas flaring differentiate only between: flaring in oil and gas extraction; and flaring in oil refineries.

Although the black carbon emission fraction is not explicitly given for oil refineries, the subchapter essentially recommends the same percentage as given for oil and gas extraction, i.e., 24%.

Interestingly, the subchapter refers to a model by McEwen and Johnson (2012), which is a function of the volumetric heating value of the flared gas and, when solved, provides a black carbon

Oil rig in Beaufort Sea / Getty Images / Stockbyte

emission factor rather than a black carbon fraction. The 24% black carbon fraction given for oil and gas extraction thus appears to have been derived by applying the McEwen-Johnson function under an assumed heating value and flare gas density and dividing by a corresponding $PM_{2.5}$ emission factor.

Further guidance and/or emission coefficients for *Higher Tier* methods for $PM_{2.5}$ and black carbon emissions are not provided in subchapter 1.B.2.c.

2.1.2.2.3 **Shipping**

The recommended methods for estimating black carbon emissions from maritime shipping are provided in subchapter *1.A.3.d Navigation (shipping)* in Part B of the 2016 EMEP/EEA Guidebook.

According to subchapter 1.A.3.d, pollutant emissions from shipping consider those emissions arising from fuel combustion to propel water-borne vessels from recreational craft to large ocean going cargo vessels.

The activity data considered for calculating these emissions are annual national consumption statistics for fuels used to power ships (tonnes fuel sold for shipping activities). Using these statistics, $PM_{2.5}$ emissions are calculated by multiplying the fuel statistics by respective $PM_{2.5}$ emission factors (kg t^{-1}). Black carbon emissions are then derived by multiplying the $PM_{2.5}$ emissions by corresponding black carbon fractions (% of $PM_{2.5}$).

Tier 1 methods/emission coefficients (see Appendix A1 to this report, Table A1.4) for shipping differentiate only between the following three fuel types: bunker fuel oil; marine diesel oil and marine gas oil; and gasoline.

Tier 2 $PM_{2.5}$ emission factors and black carbon fractions are also provided which differentiate between fuel type and engine type (see Appendix A1, Table A1.5). The subchapter also details how fuel consumption should be split between the different engine types and where the respective data (e.g., port arrivals by engine type) can be sourced (e.g., Eurostat). However, as Table A1.5 shows, only the $PM_{2.5}$ emission factors vary between engine type. With the exception of an additional factor for diesel recreational boats, black carbon emission factors are the same as the Tier 1 factors, differentiated according to fuel type only. Therefore Tier 2 methods are given; but only Tier 1 black emission factors are provided.

It should be noted that subchapter 1.A.3.d also provides Tier 3 methods and emission factors which are split according to fuel and engine type, and ship movement. Emissions depend strongly on whether the vessel is *cruising*, *hotelling* or *manoeuvring* and the subchapter provides $PM_{2.5}$ emission factors for these trip classes. However, as for the Tier 2 methods, the given black carbon percentages are assumed to vary only according to fuel type. Furthermore, despite the description of *Higher Tier* methods for particulate matter and black carbon, these methods/emission coefficients do not take into account varying fuel sulphur contents.

Finally, it should be noted that an Appendix on black carbon is included at the end of subchapter 1.A.3.d. This reviews literature emission factors and justifies the black carbon emission factors given in the text.

2.1.2.2.4 **Agricultural open burning**

The recommended methods for estimating black carbon emissions from agricultural open burning are provided in subchapter *3.F Field burning of agricultural wastes* in Part B of the 2016 EMEP/EEA Guidebook.

Cruise Ship in the Svalbard Archipelago, Norway / Getty Images / Busà Photography

According to subchapter 3.F, pollutant emissions from open agricultural burning consider those emissions arising from the burning of crop residues as a means of clearing land rapidly.

The activity data considered for calculating these emissions are annual national statistics for total crop biomass burnt in kilograms of dry matter (dm), which must be derived from statistics for the annual total area where residues are burned, crop yield per hectare, residue:yield ratios, dry matter content, percentage residue burnt, and combustion factors. Using total crop biomass, burnt black carbon emissions are calculated directly (i.e., not from $PM_{2.5}$ emissions) by multiplying by corresponding black carbon emission factors (mg kg^{-1} dm).

For the Tier 1 method, annual total dry matter crop biomass burnt is multiplied by a single black carbon emission factor (500 mg BC kg^{-1} dm). While the emission factor is aggregated for all crop types, the total annual dry matter crop biomass burnt reflects the contributing crops in terms of their respective yields, residue:yield ratios, dry matter contents, and combustion factors. Tier 2 methods use total annual dry matter biomass burnt for different crop types derived from burnt area data

Burning agricultural field / Kristo Robert / Alamy Stock Photo for each of the respective crop types. However, the subchapter only provides Tier 2 black carbon emission factors for four crops: wheat, barley, maize, and rice (see Appendix A1 to this report, Table A1.6).

2.1.2.2.5 **Road transport**

The recommended methods for estimating black carbon emissions from road transport are provided in subchapter *1.A.3.b.i-iv Exhaust emissions from road transport* in Part B of the 2016 EMEP/EEA Guidebook.

According to subchapter 1.A.3.b.i-iv, pollutant emissions from road transport consider those emissions arising from the combustion of fuels such as petrol, diesel, liquefied petroleum gas and natural gas in internal combustion engines of road vehicles.

The activity data considered for calculating these emissions using a Tier 1 method are annual national consumption statistics for fuels used for road transport (fuel sold for off-road transport/machinery in agriculture and forestry should be subtracted as emissions from these sectors are reported under another category). Using these statistics, expressed in kilograms, $PM_{2.5}$ emissions are calculated by multiplying by respective $PM_{2.5}$ emission factors (g kg^{-1}) with black carbon emissions derived by multiplying the $PM_{2.5}$ emissions by corresponding black carbon fractions (% of $PM_{2.5}$).

Tier 1 methods/emission coefficients for road transport differentiate between four fuel types and four vehicle categories (see Appendix A1 to this report, Table A1.7). The subchapter states how consumption of the respective fuels should be distributed between the different vehicle categories. National vehicle statistics are the basis for this disaggregation, which should be weighted by respective estimates for annual usage in kilometres and fuel consumption per kilometre for each vehicle type.

Tier 2 methods/emission coefficients for road transport further differentiate within the vehicle category and moreover are expressed in grams per vehicle-kilometre as *Higher Tier* activity data are expressed in annual distance driven per vehicle-fuel-engine type (see Appendix A1, Table A1.8). The subchapter states that these data should be available from national statistical offices as well as international statistical organisations (e.g., Eurostat, International Road Federation). While these data may be somewhat independent of national fuel consumption statistics, the subchapter advises that total national fuel consumption derived from these data using average values for fuel consumption per kilometre for each vehicle-fuel-engine type (see Table 3.27, p. 37 of subchapter 1.A.3.b.i-iv) should correspond to national statistics for total fuel consumed in the country for road transport.

At Tier 2 level, the vehicle category is further disaggregated in terms of size and engine technology, the latter being defined in terms of European norms and standards. Note, that black carbon fractions are not available for the most recent Euro standards, for example Euro 5 and 6. Furthermore, the Tier 2 $PM_{2.5}$ emission factors are more disaggregated than the corresponding black carbon fractions.

Table 3.88 p. 104 of subchapter 1.A.3.b.i-iv also provides respective aggregated black carbon fractions for the diesel passenger cars and light commercial vehicles (Euro 3, 4, 5) equipped with a diesel particle filter (DPF) and allow fuel additives (10%) and those equipped with a catalysed DPF (20%).

The subchapter also provides guidance on Tier 3 methods, detailing emission factors differentiated between engine operating states (stabilised operation vs. transient thermal operation) and driving conditions (i.e., urban roads vs. rural roads vs. motorways). In terms of $PM_{2.5}$ the subchapter provides urban-, rural- and motorway particulate matter emission factors (expressed in total particle number per kilometre) for several vehicle-fuel-engine types (Tables 3.48 to 3.54, p. 71–77 of subchapter 1.A.3.b.i-iv) but does not provide corresponding black carbon fractions.

Street Sign / Photo RikoBest / Shutterstock

2.1.2.3 Suitability and adequacy of the recommended inventory methods for estimating emissions

As demonstrated in Section 2.1.2.2, inventory methods and emission coefficients are available in the EMEP/EEA Guidebook (EEA, 2016) for CLRTAP Parties to calculate national black carbon emissions from most of the relevant source sectors. The Guidebook also provides methods and emissions coefficients for the five priority source sectors of this review: residential combustion, gas flaring, international shipping, open burning of agricultural residues, and road transport. Considering that black carbon is not a mandatory pollutant in terms of reporting, the recommended methods may at first glance seem appropriate. However, given that inventory and reporting systems are fundamental to designing, implementing and monitoring measures to reduce black carbon emissions, compelling arguments can be made that the current set of recommended methods are in need of improvement.

The review of the EMEP/EEA Guidebook (EEA, 2016) revealed that Tier 1 methods are available for almost all relevant black carbon source sectors. Although Tier 1 methods are useful in providing first estimates or emissions estimates for negligible source sectors, they are totally unsuitable for monitoring the success of black carbon mitigation measures. Being static and aggregated, inventories using Tier 1 methods will only document emissions reductions due to changes in fuel consumption totals which affect aggregated activity data rather than potentially significant technological changes affecting a country's implied emission factor (= emission/activity data). Only at Tier 2 or above, are the activity data and emission coefficients sufficiently stratified (such as between fuel type, technology, and application context) to capture potential emission reductions due to introduced policies and/or legislation. Using the European Union as an example, the only way that the Ecodesign Directive 2009/125 can be gauged in terms of black carbon emission reductions from residential combustion is if the Member State inventory methods account for shares of stoves and boilers in use that meet the eco-design requirements. That only 16 of 56 Guidebook subchapters provide Tier 2 black carbon emission coefficients for their respective source sectors thus represents a significant limitation of the current inventory methods recommended for CLRTAP black carbon reporting.

Of the five priority source sectors, both residential combustion and road transport are relatively well provided for in terms of *Higher Tier* methods and coefficients for estimating black carbon emissions. Given the substantial black carbon emissions here, as well as significant technological changes occurring in these sectors, meaningful emissions estimates can only be derived when applying at least Tier 2 methods. While there is clearly room for further methodological improvement for these source sectors (such as methods for residential combustion which further take into account the significant influence of combustion behaviour on black carbon emissions; Kindbom et al., 2017), it appears that the recommended black carbon inventory methods for the other three source sectors require more substantial improvements. For open burning of agricultural waste, the EMEP/EEA Guidebook provides Tier 2 black carbon emission factors for four crop types only, while for shipping and gas flaring only Tier 1 black carbon fractions are provided. The review therefore highlights that *Higher Tier* black carbon inventory methods are lacking. Indeed in a questionnaire sent to the CEIP contact points for each CLRTAP Party (see Appendix A2 to this report), all national inventory experts who responded highlighted the lack of emission factors as an issue limiting the improvement of the black carbon emissions estimates (either in general or for specific source sectors). In addition to availability, it should also be mentioned that relative to other pollutants, black carbon emission coefficients are typically given with a high degree of uncertainty For instance, of the 30 *Higher Tier* black carbon fractions given in subchapter *1.A.3.b.i-iv Exhaust emissions from road transport* in Part B of the 2016 EMEP/EEA Guidebook, around two-thirds were associated with a relative uncertainty (95% confidence limit relative to the value) of >30% while 13 of the coefficients were estimated with a relative uncertainty of 50%. High uncertainty in the emission coefficients was also highlighted by some CEIP contact points as a factor restricting reporting/improvement of their respective black carbon emissions inventories.

A tempting recommendation would thus be to propose that the EMEP/EEA Guidebook (EEA, 2016) be improved in terms of *Higher Tier* black carbon fractions and reduced uncertainty in these coefficients. However, before committing to such action, the Convention and European Union may well consider a fundamental change in the methodological approach for estimating black carbon emissions. As described in Section 2.1.2.2, black carbon emissions are generally estimated by multiplying source level $PM_{2.5}$ emissions by respective black carbon fractions. However, an argument can be made, for certain source sectors at least, that emissions should be estimated using direct black carbon emission factors rather than black carbon fractions of $PM_{2.5}$ emissions. As with Tier 1 emission factors, the limitations of static coefficients (such as black carbon fractions) restrict the degree to which derived inventory estimates reflect real emissions. For certain sectors, primary technological changes reducing $PM_{2.5}$ emissions, such as installing cyclones on small solid fuel boilers or even improving the efficiency of electrostatic precipitators in large combustion plants, do not lead to the same proportional reductions in black carbon emissions (Kupiainen and Klimont, 2004). Similarly, respective larger proportional emissions reductions in particulate matter than black carbon can result from measures reducing the sulphur content of bunker fuel in international shipping (Lack and Corbett, 2012) or improving combustion efficiency of household ovens and stoves (Savolahti et al., 2016). Given that such a methodological switch would represent a fundamental change, this may constitute a potential mid- to long-term goal. Indeed, if developments do proceed in this direction, care must still be taken in terms of mass balance consistency between emissions estimates of black carbon and aggregate particulate matter.

Finally, given that the Guidebook was developed and is updated by the European Environment Agency (EEA) together with EMEP for the purpose of reporting under CLRTAP and the EU NEC Directive, the applicability of the methods and emission coefficients outside the European Union is somewhat limited. For instance, the *Higher Tier* methods for road transport are based on engine technology splits along EURO standards. In that regard, developments within the Intergovernmental Panel on Climate Change (IPCC) Task Force on National Greenhouse Gas Inventories should be noted. This Task Force, whose

Guidelines for National Greenhouse Gas Inventories (IPCC, 1996, 2006) represent the recommended methodologies for compiling national greenhouse gas inventories to be submitted under the UNFCCC, convened in May 2018 to discuss inventory methods for short-lived climate forcers (SLCFs). With respect to inventory methodologies for SLCFs including black carbon, the meeting concluded, *inter alia*, that "The IPCC can play an important role because of its unique position, and therefore it is considered to be the right organisation to fill gaps in existing methodologies and to develop and disseminate an internationally agreed, globally applicable methodological guidance based on existing methodologies" (see meeting report IPCC, 2018a). The meeting report also states that should the IPCC Plenary decide to start work in this direction, it is important that cooperation and collaboration be sought with the UNECE Task Force on Emissions Inventories and Projections and other relevant international bodies such as CCAC, the Arctic Council, the International Civil Aviation Organization (ICAO) and the International Maritime Organization (IMO). Finally, the meeting report expresses the IPCC Task Force's position that current inventory approaches using black carbon fractions of $PM_{2.5}$ might need "assessment, improvement or new elaboration due to significant challenges in deriving BC from PM2.5 and variability in observations".

2.2 Arctic Council

In 2015, the Arctic Council adopted a Framework for Action (see Figure 2.3) with a common vision to accelerate the decline in their overall black carbon emissions and to significantly reduce their overall methane emissions (Arctic Council, 2015). In the Ministerial Declaration from Fairbanks in 2017 the Arctic Council "Adopt[ed] the first Pan-Arctic report on collective progress to reduce black carbon and methane emissions by the Arctic States and numerous Observer States and its recommendations, including an aspirational collective goal, acknowledge[d] the importance of implementing those recommendations as nationally appropriate, recognising that Arctic communities are entitled to develop in accordance with their needs and interests…"[5]. The aspirational collective goal presented in the first pan-Arctic report on collective progress to reduce black carbon and methane emissions states that the black carbon emissions be further collectively reduced by at least 25–33% below 2013 levels by 2025 (Arctic Council, 2017).

As part of the Framework the countries provide biennial national reports on emissions and policy actions. The Framework does not have a separate reporting structure or system. Instead, the Framework guides countries to provide a high-level summary of CLRTAP black carbon emission submission, a summary that is generally consistent with the guidelines under CLRTAP, or the same submission as provided to CLRTAP. The national reports include a summary of black carbon emission inventories and, if available, projections using, where possible, relevant guidelines from CLRTAP. The overall idea of reporting national emission data in connection with the Arctic Council Framework is to provide material to estimate collective emissions on aggregated sectors (such as diesel mobile sources, flaring and residential biomass combustion) to monitor progress towards the common vision and the collective goal, and the Arctic Council is seen as the forum for promoting black carbon emissions reporting in countries that are yet to do so.

As black carbon and methane emitted beyond the borders of the Arctic States have an important impact on the Arctic, the Arctic Council Observer States are also invited to participate in the implementation of the Framework including by strengthening their domestic actions, developing robust emission inventories, taking part in relevant meetings and submitting national reports.

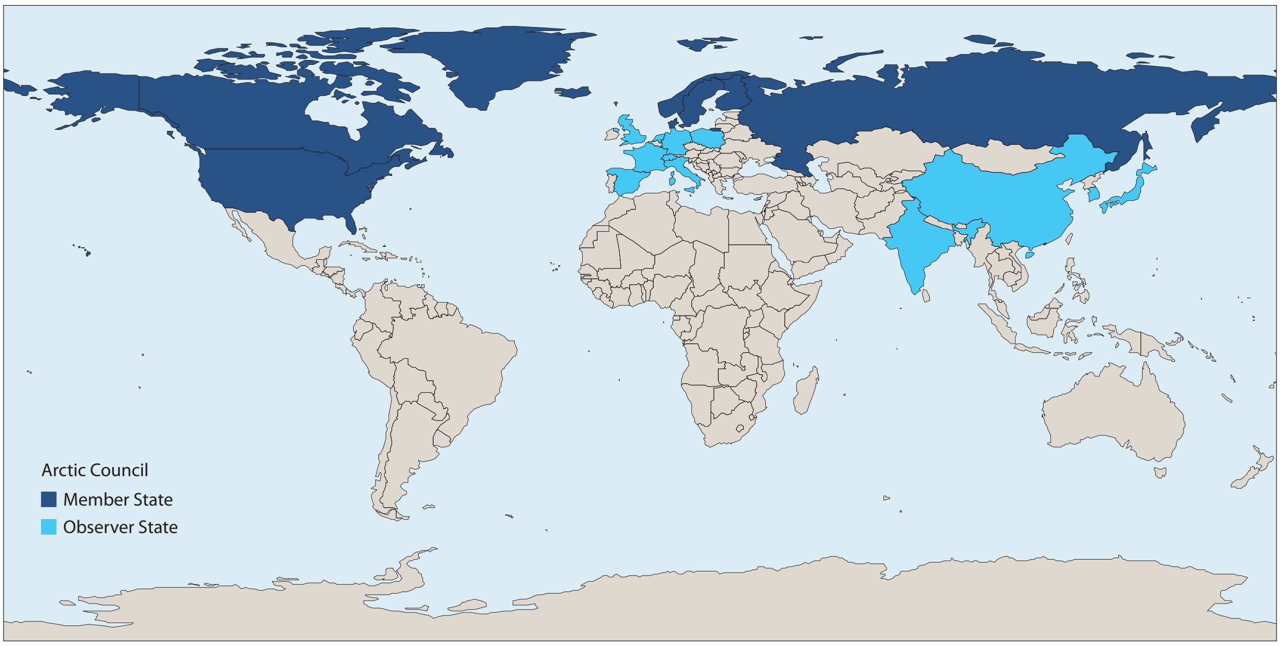

Figure 2.3 Geographical scope of the *Arctic Council Enhanced Black Carbon and Methane Emissions Reductions: An Arctic Council Framework for Action*. The graphic indicates Member States and Observer States of the Arctic Council.

[5] https://www.state.gov/e/oes/rls/other/2017/270802.htm

2.3 Other international frameworks

In addition to CLRTAP and the Arctic Council, black carbon has also begun to emerge as an issue within other international fora where national emissions inventory data are reported.

The UNFCCC represents the key international legal framework for tackling climate change. The ultimate objective of the Convention is to stabilise greenhouse gas (GHG) concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system (see Article 2, UNFCCC, 1992). Although the framework itself does not commit the 197 Parties[6] to legally-binding GHG emissions reductions targets – Annex I Parties are committed to targets via the Kyoto Protocol (UNFCCC, 1997) and its 2012 amendment (UNFCCC, 2012) – decisions adopted at the Conference of the Parties (COP) meetings do oblige the Parties to report GHG emissions inventory data to the UNFCCC Secretariat. While black carbon is not a GHG, recent developments following the Paris Agreement (UNFCCC, 2015) appeared to open up the possibility of black carbon's inclusion in the international climate regime.

Decision 24/CP.19 (UNFCCC, 2013) describes the current emissions reporting obligations for the UNFCCC Annex I Parties, while Decisions 17/CP.8 (UNFCCC, 2002) and 2/CP.17 (UNFCCC, 2011) outline the current reporting guidelines for the non-Annex I Parties. While the emissions reporting requirements vary between Annex I and non-Annex I Parties, the respective decisions essentially oblige the Parties to report GHG emissions. Both Annex I and non-Annex I Parties are obliged to report emissions of carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O), while reporting of emissions of perfluorocarbons (PFCs), hydroflourocarbons (HFCs), sulphur hexafluoride (SF_6) and nitrogen triflouride (NF_3) is mandatory for Annex I Parties but only encouraged for non-Annex I Parties. The decisions also encourage the reporting of precursor gases such as carbon monoxide (CO) and nitrogen oxides (NO_X), as well as other pollutants such as sulphur oxides (SO_X). However, there is no mention of black carbon in these texts meaning that reporting of national black carbon emissions to the UNFCCC Secretariat is currently neither mandatory nor encouraged.

The Paris Agreement (UNFCCC, 2015) was seen as a potential 'game changer' for black carbon within the UNFCCC. The Paris Agreement, which to date (1 May 2019) has been ratified by 185[7] of the 197 UNFCCC Parties, aims to hold the increase in global average temperature to well below 2°C above pre-industrial levels and to pursue efforts to limit the temperature increase to 1.5°C. The Paris Agreement requires each Party to prepare, communicate and maintain successive NDCs outlining, *inter alia*, their domestic mitigation measures and emissions reduction targets.

The central explicit goal of the Paris Agreement is to limit the global average temperature rise but despite references to GHG emissions reductions, the Agreement does not specify which GHGs or other warming substances fall under its scope. In fact, the Paris Agreement's country-driven approach to mitigation – according to which Parties define and regularly update their NDCs – offers Parties broad discretion in defining the types of emission covered by their climate efforts to meet its goals. Therefore, although the Paris Agreement does not explicitly address black carbon, the legal design of the Paris Agreement "leaves ample scope to accommodate diverse mitigation efforts" thus allowing Parties to address black carbon in their NDCs (Yamineva and Kulovesi, 2018). Indeed, national submissions made by Canada, Chile, Mexico and Nigeria explicitly address black carbon (see NDC Registry[8]), with other Parties addressing SLCFs more broadly. For example, Mexico's NDC includes a 51% reduction target of black carbon whereas the Central African Republic, for example, "aspires to reduce emissions" of SLCFs. These national submissions essentially represent the first formal inclusion of black carbon emissions under the UNFCCC and hint at a real possibility of black carbon emissions reporting within the international climate regime in the future.

Compelling arguments have been put forward for formally bringing black carbon under the international climate regime. Indeed this step represents an important opportunity to align the global climate change agenda with the air quality and public health agendas (Khan and Kulovesi, 2018). CCAC, which is a voluntary coalition of State and non-state Partners formed in 2012, has made the inclusion of SLCFs in the country NDCs a key organisational goal. This step was taken in light of the IPPC Special Report *Global Warming of 1.5°C* (IPCC, 2018b), which notes the key role of reducing SLCFs including black carbon in enabling a pathway consistent with limiting global warming to a 1.5°C increase above pre-industrial levels. While CCAC has been a vocal advocate for a formal and meaningful inclusion of black carbon under the Paris Agreement, it is important to note that the Coalition also provides guidance to its partners on national black carbon emissions inventories. Through the Supporting National Action and Planning (SNAP) initiative, CCAC is currently supporting 11 countries (Bangladesh, Chile, Colombia, Cote d'Ivoire, Ghana, Maldives, Mexico, Morocco, Nigeria, Philippines, Togo) in developing black carbon and other SLCF inventory models to aid estimation of current and past emissions, and to evaluate via scenarios the potential impacts of mitigation measures. This initiative uses the LEAP-IBC tool for estimating emissions which was developed by the Stockholm Environment Institute. With regard to black carbon, the tool's default emission factors are based largely on the emission coefficients from the 2016 EMEP/EEA Guidebook (EEA, 2016) but also on some emission factors from the scientific literature (CCAC, 2018).

The extent to which black carbon may become formally embedded within the UNFCCC Paris Agreement was set to depend on the Paris Agreement Work Programme, also known as the 'Paris Rulebook'. Given the scope afforded to the Parties in developing their NDCs, it seems unlikely that black carbon will be prohibited from subsequent NDCs. However, whether Parties' black carbon emissions reductions will be formally accounted for in the *global stocktake* on progress to the Paris Agreement goals hinged on the implementation procedures and modalities to be contained in the Paris Rulebook. For instance, whether black carbon emissions reporting will be mandatory, or at least officially encouraged, was to become clear once the reporting rules and guidelines of the enhanced transparency

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6 https://unfccc.int/process/the-convention/what-is-the-convention/status-of-ratification-of-the-convention
7 https://unfccc.int/process/the-paris-agreement/status-of-ratification
8 https://www4.unfccc.int/sites/NDCStaging/Pages/All.aspx

framework were finalised. The deadline for finalising the *Paris Rulebook* was set for December 2018 at COP24 in Katowice, Poland. Despite doubts as to whether the technical details of the transparency framework (such as reporting obligations and recommendations for the Parties) would be agreed upon by the end of COP24 (see Neier et al., 2018), a decision pertaining to Article 13 of the Paris Agreement was agreed. However, the advance version of this decision[9] on the *Modalities, procedures and guidelines for the transparency framework for action and support referred to in Article 13 of the Paris Agreement* makes no mention of black carbon. As this text is fundamentally agreed and will now be subject only to language editing, it appears highly unlikely that the reporting tables/formats and review procedures of the UNFCCC emissions reporting system will be adapted for curating and auditing submissions of national black carbon emissions data.

Finally, developments with regard to emissions reporting under European Union legislation are also worthy of note. In addition to reporting requirements under UNFCCC and UNECE-CLRTAP, EU Member States are currently obliged to report to the European Union their national emissions of GHGs under the greenhouse gas Monitoring Mechanism Regulation (MMR) 525/2013 and their emissions of air pollutants under NEC Directive 2016/2284[10]. Respective emissions reductions commitments for GHGs are set out in the EU Emissions Trading System (ETS) Directive 2009/29/EC and the Effort Sharing Decision (ESD) 406/2009/EC[11], while the NEC Directive sets out both the reporting obligations and the emission reduction commitments. While neither MMR nor ETS/Effort Sharing legislation mention black carbon, the NEC Directive, which was revised in 2016, explicitly addresses black carbon. The revised NEC Directive establishes new national emission reduction commitments (NERCs), applicable from 2020 and 2030, for certain air pollutants including $PM_{2.5}$. Under these commitments, the European Union is set to reduce its $PM_{2.5}$ emissions by 22% by 2020, and 49% by 2030. Although the Directive does not set NERCs for black carbon *per se*, it requires Member States to "prioritise" emission reduction measures for this pollutant when acting on $PM_{2.5}$. Indeed, the text of the NEC Directive replicates parts of the 2012 amendment to the 1999 Gothenburg Protocol that cover black carbon. Crucially however, while the amendment of the Gothenburg Protocol has not yet entered into force, the NEC Directive and its content on black carbon is in force. For an up-to-date review of EU legislation related to black carbon the reader is referred to Romppanen (2018).

The NEC Directive also requires the drawing up, adoption and implementation of national air pollution control programmes (NAPCPs), and the monitoring and reporting of emissions of the pollutants covered by the Directive. The EU NEC Directive thus represents an international reporting system for national black carbon inventories. Under the NEC Directive, Member States must report their annual black carbon emissions, but only if such inventories are available. Theoretically, as with the other pollutants, the emissions data submitted under CLRTAP are the same as those reported under the NEC Directive. However, reflecting the caveat that black carbon emissions data are to be reported "only if such inventories are available", black carbon emissions inventory estimates reported by Member States are yet to undergo rigorous review under the annual NEC review. This means that as under CLRTAP, emissions estimates for black carbon reported under NEC are currently taken at face value. However, it appears that this may be about to change and that Member State black carbon inventories will soon be subject to review. At the 2018 EMEP Task Force on Emissions Inventories and Projections (TFEIP) Meeting in Sofia, a presentation given on behalf of the European Commission[12] outlined plans for the 2021 NEC review to include black carbon inventories. During this round of reviews, Member States would have to respond and potentially adjust their black carbon inventory calculations according to the technical corrections and recommendations highlighted by the expert review teams.

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[9] https://unfccc.int/documents/187724
[10] https://eur-lex.europa.eu/legal-content/EN/TXT/?qid=1547796572685&uri=CELEX:32016L2284
[11] New EU targets from 2021–2030 are provided in the Energy Union Governance Package including several amendments of the existing legislation (MMR, ETS and Effort Sharing): https://ec.europa.eu/energy/en/topics/energy-strategy-and-energy-union/governance-energy-union
[12] https://tfeip-secretariat.org/assets/Uploads/TFEIP-DG-ENV-presentation.pdf

3. Evaluation of black carbon emissions reporting within international frameworks

3.1 UNECE CLRTAP

This section reviews the current status of black carbon emissions reporting by the 51 Parties to CLRTAP. The review was conducted according to a methodological framework detailed in Section 3.1.1. The findings of the review are addressed in Section 3.1.2.

3.1.1 Review framework

The review of black carbon emissions reporting by Parties to CLRTAP followed a hierarchical framework. First, emissions data which had been officially submitted to the EMEP Centre on Emissions Inventories and Projections (CEIP) were downloaded from the CEIP archive (access date 28 August 2018)[13]. Specifically, data on black carbon and $PM_{2.5}$ emissions (national total emissions and source-sector emissions at NFR category level) were downloaded. From these data the review identifies which Parties have submitted estimates of national total black carbon and $PM_{2.5}$ emissions and which have submitted projected estimates of future black carbon emissions. The review also identifies which Parties have submitted black carbon emissions estimates at source-sector level, and which source sectors have been estimated.

For each Party which had submitted national black carbon emissions estimates for the five priority source sectors, the latest respective *Informative Inventory Report* (including auxiliary documentation) was downloaded from the CEIP website (access date 28 August 2018). These documents were consulted to identify whether methods to estimate black carbon emissions for the priority source sectors (residential combustion, gas flaring, shipping, open agricultural burning, road transport) are described and which Tier methods have been applied. For each source sector, each of the Informative Inventory Reports (IIRs) were evaluated against three questions:

Q1. Which Tier(s) have been applied to estimate emissions of reported pollutants from the source sector in general?

Q2. Which Tier black carbon fractions/emission factors have been applied?

Q3. From which documents and/or databases have the black carbon fractions/emission factors been taken?

3.1.2 Review results and discussion

3.1.2.1 Submission of emissions data

Since 2015, when reporting templates were updated to accommodate black carbon emissions data the number of Parties submitting estimates for national total black carbon emissions has been increasing. According to the CEIP *Inventory Review 2018* (CEIP, 2018), 28, 34, 36, and 39 Convention Parties submitted black carbon emissions data to CEIP in the years 2015, 2016, 2017 and 2018, respectively.

As of 28 August 2018, a total of 41 of the 51 CLRTAP Parties had submitted estimates for national total black carbon emissions (Figure 3.1). The ten countries yet to submit black carbon emissions data to CEIP are Albania, Austria, Bosnia and Herzegovina, Liechtenstein, Luxembourg, Macedonia, Montenegro, Russia, Turkey, and Ukraine. It is notable, that eight of the ten Parties not yet submitting data on black carbon emissions, have nonetheless submitted estimates for national total emissions of $PM_{2.5}$. Turkey and Bosnia and Herzegovina are the two Parties yet to submit national emissions estimates for $PM_{2.5}$ (see Appendix A1 to this report, Figure A1.2).

As illustrated in Figure 3.2, national total black carbon emissions for the 41 reporting Parties vary over five orders of magnitude. Monaco is the smallest emitter, reporting total black carbon emissions of 0.0024 Gg in 2016, while the United States is the largest emitter with 2014 emissions reported at 315 Gg.

As Figure 3.1 illustrates, around three-quarters of those Parties reporting black carbon data have submitted national total emissions for the years 2000 to 2016 (32 Parties, plus Moldova which reported 2000 to 2015), with about half of the reporting Parties submitting black carbon emissions time series since 1990 (21 Parties, plus Moldova which reported for all years except 2016). Of the remaining reporting Parties, Georgia has reported national total black carbon emissions for the years since 2007, Malta since 2005, Canada since 2013, Azerbaijan since 2014, and Kyrgyzstan since 2015, while Belarus and Armenia recently submitted their first annual total black carbon estimates for the year 2016. The United States has provided inventory estimates of national total black emissions for the years 2011 and 2014.

In addition to reporting past emissions totals up to 2016, some Parties have also submitted projected national total emissions for black carbon for post-2020. Twelve Parties (Cyprus, Denmark, Finland, Greece, Ireland, Latvia, Lithuania, Netherlands, Norway, Sweden, Switzerland, United Kingdom) have submitted projected emissions based on a *with existing measures* (WEM) scenario (Table 3.1). Eleven of the 12 Parties have submitted projected national total black carbon emissions for the years 2020, 2025, and 2030, with Finland the exception in submitting projected national total emissions for 2030 only. Switzerland, in contrast to the other 11 Parties, has also provided a WEM black carbon emissions projection for 2050. With respect to projections under respective *with additional measures* (WAM) scenarios, only four Parties have provided emissions estimates. Ireland, Latvia, and Lithuania have submitted emissions estimates for the years 2020, 2025, and 2030, while Switzerland has provided a further emissions estimate for 2050 (Table 3.2).

As reported in Table 3.3, almost all Parties reporting national total black carbon emissions data have also submitted data on black carbon emissions at source-sector level (NFR category); the United States is the only Party which reported national

[13] http://webdab1.umweltbundesamt.at/login/

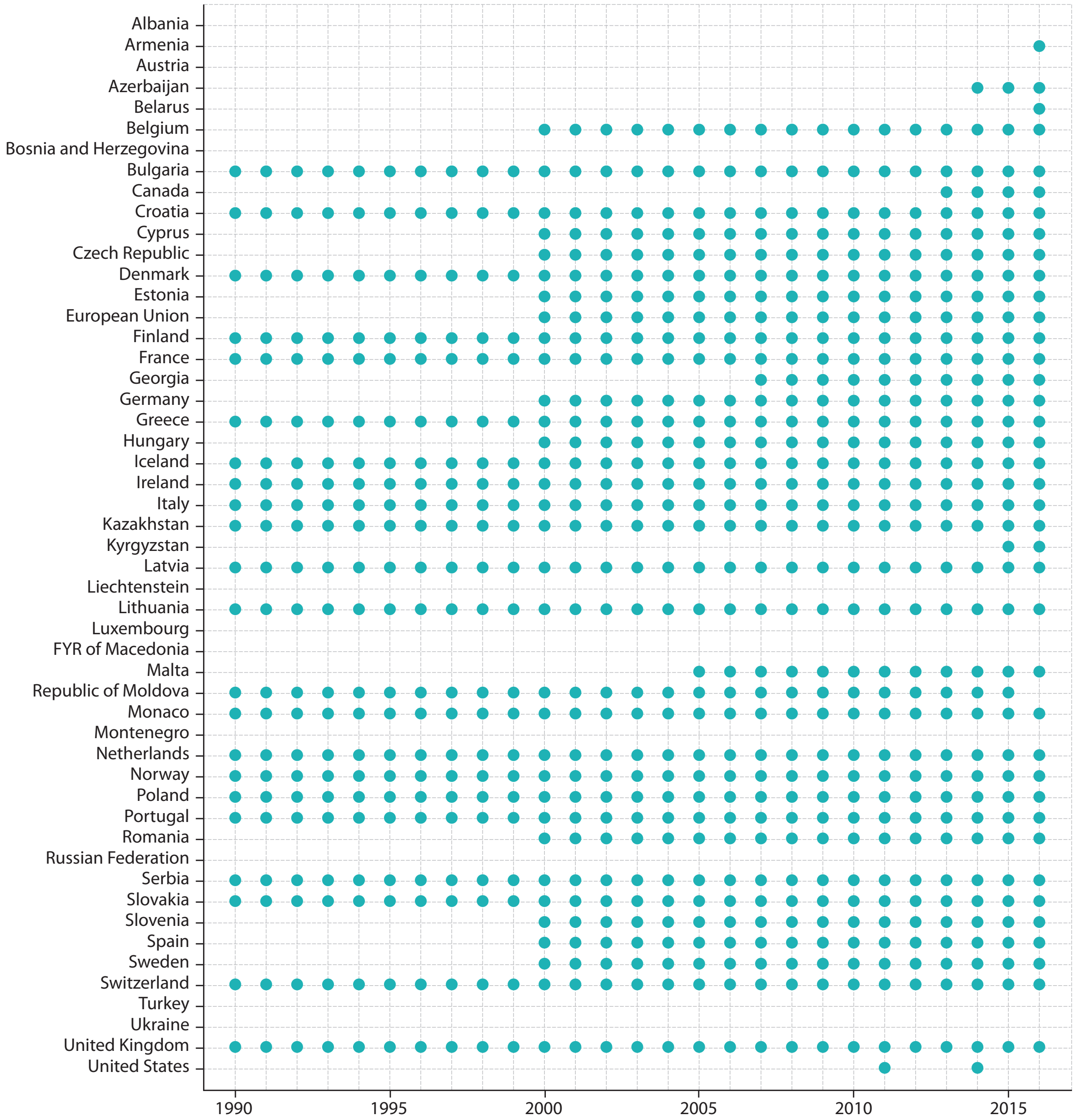

Figure 3.1 Reporting of annual total emissions of black carbon by CLRTAP Parties. Dots mark the years for which black carbon emissions were reported.

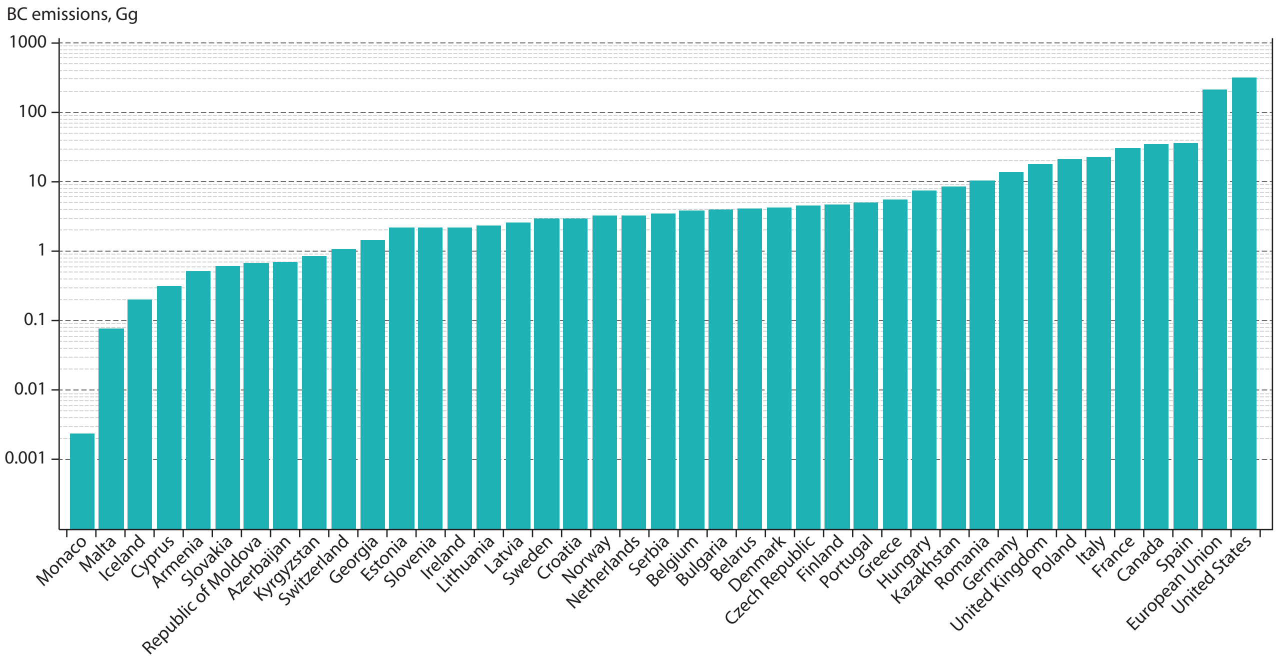

Figure 3.2 Most recent annual estimate of national total black carbon emissions. For most Parties this is the 2016 estimate; the most recent estimates for the United States and Moldova are for 2014 and 2015, respectively.

Table 3.1 Projected estimates of annual national total emissions of black carbon (Gg) under a *with existing measures* (WEM) scenario.

Country	2020	2025	2030	2050
Cyprus	0.24	0.19	0.14	-
Denmark	3.15	2.86	2.70	-
Finland	-	-	3.43	-
Greece	6.48	6.38	6.38	-
Ireland	3.98	4.42	5.12	-
Latvia	2.38	2.07	2.07	-
Lithuania	2.29	2.28	2.27	-
Netherlands	3.15	3.01	2.89	-
Norway	2.90	2.70	2.55	-
Sweden	3.05	2.77	2.61	-
Switzerland	1.21	0.88	0.66	0.35
United Kingdom	17.90	17.82	17.55	-

A dash indicates data were not reported.

Table 3.2 Projected estimates of annual national total emissions of black carbon (Gg) under a *with additional measures* (WAM) scenario.

Country	2020	2025	2030	2050
Switzerland	1.04	0.72	0.50	0.19
Ireland	3.87	4.11	4.46	-
Lithuania	2.13	1.97	1.80	-
Latvia	2.38	2.12	2.15	-

A dash indicates data were not reported.

totals but has not submitted emissions estimates at the NFR source sector level. Despite the absence of US NFR source sector emissions data, a total of 41 Parties have submitted black carbon emissions at source sector level. Montenegro has submitted source sector level emissions estimates for black carbon despite not submitting estimates of national total emissions.

With respect to the US black carbon reporting, it should be noted that for the other, mandatory pollutants, the United States has only submitted emissions estimates at source sector level for 1999. For all other years, the United States has submitted only national total emissions estimates for the mandatory pollutants in the reporting template submitted to CEIP. Nonetheless, the United States *Informative Inventory Report 2018* does detail source sector black carbon emissions, albeit using a more aggregated source sector split than the NFR system. Lying outside the EMEP domain, the United States and Canada are welcomed, but not obliged, to follow the reporting guidelines and submit emissions estimates at the NFR category level. Canada does however provide its emissions estimates using the NFR source sector split, although black carbon emissions are submitted as a separate data file later in the year and not in the reporting template with the other mandatory pollutants for submission before CLRTAP's 15 February deadline.

It should also be noted that in Table 3.3, only the NFR categories which count towards the national totals are considered; *memo items*, which comprise emissions estimates from international and domestic aviation during the *cruise* flight phase, total transport (based on total fuel used), multilateral operations, natural sources, and international maritime navigation are not counted here. The source sector *international maritime navigation* is however addressed later in the chapter.

As Table 3.3 reports, the number of source sectors for which black carbon emissions were estimated varies both between Parties and over time. Excluding the EU28, whose inventory is a synthesis of its Member States' national total- and source sector emissions estimates, the number of black carbon source sectors reported by CLRTAP Parties for 2016 ranged from four (Armenia) to 52 (Norway). Furthermore, while seven Parties have consistently reported black carbon emissions for the same number of source sectors over their respective time series (Armenia, Belarus, Bulgaria, Canada, Kyrgyzstan, Monaco, Netherlands), the number of black carbon source sectors reported by the remaining 33 Parties has varied over time. For ten of these Parties, the variation is due to additions/exclusions of single source sectors (France, Germany, Greece, Hungary, Ireland, Malta, Moldova, Poland, Spain, Sweden). For example, Germany reported black carbon emissions for 27 source sectors for the years 2000 to 2007 and then for 28 source sectors for the years since 2008. Sweden on the other hand first reported black carbon emissions for 44 source sectors (2000 to 2004), then for 45 source sectors (2005–2014), and then again for 44 source sectors (2015, 2016). For other Parties the number of source sectors reported can vary significantly. Such is the case for Azerbaijan (21 to 32), Estonia (27 to 41), and Georgia (2 to 19).

Given the diversity in national circumstances, it is clear that there will be some variation in the respective national constellations of source sectors emitting black carbon and other pollutants. Nonetheless, the wide range in source sectors reported indicates a lack of comparability between the national total black carbon emissions estimates of the different CLRTAP Parties.

According to the current reporting obligations, since 2017 CLRTAP Parties within the EMEP domain have been required to report spatially disaggregated emissions of the mandatory pollutants using either the new 0.1° × 0.1° EMEP grid or the old 50 × 50 km^2 grid every four years (see Figure 2.2). These disaggregated emissions, which should be at the aggregated source sector level (so called GNFR sectors), may include voluntary submissions of gridded black carbon emissions data. Since 2017, 31 Parties have submitted spatially disaggregated emissions data for mandatory pollutants, with 27 of those Parties also reporting gridded black carbon emissions data (Table 3.4). Austria and Luxembourg are yet to report any black carbon emissions data, while Denmark and Germany have reported black carbon emissions (national totals and source sector level) but are yet to report gridded black carbon emissions estimates. As Table 3.4 shows, the reported time series vary between Parties; but all 27 reporting Parties with the exception of Malta have provided gridded black carbon emissions estimates for 2015. Table A1.9 in Appendix A1 to this report reports GNFR source sectors for which the Parties submitted gridded black carbon emissions estimates for 2015 (2016 for Malta). It should nonetheless be noted that the

Table 3.3 Number of NFR categories included in the annual inventory estimates of black carbon emissions for the CLRTAP Parties for each year between 1990 and 2016. To aid visualisation, the table cells are colour-coded along a red-yellow-green gradient according to the number of NFR categories included.

Country	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
Albania	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Armenia	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4
Austria	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Azerbaijan	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	32	27	21
Belarus	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	19
Belgium	0	0	0	0	0	0	0	0	0	0	47	47	47	47	47	47	47	47	47	47	47	46	46	47	47	45	45
Bosnia and Herzegovina	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Bulgaria	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
Canada	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	24	24	24	24
Croatia	35	35	34	34	34	32	32	32	32	32	32	37	37	37	36	36	36	36	36	35	35	35	35	35	35	34	34
Cyprus	0	0	0	0	0	0	0	0	0	0	26	26	26	26	25	24	22	22	23	23	23	23	22	23	23	22	22
Czech Republic	0	0	0	0	0	0	0	0	0	0	31	33	36	36	35	33	33	34	32	35	36	36	36	34	32	32	32
Denmark	42	42	42	42	42	42	42	42	42	42	42	40	42	40	40	41	39	39	39	40	38	38	38	40	38	40	38
Estonia	0	0	0	0	0	0	0	0	0	0	27	27	27	29	29	29	29	28	34	35	38	41	40	39	39	40	41
EU28	0	0	0	0	0	0	0	0	0	0	73	72	73	72	71	70	70	70	72	72	73	73	73	73	72	73	72
Finland	43	42	44	44	43	42	43	43	43	43	43	43	43	43	43	43	43	43	44	45	45	45	45	45	45	45	45
France	46	46	46	46	46	46	46	46	46	46	46	47	47	47	47	46	46	46	46	46	46	46	47	47	47	47	47
Georgia	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	3	4	6	5	6	19	19	19	19
Germany	0	0	0	0	0	0	0	0	0	0	27	27	27	27	27	27	27	27	28	28	28	28	28	28	28	28	28
Greece	34	34	34	34	34	34	34	34	34	34	34	35	35	35	35	35	35	35	35	35	35	34	34	34	34	34	35
Hungary	0	0	0	0	0	0	0	0	0	0	41	41	41	41	41	41	41	41	41	41	41	41	41	42	42	42	42
Iceland	20	20	20	20	20	20	20	20	20	20	24	26	26	26	26	25	26	26	26	26	27	26	25	27	27	30	30
Ireland	30	30	30	30	30	30	30	30	29	29	29	29	29	29	29	30	30	30	30	30	29	29	29	29	29	29	29
Italy	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	49	49	49	47	47	47	47	47	45	45	44	44
Kazakhstan	8	8	8	8	8	8	8	8	8	9	8	9	9	9	9	9	10	11	11	11	11	11	11	11	11	11	11
Kyrgyzstan	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	10
Latvia	32	32	32	32	32	31	32	32	33	33	34	34	35	35	35	35	35	35	35	35	35	35	34	34	35	34	32
Liechtenstein	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Lithuania	31	31	31	30	30	29	29	29	29	29	29	29	29	29	29	29	29	29	29	29	29	29	29	29	29	28	29
Luxembourg	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
FYR of Macedonia	21	21	21	21	21	21	21	21	21	20	20	21	21	21	21	21	21	21	20	21	21	21	21	21	22	22	22
Malta	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	7	7	7	7	7	7	7	7	7	8	8	7
Republic of Moldova	14	14	14	14	14	14	14	14	14	14	14	14	14	15	15	15	15	15	15	15	15	15	15	15	15	15	0
Monaco	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11
Montenegro	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Netherlands	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20
Norway	52	53	53	53	53	53	53	53	53	53	53	53	53	53	53	54	52	52	52	52	52	52	52	52	52	52	52
Poland	33	33	33	33	33	33	33	33	33	33	34	34	34	34	34	34	34	34	34	33	34	34	34	34	34	34	34
Portugal	31	31	31	31	32	32	32	32	32	32	32	32	31	31	31	32	32	32	32	32	32	32	32	32	32	33	33
Romania	0	0	0	0	0	0	0	0	0	0	30	30	30	30	29	25	28	28	28	26	25	25	24	24	23	24	24
Russian Federation	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Serbia	26	26	26	25	26	26	26	26	25	25	27	27	27	27	27	27	27	28	28	28	27	28	28	28	28	28	28
Slovakia	24	24	24	24	24	24	24	24	24	24	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	27
Slovenia	0	0	0	0	0	0	0	0	0	0	34	34	35	35	34	34	33	33	34	33	33	33	33	33	33	33	33
Spain	0	0	0	0	0	0	0	0	0	0	47	47	47	46	46	46	46	46	46	46	46	46	46	46	46	46	47
Sweden	0	0	0	0	0	0	0	0	0	0	44	44	44	44	44	45	45	45	45	45	45	45	45	45	45	44	44
Switzerland	39	39	40	40	40	39	39	39	39	39	39	39	38	38	38	38	38	37	37	37	37	37	37	37	37	37	37
Turkey	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ukraine	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
United Kingdom	52	52	52	52	51	51	51	51	51	51	51	50	50	50	49	49	49	49	49	49	49	49	49	49	49	49	49
United States	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Table 3.4 CLRTAP Parties within the EMEP domain reporting spatially disaggregated emissions estimates for the mandatory pollutants and black carbon.

Country	Years for which gridded emissions data for the mandatory pollutants are reported	Black carbon emissions included in the gridded data
Austria	2015	[red]
Belgium	2015	[green]
Bulgaria	2015	[green]
Croatia	1990, 1995, 2000, 2005, 2010, 2015	[green]
Czech Republic	2015	[green]
Denmark	2015	[red]
Finland	2015, 2016	[green]
France	2015	[green]
Georgia	2015	[green]
Germany	1990, 1995, 2000, 2005, 2010, 2015	[red]
Greece	2015	[green]
Hungary	2015	[green]
Ireland	2015	[green]
Italy	2015	[green]
Latvia	2015	[green]
Lithuania	2015	[green]
Luxembourg	2015	[red]
FYR of Macedonia	2015	[green]
Malta	2016	[green]
Monaco	2014, 2015, 2016	[green]
Netherlands	1990, 1995, 2000, 2005, 2010, 2015	[green]
Norway	1990, 1995, 2000, 2005, 2010, 2015	[green]
Poland	2015	[green]
Portugal	2015	[green]
Romania	2005, 2015	[green]
Slovakia	2015	[green]
Slovenia	2015	[green]
Spain	1990–2015	[green]
Sweden	1990, 2000, 2005, 2010, 2015	[green]
Switzerland	1980–2016	[green]
United Kingdom	2015	[green]

Colored cells indicate whether emissions are included (green) or not included (red).

wide range in NFR source sectors reported by the CLRTAP Parties (see Table 3.3) may indicate variation in the extent to which the reported aggregated GNFR source sectors, and thus the gridded data, include all relevant black carbon source sectors. For an overview of which NFR source sectors belong to which aggregated GNFR source sectors, see Table A1.10 in Appendix A1 to this report.

3.1.2.2 Inventory estimates and methodologies for emissions reporting for priority source sectors

3.1.2.2.1 Residential combustion

Emissions from residential combustion are reported to CLRTAP under the NFR category *1.A.4.b.i Residential: Stationary*. Thirty-eight Parties have submitted estimates of black carbon emissions from residential combustion (Figure 3.3). Of the 41 Parties submitting source sector level emissions estimates for black carbon, Kazakhstan, Malta and Slovakia are yet to submit black carbon emissions estimates for residential combustion.

The most recent annual black carbon emissions estimates for residential combustion range from 1 kg (Iceland) to 71 Gg (EU28) (Figure 3.4). The percentage contribution of this source to the national total black carbon emissions ranges from 0.0005% (Iceland) to 87.4% (Romania). This source sector is generally a significant contributor of black carbon emissions to the national total, as illustrated by the interquartile range in percentage contribution of between about 20% and 60% (Figure 3.5).

According to the IIRs, it appears that both *Lower Tier* and *Higher Tier* methodologies for estimating black carbon emissions from residential combustion have been applied to significant extents by the CLRTAP Parties (Table 3.5). Excluding

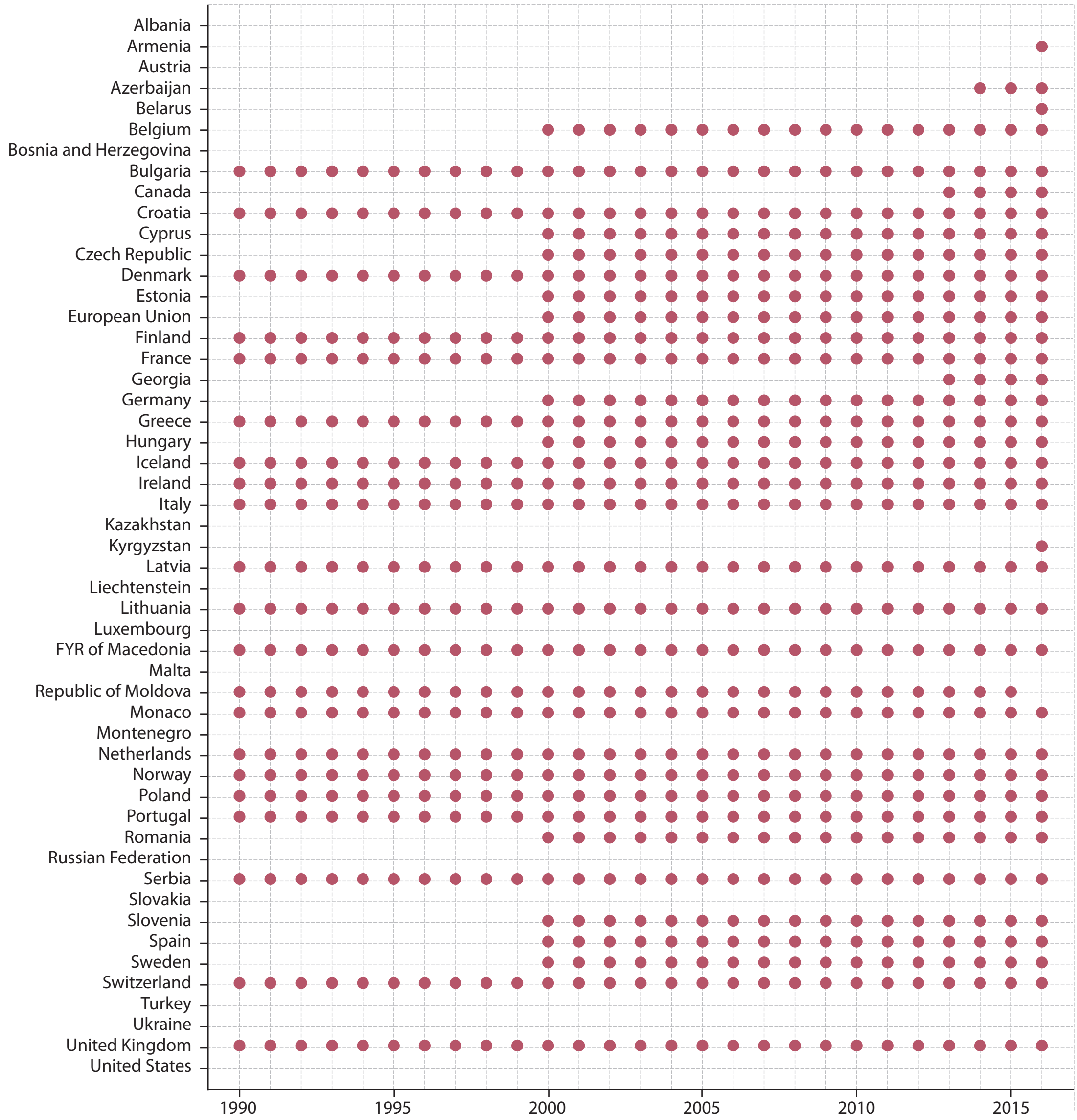

Figure 3.3 Reporting of black carbon emissions from *1.A.4.b.i Residential: Stationary* by CLRTAP Parties. Dots mark the years for which black carbon emissions were reported.

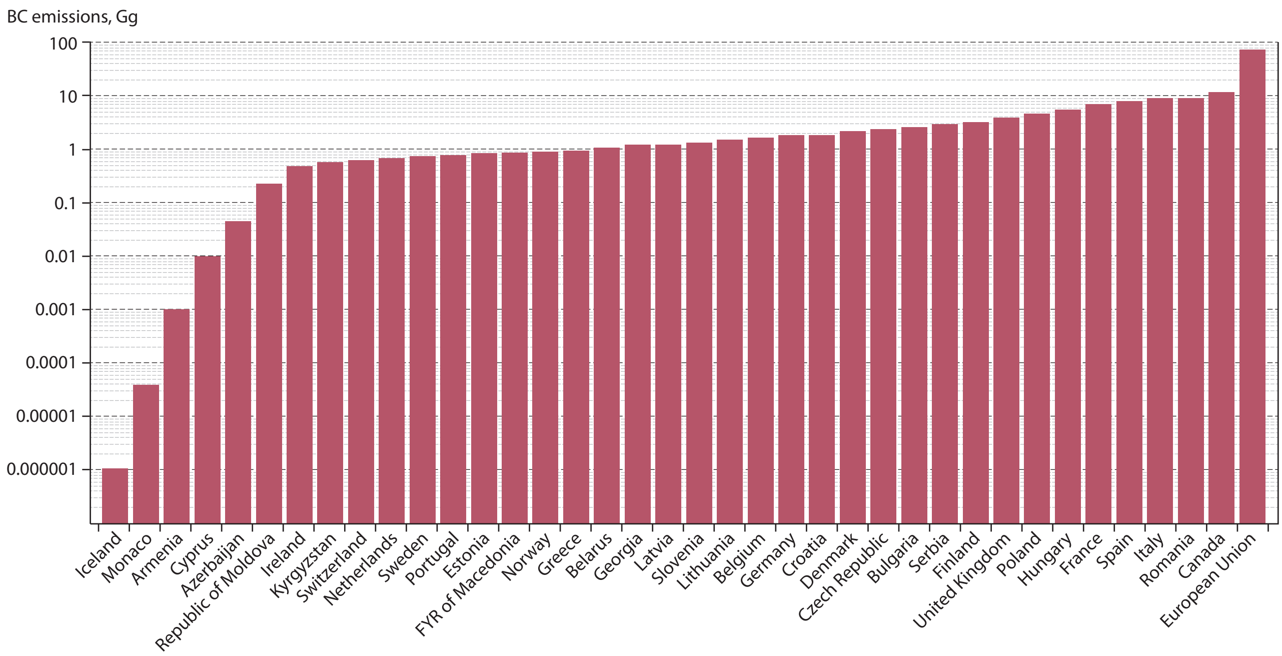

Figure 3.4 Most recent annual estimates of national black carbon emissions from *1.A.4.b.i Residential: Stationary*. For almost all Parties this is the 2016 estimate; Moldova's most recent estimate is for 2015.

Table 3.5 Summary of the methods and emission coefficients used by CLRTAP Parties to estimate black carbon emissions from the source sector *1.A.4.b.i Residential: Stationary*. Results were obtained by reviewing the latest Informative Inventory Reports submitted by those Parties reporting black carbon emissions for residential combustion.

CLRTAP Party	Informative Inventory Report		Q1: Tier methodology for source sector	Q2: Tier of black carbon fractions	Q3: Source of the black carbon fractions	Additional notes	Judgement
	Submission year	Language					
Armenia	2018	Russian	Insufficient information	Insufficient information	Insufficient information	No source sector methodological description	No judgement
Azerbaijan	2018	English	T1	T1	EEA (2016)	-	Lower Tier
Belarus	2016	English	T1	T1	EEA (2013)	-	Lower Tier
Belgium	2018	English	T2	T2	EEA (2016)	-	Higher Tier
Bulgaria	2018	English	T1	T1	EEA (2016)	-	Lower Tier
Canada	2018	English	T2	T2	US SPECIATE 4.4 Database	-	Higher Tier
Croatia	2018	English	T2	T2	EEA (2016)	-	Higher Tier
Cyprus	2018	English	T1	T1	EEA (2016)	-	Lower Tier
Czech Republic	2018	English	T2	T2	EEA (2016)	-	Higher Tier
Denmark	2018	English	T2	T2	EEA (2013)	-	Higher Tier
Estonia	2018	English	T2	T2	EEA (2016)	-	Higher Tier
Finland	2018	English	T2/T3	T2	National emission factors; but, no citation	-	Higher Tier
France	2018	French	T2	T1	EEA (2016)	-	Lower Tier
Georgia	2018	English	T1	T1	EEA (2016)	-	Lower Tier
Germany	2018	English	T2/T3	T2	EEA (2016)	-	Higher Tier
Greece	2017	English	T1	T1	EEA (2016)	-	Lower Tier
Hungary	2018	English	T1/T2	T1/T2	EEA (2016)	-	Higher Tier
Iceland	2018	English	T1	T1	EEA (2016)	-	Lower Tier
Ireland	2018	English	T1	T1	EEA (2016)	-	Lower Tier
Italy	2018	English	T2	T2	EEA (2016)	-	Higher Tier
Kyrgyzstan	2018	Russian	Insufficient information	Insufficient information	Insufficient information	-	No judgement
Latvia	2018	English	T1/T2	T1/T2	EEA (2016)	-	Higher Tier
Lithuania	2018	English	T1/T2	T1/T2	EEA (2016)	-	Higher Tier
FYR of Macedonia	2018	English	T1	T1	EEA (2013, 2016)	-	Lower Tier
Republic of Moldova	2017	English	T1	T1	EEA (2013)	-	Lower Tier
Monaco	2018	French	T1	T1	EEA (2016)	-	Lower Tier
Netherlands	2018	English	T2	Insufficient information	Insufficient information	-	No judgement
Norway	2018	English	T2	T2	National emission factors; SINTEF (2013)	-	Higher Tier
Poland	2018	English	T1/T2	T1	EEA (2016)	-	Lower Tier
Portugal	2018	English	T1	T1	EEA (2016)	-	Lower Tier
Romania	2018	English	T1/T2	T1/T2	EEA (2016)	-	Higher Tier
Serbia	2018	English	T1	T1	EEA (2016)	-	Lower Tier
Slovenia	2018	English	T1/T2	T1/T2	EEA (2016)	-	Higher Tier
Spain	2018	English	T1/T2	T1/T2	EEA (2016)	-	Higher Tier
Sweden	2018	English	T1	T1	Insufficient information	-	Lower Tier
Switzerland	2018	English	T2	T2	Nussbaumer and Hälg (2015)	-	Higher Tier
United Kingdom	2018	English	T1/T2	T1/T2	EEA (2016) / National emission factors	-	Higher Tier

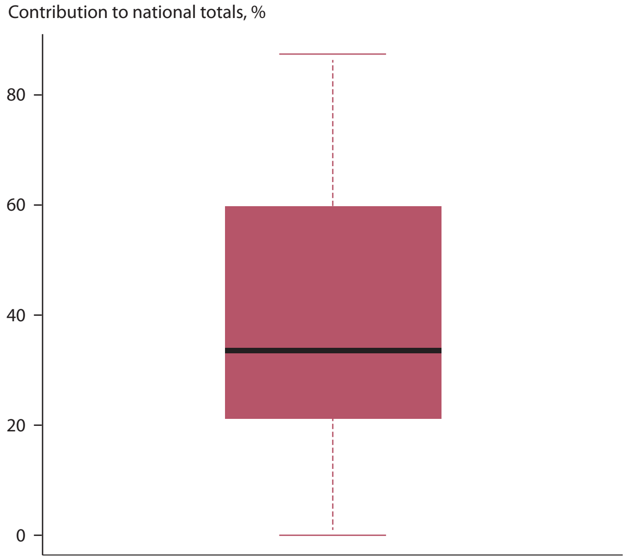

Figure 3.5 Boxplot of the contributions of black carbon emissions from *1.A.4.b.i Residential: Stationary* to national total emissions for the CLRTAP Parties reporting residential combustion as well as national total black carbon emissions. The box plots the range between the first and third quartiles, with the second quartile (median) marked by the thick horizontal band. Whiskers plot the lowest datum within 1.5 the interquartile range of the first quartile and the highest datum within 1.5 interquartile range of the third quartile.

the European Union as a reporting Party, of the 37 Parties reporting black carbon emissions from residential combustion, 16 were judged to have applied a *Lower Tier* (i.e., Tier 1) methodology for the sector activity data in general as well as Tier 1 black carbon fractions (Azerbaijan, Belarus, Bulgaria, Cyprus, Georgia, Greece, Iceland, Ireland, FYR Macedonia, Moldova, Monaco, Portugal, Serbia, Sweden) or a Tier 1/2 sector split with the application of Tier 1 black carbon fractions (France, Poland). Eighteen Parties were judged to have applied a *Higher Tier* methodology, i.e. applying a general sector split in activity data statistics and black carbon fractions at Tier 2 (or Tier 1/2) level (Belgium, Canada, Croatia, Czech Republic, Denmark, Estonia, Finland, Germany, Hungary, Italy, Latvia, Lithuania, Norway, Romania, Slovenia, Spain, Switzerland, United Kingdom).

For Armenia and Kyrgyzstan, no judgement on the source sector methods could be made due to the lack of methodological descriptions in the respective IIRs. In the case of the Netherlands, it was clear that a Tier 2 methodology for the sector has been applied; however, there was insufficient information in the IIR to directly or indirectly infer the Tier of the applied black carbon fractions.

In terms of the source reference for the black carbon fractions applied, the 2016 EMEP/EEA Guidebook (or previous version) was referenced by 29 of the Parties reporting black carbon emissions from residential combustion. In three cases (Finland, Norway, Switzerland) national source material or studies on black carbon fractions were referred to, while Canada cited the US SPECIATE database[14] as the origin of its black carbon fractions. In the cases of Armenia, Kyrgyzstan, Netherlands and Sweden, no reference source for black carbon fractions was given in the respective IIRs.

3.1.2.2.2 Gas flaring

Emissions from gas flaring are reported to CLRTAP under the NFR category *1.B.2.c Venting and flaring (oil, gas, combined oil and gas)*. As the category title clearly indicates, emissions from gas flaring are not reported separately but rather together with oil and combined oil and gas flaring. Sixteen Parties have submitted estimates of black carbon emissions from venting and flaring (Figure 3.6): Belgium, Canada, Croatia, Denmark, Estonia, France, Germany, Hungary, Norway, Portugal, Romania, Slovenia, Spain, Sweden, United Kingdom, and the European Union.

The most recent annual black carbon emissions estimates for venting and flaring range from 56 kg (Estonia) to 3.4 Gg (Norway) (Figure 3.7). The percentage contribution of this source to the national total black carbon emissions is typically below 1% (Figure 3.8). The exception is Norway, where black carbon emissions from venting and flaring accounted for about 10% of the 2016 national total emissions.

Despite the generally low contribution of this source to national total emissions of black carbon, gas flaring is a priority source sector for this EU Action on Black Carbon in the Arctic given the potentially significant impacts of high latitude black carbon emissions from gas flaring on the Arctic. It is thus important to highlight that of the Arctic Council Member States only Norway has reported spatially disaggregated black carbon emissions for the GNFR sector containing flaring, *D_Fugitive* (Appendix A1 to this report, Table A1.9).

Reflecting the generally minor contributions of this source sector to the respective national totals, it appears that most of the Parties reporting black carbon emissions from venting and flaring have been applying *Lower Tier* methods (Table 3.6). Furthermore, methodological descriptions for the source sector, particularly in terms of black carbon emissions, were generally limited. Excluding the EU as a reporting Party, of the 15 Parties reporting black carbon emissions from venting and flaring, eight were judged to have applied a *Lower Tier* methodology (i.e., Tier 1) for the sector activity data in general as well as Tier 1 black carbon fractions (Denmark, Estonia, Portugal, Romania, Slovenia, Sweden) or a Tier 1/2 sector split but with the application of Tier 1 black carbon fractions (Croatia, Hungary). Considering the descriptions in the 2016 EMEP/EEA Guidebook, the Tier 2 methods of mixed Tier 2/1 sector methodologies are likely only to be relevant for gaseous pollutants rather than particle emissions.

Three Parties were judged to have applied a *Higher Tier* methodology. Both Canada and the United Kingdom utilise facility level particulate matter data (Tier 3). While it was unclear what Tier black carbon emission factor the United Kingdom uses, Canada reports that it uses a Tier 1 black carbon fraction to derive the black carbon emissions from the facility level particulate matter data. In contrast, Norway reports that it applies a Tier 1/2 general sector split, but with a Tier 2 black carbon emission factor. For Belgium, France, Germany, and Spain, no overall judgement could be made due to insufficient information in the respective IIRs.

In terms of the source material for the black carbon fractions applied, the seven Parties providing information essentially cited the same source. This is the emission factor

[14] https://www.epa.gov/air-emissions-modeling/speciate-version-45-through-40

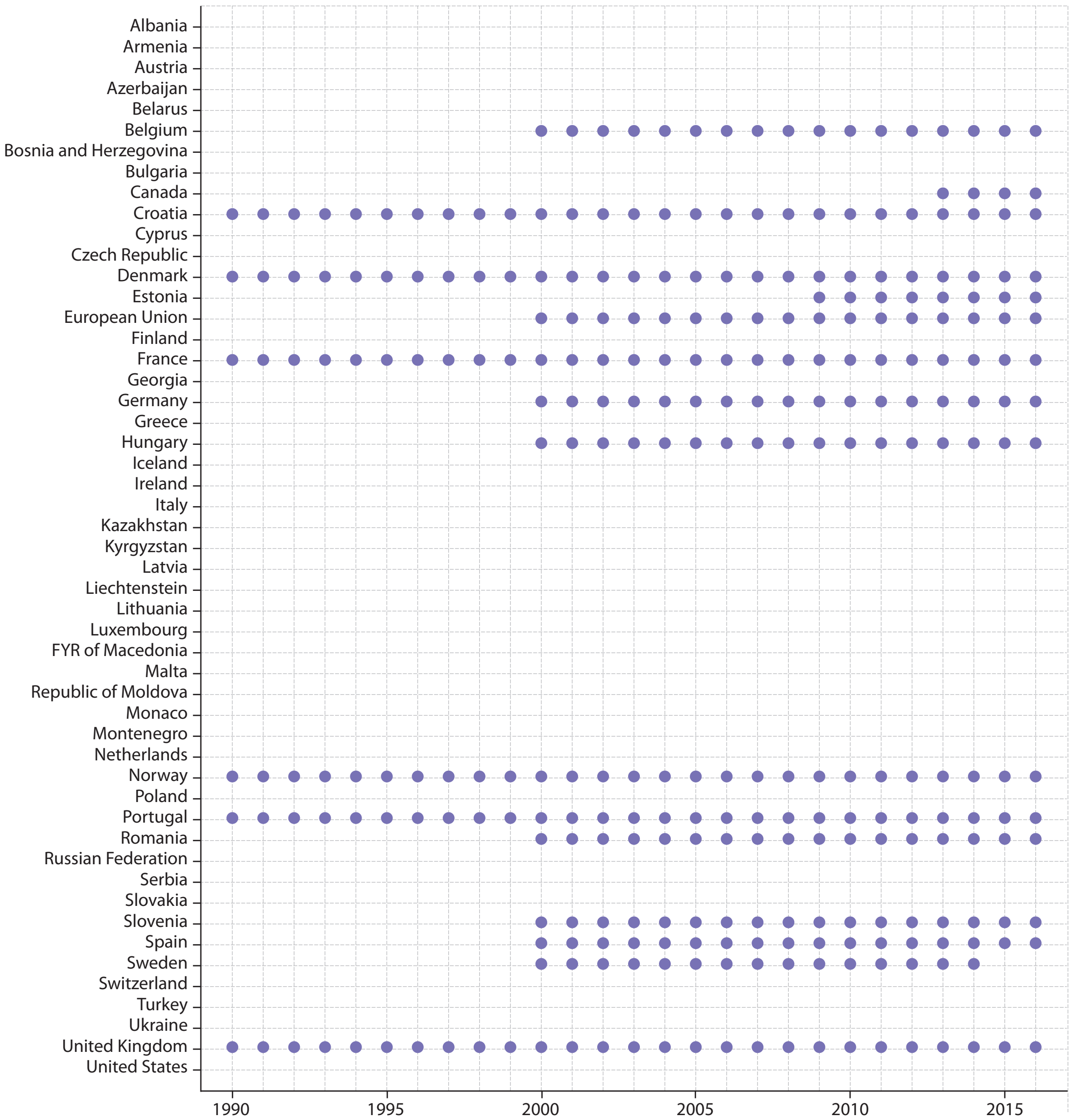

Figure 3.6 Reporting of black carbon emissions from *1.B.2.c Venting and flaring* by CLRTAP Parties. Dots mark the years for which black carbon emissions were reported.

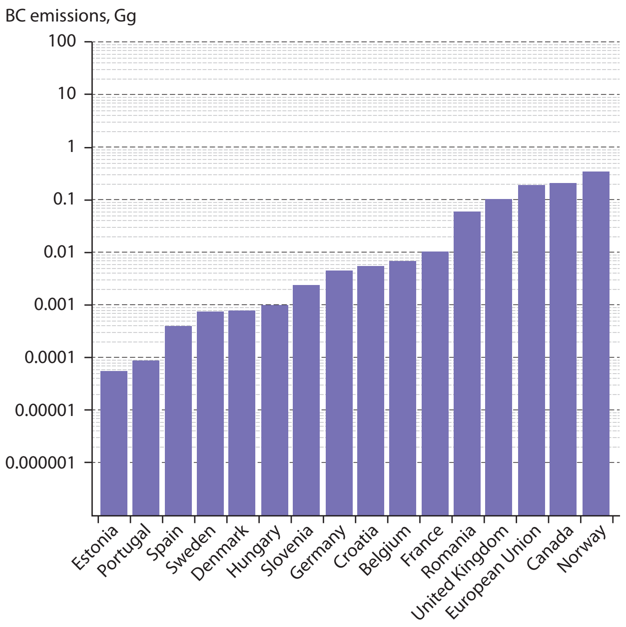

Figure 3.7 Most recent annual estimates of national black carbon emissions from *1.B.2.c Venting and flaring*. For almost all Parties this is the 2016 estimate; Sweden's most recent estimate is for 2014.

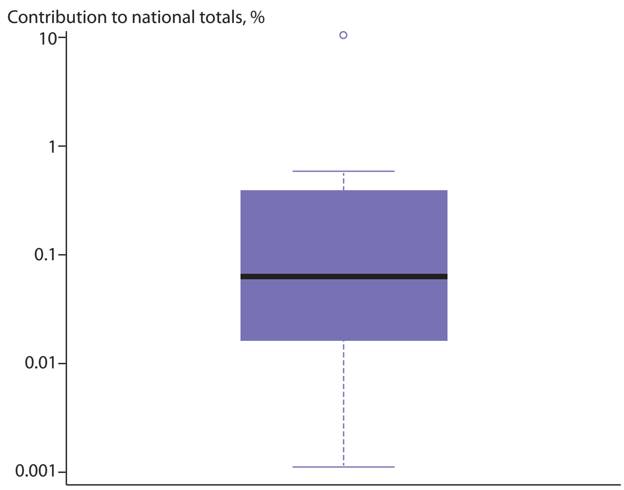

Figure 3.8 Boxplot of the contributions of black carbon emissions from *1.B.2.c Venting and flaring* to national total emissions for the CLRTAP Parties reporting venting and flaring as well as national total black carbon emissions. The box plots the range between the first and third quartiles, with the second quartile (median) marked by the thick horizontal band. Whiskers plot the lowest datum within 1.5 the interquartile range of the first quartile and the highest datum within 1.5 interquartile range of the third quartile. The circle marks data outside this range.

Table 3.6 Summary of the methods and emission coefficients used by CLRTAP Parties to estimate black carbon emissions from the source sector *1.B.2.c Venting and flaring*. Results were obtained by reviewing the latest Informative Inventory Reports submitted by those Parties reporting black carbon emissions for venting and flaring.

CLRTAP Party	Informative Inventory Report		Q1: Tier methodology for source sector	Q2: Tier of black carbon fractions	Q3: Source of the black carbon fractions	Additional notes	Judgement
	Submission year	Language					
Belgium	2018	English	Insufficient information	Insufficient information	Insufficient information	-	No judgement
Canada	2018	English	T3	T1	McEwen (2013)	Facility level particulate matter data	Higher Tier
Croatia	2018	English	T1/T2	T1	EEA (2016)	-	Lower Tier
Denmark	2018	English	T1	T1	EEA (2016)	-	Lower Tier
Estonia	2018	English	T1	Insufficient information	Insufficient information	-	Lower Tier
France	2018	French	Insufficient information	Insufficient information	Insufficient information	-	No judgement
Germany	2018	English	T1/T2	Insufficient information	Insufficient information	-	No judgement
Hungary	2018	English	T1/T2	T1	EEA (2016)	-	Lower Tier
Norway	2018	English	T1/T2	T2	McEwen and Johnson (2012)	Applied McEwen and Johnson (2012) function using national heating value	Higher Tier
Portugal	2018	English	T1	Insufficient information	Insufficient information	-	Lower Tier
Romania	2018	English	T1	T1	EEA (2016)	-	Lower Tier
Slovenia	2018	English	T1	T1	EEA (2016)	-	Lower Tier
Spain	2018	English	T1/T2/T3	Insufficient information	Insufficient information	Mixed Tier method including facility level data; not clear in terms of black carbon	No judgement
Sweden	2018	English	T1	Insufficient information	Insufficient information	-	Lower Tier
United Kingdom	2018	English	T3	Insufficient information	Insufficient information	Facility level data; not clear in terms of black carbon	Higher Tier

derived using the McEwen and Johnson (2012) function. This was cited either directly or indirectly via the 2016 EMEP/EEA Guidebook or a 2013 publication by McEwen. Note that Norway was judged to have applied a Tier 2 emission factor as it was explicitly described in the Norway IIR that the McEwen-Johnson function was solved using a national heating value and not the default heating value used to derive the Tier 1 emission factor provided in the 2016 EMEP/EEA Guidebook (see Section 2.1.2.2.2).

3.1.2.2.3 International shipping

Emissions from shipping in international waters are reported to CLRTAP under the NFR categories *1.A.3.d.i(i) International maritime navigation* and *1.A.3.d.ii National navigation*. International maritime navigation refers to journeys which depart from a port of one country and arrive at a port of another country. It is also important to note that Parties are required to report the emissions (of the mandatory pollutants) of those international maritime journeys departing their ports after refuelling and that these emissions are included as a *memo item* in their submissions. As a *memo item*, the emissions here are not to be included in their national totals. Emissions from National navigation refer to those emissions from vessels which depart and return to national ports and are included in the national emissions totals.

Given that the EU Action on Black Carbon in the Arctic and thus this report focuses on black carbon emissions from maritime shipping in Arctic waters, the following sector review focuses on Arctic Council Member States only. Of the eight Arctic States, Denmark, Iceland and Sweden have submitted estimates of black carbon emissions from both international maritime navigation and national navigation. Canada, Finland and Norway have submitted black carbon emissions estimates

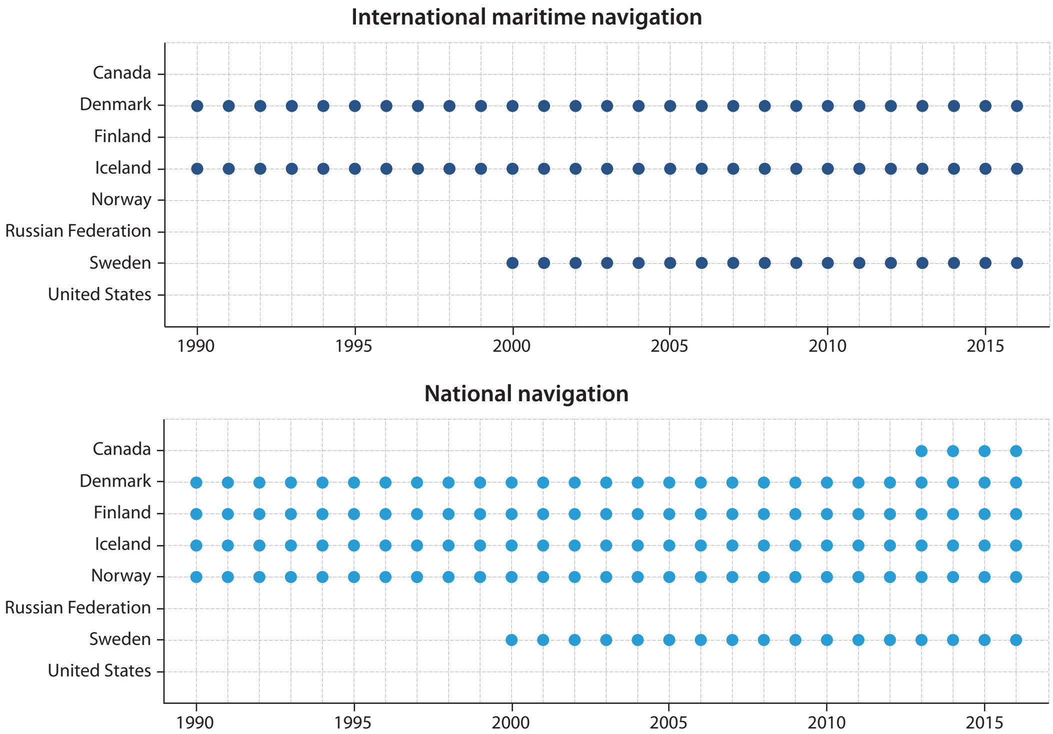

Figure 3.9 Reporting of black carbon emissions from *1.A.3.d.i(i) International maritime navigation* and *1.A.3.d.ii National navigation* by Arctic Council Member States to CLRTAP. Dots mark the years for which black carbon emissions were reported.

for national navigation but not for international maritime navigation (Figure 3.9). For the reporting Parties, the most recent annual emissions estimates for international maritime navigation ranged from 0.03 Gg BC (Iceland) to 0.96 Gg BC (Sweden), while the most recent annual emissions estimates for national navigation ranged from 0.004 Gg BC (Iceland) to 1.28 Gg BC (Canada) (Figure 3.10). National navigation for those reporting countries contributes between about 1% (Finland, Denmark) and 10% (Norway) to national total black carbon emissions.

Together with gas flaring, international shipping is a priority source sector for this EU Action on Black Carbon in the Arctic given the potentially significant impacts of black carbon emissions from shipping in Arctic waters on the Arctic region. It is thus important to point out that of the eight Arctic States, Finland, Sweden and Norway have reported spatially disaggregated black carbon emissions for the GNFR sector containing national navigation, *G_Shipping*. Interestingly, despite not reporting national total black carbon emissions from international maritime shipping, Norway has reported spatially

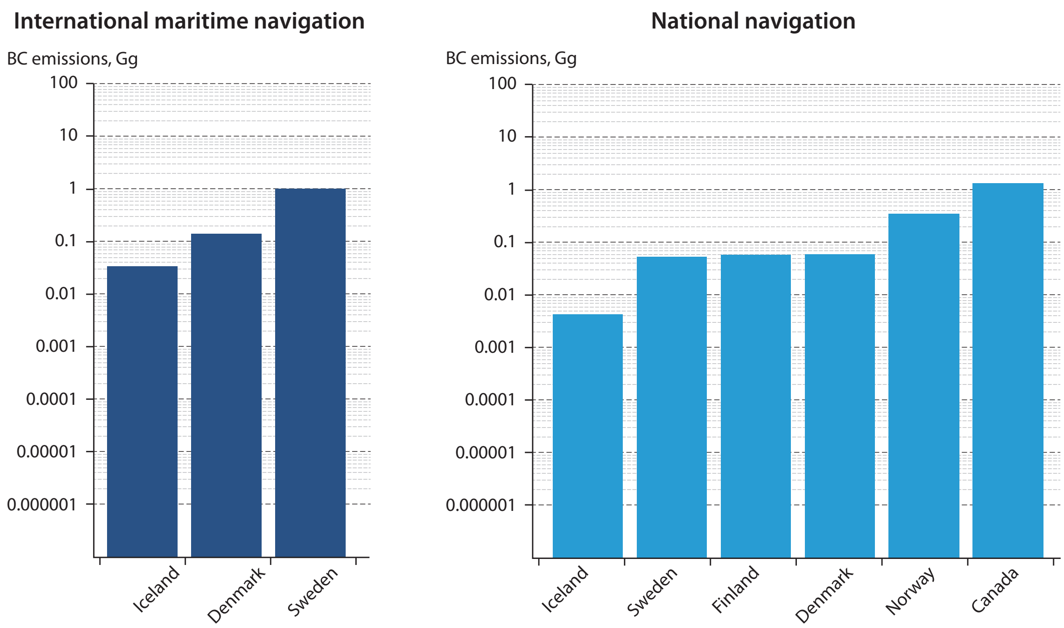

Figure 3.10 Most recent annual estimates by Arctic Council Member States of their national black carbon emissions from *1.A.3.d.i(i) International maritime navigation* and *1.A.3.d.ii National navigation*. For all Parties this is the 2016 estimate.

Table 3.7 Summary of the methods and emission coefficients used by Arctic Council Member States to estimate black carbon emissions from the source sectors *1.A.3.d.i(i) International maritime navigation* and *1.A.3.d.ii National navigation*. Results were obtained by reviewing the latest Informative Inventory Reports submitted by those Parties reporting black carbon emissions for shipping.

CLRTAP Party	Informative Inventory Report		Q1: Tier methodology for source sector	Q2: Tier of black carbon fractions	Q3: Source of the black carbon fractions	Additional notes	Judgement
	Submission year	Language					
Canada	2018	English	T3	T1	EEA (2016) / US SPECIATE 4.4 Database	T3 Model: MEIT	Higher Tier
Denmark	2018	English	T2/T3	Insufficient information	Insufficient information	-	Higher Tier
Finland	2018	English	T3	T1	EEA (2016)	T3 Model: LIPASTO (MEERI sub-model)	Higher Tier
Iceland	2018	English	T1	T1	EEA (2016)	-	Lower Tier
Norway	2018	English	T2	T2	Kupiainen and Klimont (2007)	-	Higher Tier
Sweden	2018	English	T1	T1	Use of national emission factors, sources: Swedish maritime Administration & Swedish Transport Agency	-	Lower Tier

disaggregated black carbon emissions for the GNFR sector containing international maritime shipping, *P_IntShipping* (Appendix A1 to this report, Table A1.9).

Of the six Arctic States reporting black carbon emissions from international and/or national maritime shipping (Table 3.7), two were judged to have applied a *Lower Tier* methodology (i.e., Tier 1) for the sector activity data in general as well as Tier 1 black carbon fractions (Iceland, Sweden). Iceland reports using Tier 1 methods and emissions factors in the 2016 EMEP/EEA Guidebook (EEA, 2016), while Sweden refers to a Tier 1 method using emission factors from national agencies.

The remaining four Arctic States were judged to have applied a *Higher Tier* methodology. Norway reports that a Tier 2 sector split in activity data and black carbon fractions is applied. In terms of the source of black carbon fractions, Norway explicitly references the Tier 2 black carbon fractions given by Kupiainen and Klimont (2007). Canada and Finland report the application of Tier 3 models which calculate particulate matter emissions taking into account distribution in fuel and vessel/engine types as well as the influence of ship movements (i.e., time the vessels spend *cruising*, *hotelling* or *manoeuvring*, see Section 2.1.2.2.3). To arrive at black carbon emissions estimates, both Parties report using Tier 1 black carbon fractions. Denmark reports using a mixed Tier 2/3 method; however, it is not clear which Tier black carbon fractions have been applied.

3.1.2.2.4 **Agricultural open burning**

Emissions from open burning of agricultural waste are reported to CLRTAP under the NFR category *3.F Field burning of agricultural residues*. Fifteen Parties have submitted estimates of black carbon emissions from *3.F Field burning of agricultural residues* (Figure 3.11): Bulgaria, Cyprus, Denmark, Finland, France, Greece, Italy, Moldova, Norway, Poland, Portugal, Romania, Spain, United Kingdom and the European Union.

For the reporting Parties, the most recent annual emissions for open burning of agricultural waste range from 0.2 Mg BC (Bulgaria) to 2.2 Gg BC (European Union) (Figure 3.12). The percentage contribution of this source to national total black carbon emissions is typically below 1% (Figure 3.13); however, for France, Greece and Portugal, the source sector contributed about 5%, 3.2%, and 2.9% to the respective 2016 national total emissions. It is important to note that there may be underestimations due to reporting of emissions by some Parties of certain agricultural burning activities under the NFR category *5.C.2 Open burning of waste*. Finally, although the United States has not submitted black carbon emissions data using the NFR template and/or NFR source sector split (see Section 3.1.2.1), the United States *Informative Inventory Report 2018* does detail black carbon emissions for the category *Agricultural Field Burning* (6 Gg BC in 2014) using its own source sector split.

Excluding the European Union as a reporting Party, of the 15 Parties reporting black carbon emissions from open burning of agricultural waste (Table 3.8), 11 were judged to have applied a *Lower Tier* methodology (i.e., Tier 1) for the sector activity data in general as well as Tier 1 black carbon emission factors (Bulgaria, Cyprus, Denmark, Finland, Greece, Italy, Moldova, Norway, Poland, Spain, United Kingdom). Ten of these Parties referenced the Tier 1 methods and emissions factors in the 2016 EMEP/EEA Guidebook (or previous 2013 version); however, Norway reports the application of Tier 1 $PM_{2.5}$ emission factors in combination with a Tier 1 black carbon fraction from the GAINS model (Amann et al., 2011). Of the other four Parties, France, Portugal and Romania reported that Tier 2 black carbon emission factors from the 2016 EMEP/EEA Guidebook were applied and were thus judged as applying *Higher Tier* methodologies for the source sector. The United States reported using crop-specific $PM_{2.5}$ emission factors and speciation profiles and were thus also judged as applying *Higher Tier* methodologies.

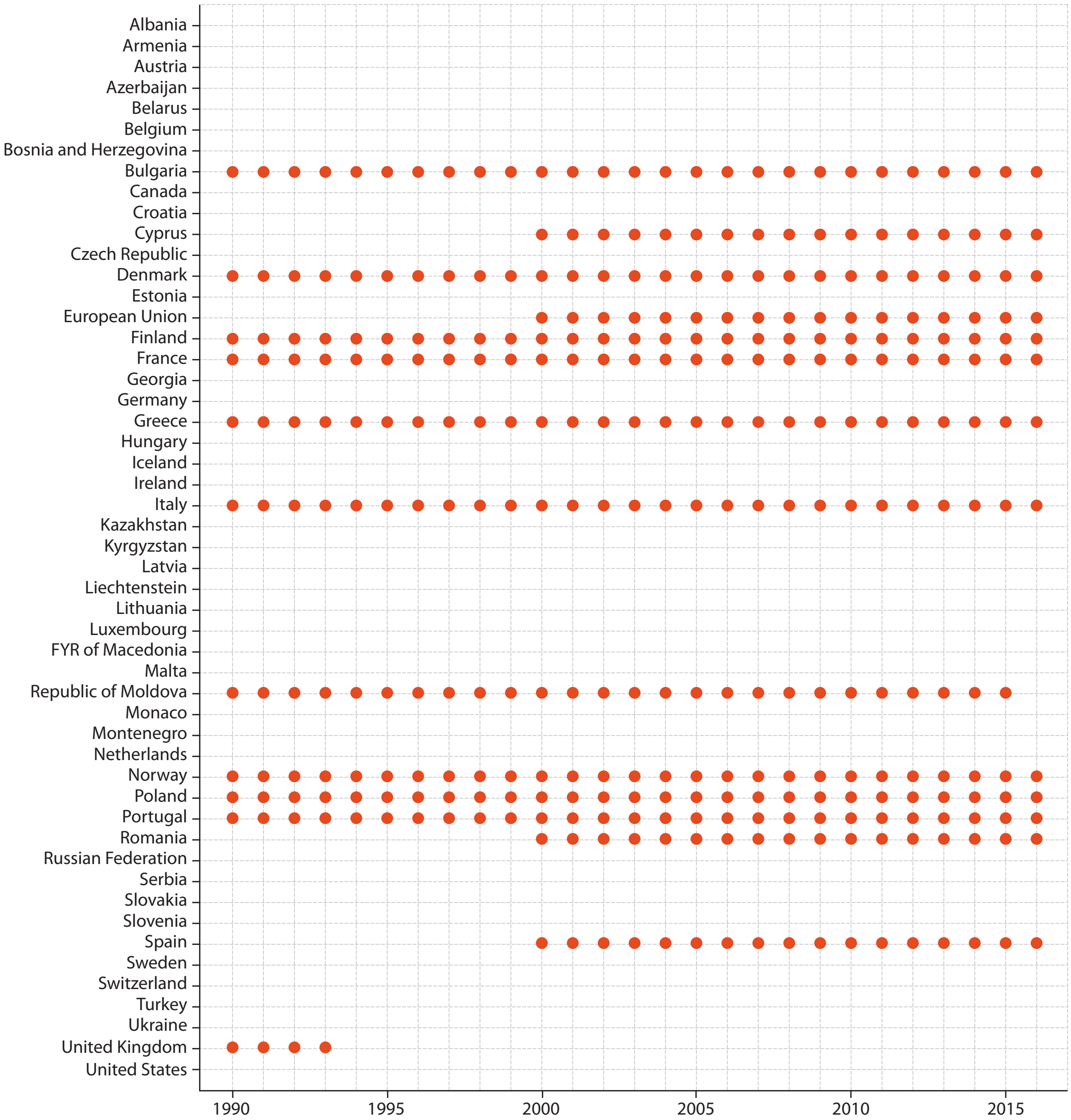

Figure 3.11 Reporting of black carbon emissions from *3.F Field burning of agricultural residues* by CLRTAP Parties. Dots mark the years for which black carbon emissions were reported.

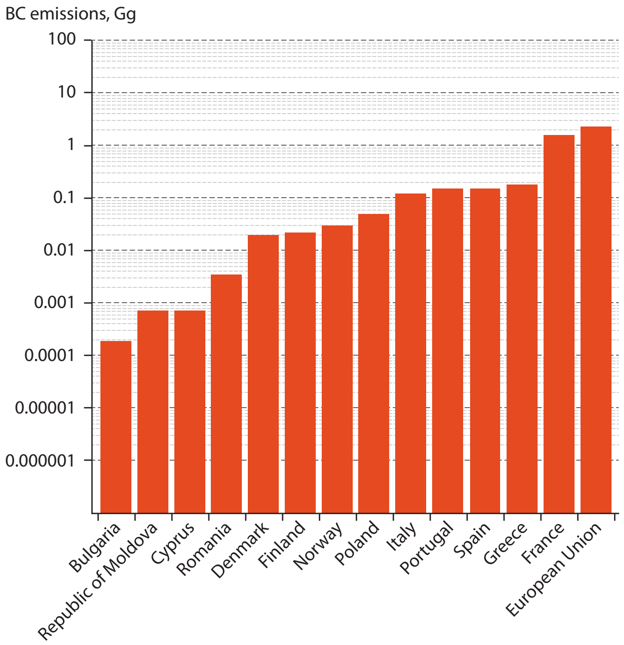

Figure 3.12 Most recent annual estimates of national black carbon emissions from *3.F Field burning of agricultural residues*. For almost all Parties this is the 2016 estimate; Moldova's most recent estimate is for 2015

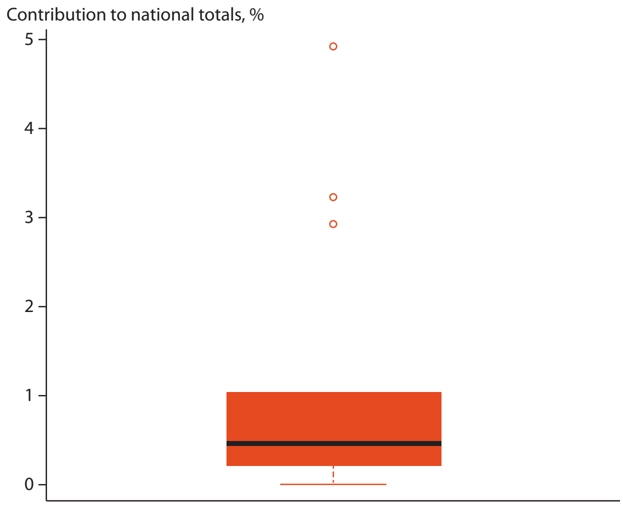

Figure 3.13 Boxplot of the contributions of black carbon emissions from *3.F Field burning of agricultural residues* to total national emissions for the CLRTAP Parties reporting open burning of agricultural waste as well as national total black carbon emissions. The box plots the range between the first and third quartiles, with the second quartile (median) marked by the thick horizontal band. Whiskers plot the lowest datum within 1.5 the interquartile range of the first quartile and the highest datum within 1.5 interquartile range of the third quartile. Circles marks data outside this range.

Table 3.8 Summary of the methods and emission coefficients used by CLRTAP Parties to estimate black carbon emissions from the source sector *3.F Field burning of agricultural residues*. Results were obtained by reviewing the latest Informative Inventory Reports submitted by those Parties reporting black carbon emissions for open burning of agricultural waste.

CLRTAP Party	Informative Inventory Report		Q1: Tier methodology for source sector	Q2: Tier of black carbon emission factors	Q3: Source of the black carbon emission factors	Additional notes	Judgement
	Submission year	Language					
Bulgaria	2018	English	T1	T1	EEA (2016)	-	Lower Tier
Cyprus	2018	English	T1	T1	EEA (2016)	-	Lower Tier
Denmark	2018	English	T1	T1	EEA (2013)	-	Lower Tier
Finland	2018	English	T1	T1	EEA (2016)	-	Lower Tier
France	2018	French	T2	T2	EEA (2016)	-	Higher Tier
Greece	2017	English	T1	T1	EEA (2016)	-	Lower Tier
Italy	2018	English	T1	T1	EEA (2013)	-	Lower Tier
Republic of Moldova	2017	English	T1	T1	EEA (2013)	-	Lower Tier
Norway	2018	English	T1	T1	EEA (2016) / GAINS model	-	Lower Tier
Poland	2018	English	T1	T1	EEA (2016)	-	Lower Tier
Portugal	2018	English	T2	T2	EEA (2016)	-	Higher Tier
Romania	2018	English	T2	T2	EEA (2016)	-	Higher Tier
Spain	2018	English	T1	T1	EEA (2016)	-	Lower Tier
United Kingdom	2018	English	T1	T1	EEA (2016)	-	Lower Tier
United States[a]	2018[b]	English	T2	T2	US SPECIATE Database		Higher Tier

[a]United States report emissions for the source sector *Agricultural Field Burning* according to the country's own inventory system. [b]Information derived for the United States by following IIR reference to the *2014 National Emissions Inventory, version 2 Technical Support Document* and other references therein.

3.1.2.2.5 **Road transport**

Exhaust emissions from road transport are reported to CLRTAP under the following four NFR categories *1.A.3.b.i Road transport: Passenger cars, 1.A.3.b.ii Road transport: Light duty vehicles, 1.A.3.b.iii Road transport: Heavy duty vehicles and buses*, and *1.A.3.b.iv Road transport: Mopeds & motorcycles*. Thirty-five Parties have submitted estimates of black carbon emissions from *1.A.3.b.i-iv Road transport* (Figure 3.14): Armenia, Azerbaijan, Belarus, Belgium, Bulgaria, Canada, Croatia, Cyprus, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Latvia, Lithuania, Malta, Monaco, Netherlands, Norway, Poland, Portugal, Romania, Slovakia, Slovenia, Spain, Sweden, Switzerland, United Kingdom, and the European Union. However, Norway Switzerland, and the Czech Republic have not given explicit estimates for black carbon emissions from mopeds and motorcycles (*1.A.3.b.iv*), while Azerbaijan and Belarus have not given explicit estimates for emissions from either mopeds and motorcycles (*1.A.3.b.iv*) or light duty vehicles (*1.A.3.b.ii*). Armenia has submitted only black carbon emissions estimates for the category passenger cars (*1.A.3.b.ii*). Note that the absence of certain categories may be because the emissions could not be split between vehicle type and are thus *included elsewhere* in one of the reported transport categories. Finally, although the United States has not submitted black carbon emissions data using the NFR reporting template and/or NFR source sector split (see Section 3.1.2.1), the United States *Informative Inventory Report 2018* does detail black carbon

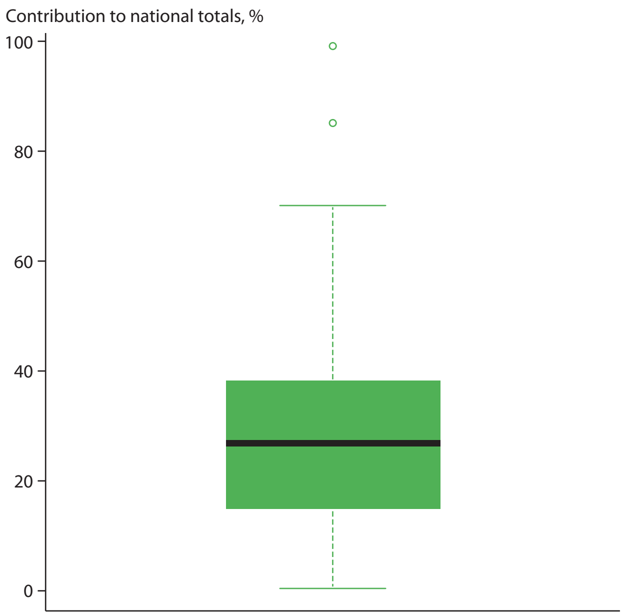

Figure 3.16 Boxplot of the contributions of black carbon emissions from road transport to total national emissions for the CLRTAP Parties reporting *1.A.3.b.i-iv Road transport* as well as national total black carbon emissions. The box plots the range between the first and third quartiles, with the second quartile (median) marked by the thick horizontal band. Whiskers plot the lowest datum within 1.5 the interquartile range of the first quartile and the highest datum within 1.5 interquartile range of the third quartile. Circles marks data outside this range.

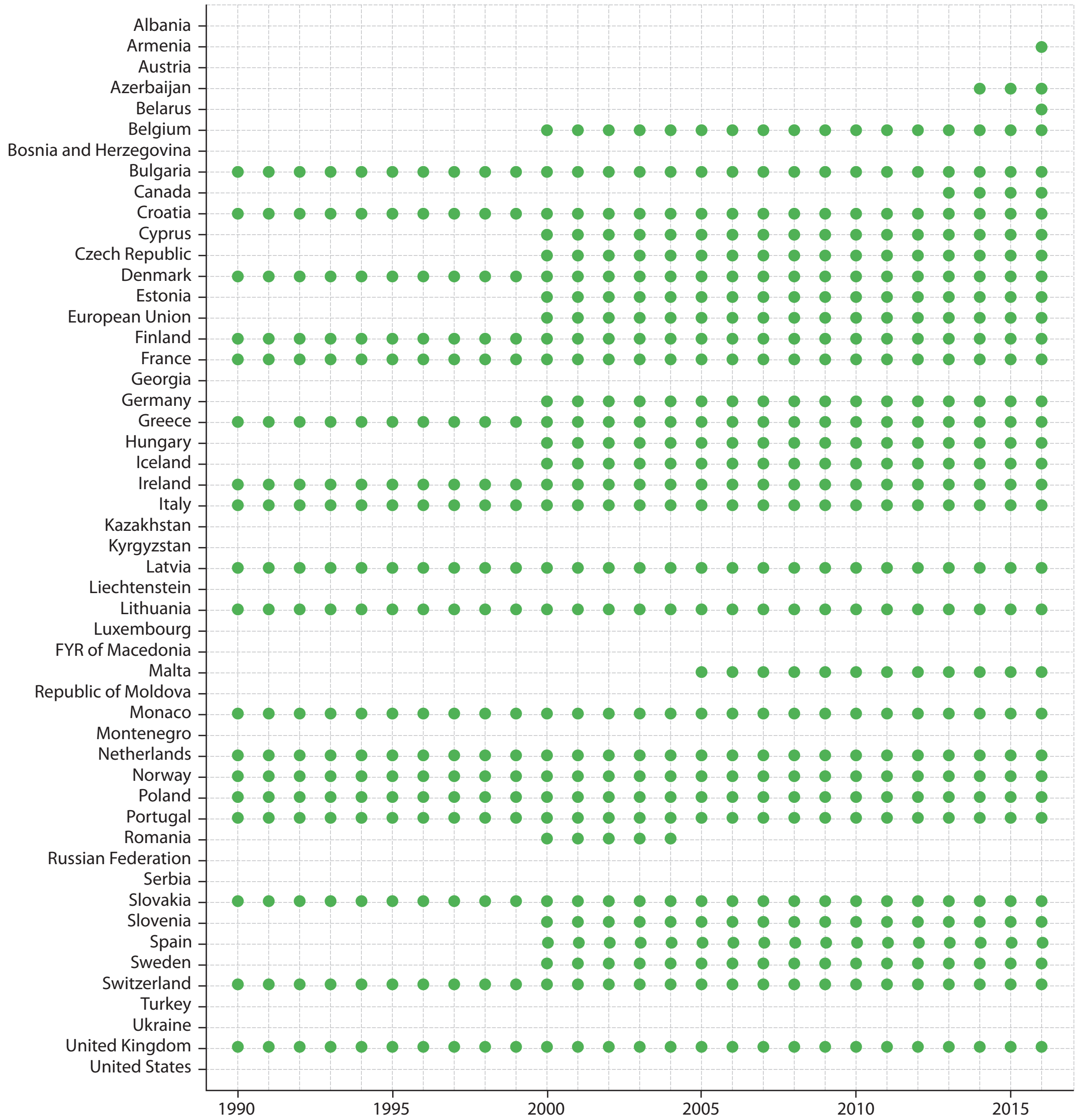

Figure 3.14 Reporting of black carbon emissions from *1.A.3.b.i-iv Road transport* by CLRTAP Parties. Dots mark the years for which black carbon emissions were reported.

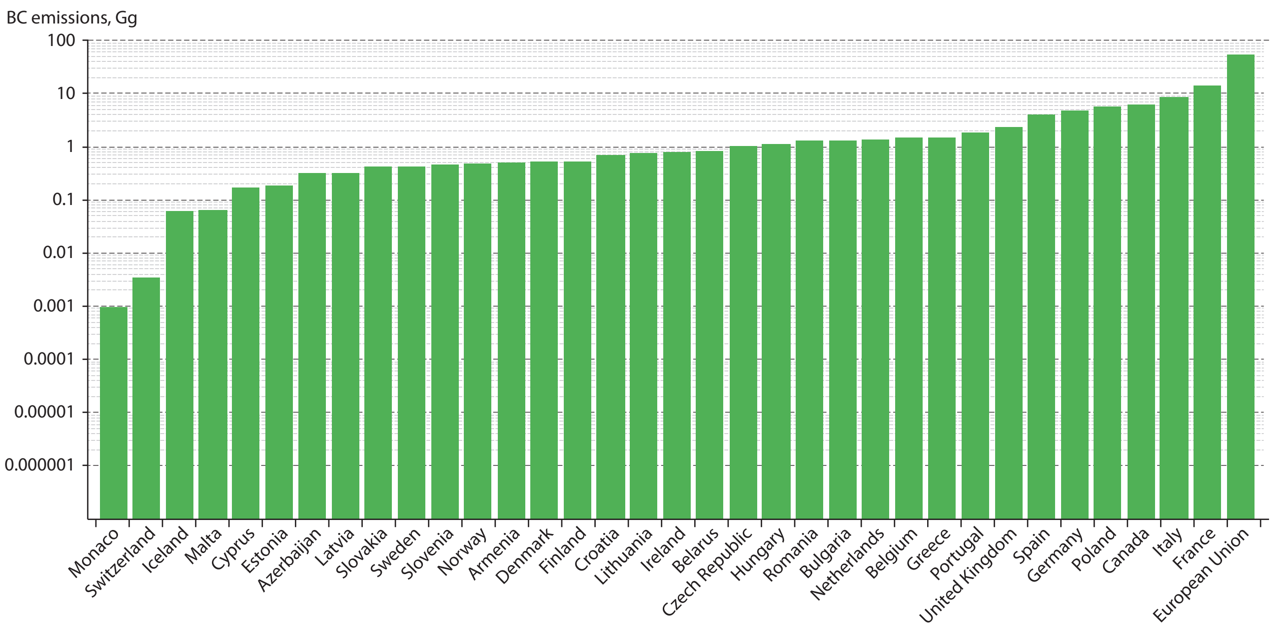

Figure 3.15 Most recent annual estimates of national black carbon emissions from *1.A.3.b.i-iv Road transport*. For almost all Parties this is the 2016 estimate; Romania's most recent estimate is for 2004.

Table 3.9 Summary of the methods and emission coefficients used by CLRTAP Parties to estimate black carbon emissions from the source sector *1.A.3.b.i-iv Road transport*. Results were obtained by reviewing the latest Informative Inventory Reports submitted by those Parties reporting black carbon emissions for road transport.

CLRTAP Party	Informative Inventory Report		Q1: Tier methodology for source sector	Q2: Tier of black carbon fractions	Q3: Source of the black carbon fractions	Additional notes	Judgement
	Submission year	Language					
Armenia	2018	Russian	Insufficient information	Insufficient information	Insufficient information	No source sector methodological descriptions	No judgement
Azerbaijan	2018	English	T1	T1	EEA (2016)	-	Lower Tier
Belarus	2016	English	Insufficient information	Insufficient information	Insufficient information	-	No Judgement
Belgium	2018	English	T3	T2	COPERT v4 / EEA (2016)	T3 Model: COPERT v4	Higher Tier
Bulgaria	2018	English	T2	Insufficient information	COPERT v5 / EEA (2016)	T2 using COPERT v5	Higher Tier
Canada	2018	English	T3	T2	US SPECIATE 4.4 Database	T3 Model: MOVES	Higher Tier
Croatia	2018	English	T2/T3	T1/T2	COPERT v5 / EEA (2016)	T3 Model: COPERT v5	Higher Tier
Cyprus	2018	English	T3	T2	COPERT v5 / EEA (2016)	T3 Model: COPERT v5	Higher Tier
Czech Republic	2018	English	T2	Insufficient information	Country-specific; but no reference	-	Higher Tier
Denmark	2018	English	T3	T2	COPERT v5 / EEA (2016)	T3 Model: COPERT v5	Higher Tier
Estonia	2018	English	T3	T2	COPERT v5 / EEA (2016)	T3 Model: COPERT v5	Higher Tier
Finland	2018	English	T3	T1	EEA (2016)	T3 Model: LIPASTO (LIISA submodel)	Higher Tier
France	2018	French	T3	T2	COPERT v5 / EEA (2016)	T3 Model: COPERT v5 & v4	Higher Tier
Germany	2018	English	T3	Insufficient information	Insufficient information	T3 Model: TREDMOD	Higher Tier
Greece	2017	English	T3	T2	COPERT v4 / EEA (2016)	T3 Model: COPERT v4	Higher Tier
Hungary	2018	English	T3	T2	COPERT v5 / EEA (2016)	T3 Model: COPERT v5	Higher Tier
Iceland	2018	English	T3	T2	COPERT v4 / EEA (2016)	T3 Model: COPERT v4	Higher Tier
Ireland	2018	English	T3	T2	COPERT v5 / EEA (2016)	T3 Model: COPERT v5	Higher Tier
Italy	2018	English	T3	T2	COPERT v5 / EEA (2016)	T3 Model: COPERT v5	Higher Tier
Latvia	2018	English	T3	T2	COPERT v5 / EEA (2016)	T3 Model: COPERT v5	Higher Tier
Lithuania	2018	English	T3	T2	COPERT v4 / EEA (2016)	T3 Model: COPERT v4	Higher Tier
Malta	2018	English	T3	T2	COPERT v5 / EEA (2016)	T3 Model: COPERT v5	Higher Tier
Monaco	2018	French	T2	Insufficient information	EEA (2016)	-	Higher Tier
Netherlands	2018	English	T3	Insufficient information	VERSIT+ & PHEM models	T3 Model: VERSIT+ & PHEM	Higher Tier
Norway	2018	English	T3	T2	HBEFA model/ Kupiainen and Klimont (2004)	T3 Model: HBEFA	Higher Tier
Poland	2018	English	T3	T2	COPERT v5 / EEA (2016)	T3 Model: COPERT v5	Higher Tier
Portugal	2018	English	T3	T2	COPERT v5 / EEA (2016)	T3 Model: COPERT v5	Higher Tier
Romania	2018	English	T1 (-2004) / T3(2004-)	T1	EEA (2016)	T3 Model: COPERT v4	Lower Tier

CLRTAP Party	Informative Inventory Report		Q1: Tier methodology for source sector	Q2: Tier of black carbon fractions	Q3: Source of the black carbon fractions	Additional notes	Judgement
	Submission year	Language					
Slovakia	2018	English	T3	T2	COPERT v5 / EEA (2016)	T3 Model: COPERT v5	Higher Tier
Slovenia	2018	English	T3	T2	COPERT v4 / EEA (2016)	T3 Model: COPERT v4	Higher Tier
Spain	2018	English	T3	T2	COPERT v5 / EEA (2016)	T3 Model: COPERT v5	Higher Tier
Sweden	2018	English	T3	Insufficient information	HBEFA model	T3 Model: HBEFA	Higher Tier
Switzerland	2018	English	T3	Insufficient information	Insufficient information	T3 Model: PHEM	Higher Tier
United Kingdom	2018	English	T3	T2	COPERT v5 / EEA (2016)	T3 Model: COPERT v5 & v4	Higher Tier
United States[a]	2018[b]	English	T3	T2	Model-inherent speciation profile	T3 Model: MOVES	Higher Tier

[a]United States report emissions for the source sector *Mobile Onroad* according to the country's own inventory system. [b]Information derived for the United States by following IIR reference to the 2014 National Emissions Inventory, version 2 Technical Support Document and other references therein.

emissions for the aggregated category *Mobile Onroad* (63 Gg BC in 2014) using its own source sector split.

Summing the available categories for each reporting Party, the most recent annual emissions estimates for *1.A.3.b.i-iv Road transport* range from about 1 Mg BC (Monaco) to 54 Gg BC (European Union) (Figure 3.15). The percentage contribution of this source to national total black carbon emissions ranges from 0.3% (Switzerland) to 99% Armenia (Figure 3.16); however, the case of Armenia is likely to reflect that this source is one of the four source sectors that the Party reports. Figure 3.15 nonetheless illustrates that the sector is typically significant, with the interquartile range in percentage contribution to national totals between about 15% and 38%.

According to the IIRs, it seems that *Higher Tier* methodologies for estimating black carbon emissions from road transport have been applied by most CLRTAP Parties reporting black carbon emissions for this source sector (Table 3.9). Excluding the European Union as a reporting Party, of the 35 Parties reporting black carbon emissions from road transport, only two (Azerbaijan, Romania) were judged to have applied a *Lower Tier* methodology. Both report using Tier 1 methods and fractions from the 2016 EMEP/EEA Guidebook. Except for Armenia and Belarus, for whom no judgement on the source sector methods could be made due to the lack of methodological descriptions in the respective IIRs, the remaining 31 reporting Parties were judged to have applied *Higher Tier* methodologies for estimating black carbon emissions from road transport.

Three *Higher Tier* methodology Parties (Bulgaria, Czech Republic, Monaco) reported using a Tier 2 sector methodology but did not specify whether Tier 1 or Tier 2 splits in the black carbon fractions were applied. Nonetheless, given that the particulate matter emissions, from which black carbon emissions are derived, take into account fuel-, vehicle- and engine type, the methodologies applied by these Parties were judged as *Higher Tier*. While the Tier for black carbon fractions could not be determined, it was possible to infer where the fractions were sourced: EMEP/EEA Guidebook (Bulgaria, Monaco) and country-specific fractions (Czech Republic).

The remaining 28 *Higher Tier* methodology Parties reported using Tier 3 transport emissions models, which at least for particulate matter emissions, also take into account different engine operating states and driving conditions (see Section 2.1.2.2.5). In many cases the Tier of the black carbon fractions was not given explicitly. For the 20 Parties employing the COPERT model[15] (Belgium, Croatia, Cyprus, Denmark, Estonia, France, Greece, Hungary, Iceland, Ireland, Italy, Latvia, Lithuania, Malta, Poland, Portugal, Slovakia, Slovenia, Spain, United Kingdom), Tier 2 black carbon fractions from the 2016 EMEP/EEA Guidebook were assumed given that it is the COPERT methods that are described in EMEP/EEA Guidebook subchapter *1.A.3.b.i-iv Exhaust emissions from road transport*. However, for Germany (Tier 3 Model: TREDMOD[16]), the Netherlands (Tier 3 Models: VERSIT+[17] and PHEM[18]), Sweden (Tier 3 Model: HBEFA[19]) and Switzerland (Tier 3 Model: PHEM), the Tier of the black carbon fractions could not be inferred.

Three Parties applying Tier 3 methodologies did specify the Tier of the black carbon emissions factors used. Finland reported applying Tier 1 black carbon fractions (2016 EMEP/EEA Guidebook) to the particulate matter emission output from the Tier 3 model LIPASTO[20], while Canada (Tier 3 Model: MOVES[21]) and Norway (Tier 3 Model: HBEFA) reported applying Tier 2 fractions sourced from the US SPECIATE Database and Kupiainen and Klimont (2004), respectively. The United States reported using the MOVES model with the in-built $PM_{2.5}$ speciation profiles to estimate their road transport black carbon emissions.

[15] https://www.emisia.com/utilities/copert/
[16] https://www.ifeu.de/methoden/modelle/tremod/
[17] https://www.tno.nl/media/2451/lowres_tno_versit.pdf
[18] https://www.ivt.tugraz.at/en/emissions.html
[19] http://www.hbefa.net/e/index.html
[20] http://lipasto.vtt.fi/en/index.htm
[21] https://www.epa.gov/moves

3.2 Arctic Council

In the 2015 and 2017 national reporting, all Arctic Council Member States (Russia only for 2015) and most (10 out of 13) Observer States have some level of black carbon emission data available. Most of the Member States that report black carbon emissions to CLRTAP have directly used that information in their national reports, often aggregated to key sectors utilising for instance the GNFR level. For example, Canada, Denmark, Finland, Iceland, Norway and Sweden report using the NFR structure while Russia and the United States have used their own sectoral distributions in reporting emissions. Of the Observer States, France, Germany, Italy, Japan, Netherlands, Poland, Spain, Switzerland, and the United Kingdom have NFR emissions available. Japan and South Korea, that are not Parties to CLRTAP, have provided black carbon emissions data. Of the Arctic Council Observer States, China, India and Singapore have not provided black carbon emissions data. As most countries reporting to the Arctic Council use the CLRTAP reports, observations on the Tier levels used made in previous sections also apply to reporting to the Arctic Council. Countries that are not signatories to CLRTAP are recommended to use the same CLRTAP methodologies in their reporting to the Arctic Council.

3.3 Comparison of emissions reported to CLRTAP and the Arctic Council with independent emissions inventory datasets

Four independent black carbon emission inventories for the Arctic Council Member States and Observer States were compared to the reported emissions to CLRTAP/Arctic Council. The inventories were EDGAR v4.3.2, TNO MACC-III, ECLIPSEv5a and the latest GAINS model estimates. Emissions were compared for 2010, as this was a common year for all inventories, except for TNO MACC-III for which 2011 was used.

The Emissions Database for Global Atmospheric Research (EDGAR v4.3.2) is an air pollution emission inventory developed at the Joint Research Centre (Janssens-Maenhout et al., 2017; Crippa et al., 2018). It consists of gridded global anthropogenic gaseous and particulate emissions for the period 1970–2012. The inventory is based on publicly available statistics, and is aimed for use in atmospheric models and policy evaluation. Emissions are aggregated into 26 sectors for nine substances on a 0.1° × 0.1° spatial resolution. The data are available via the EDGAR website[22]. The activity data used are from the International Energy Agency (IEA), Food and Agriculture Organization Statistics Division (FAOSTAT), U.S. Geological Survey (USGS) and United Nations Statistics Division (UN STATS). The emission factors are mostly based on the 2013 EMEP/EEA Guidebook (EEA, 2013).

The TNO MACC-III (Monitoring Atmospheric Composition and Climate) air pollution emission dataset (Kuenen et al., 2014) is developed at the Netherlands Organisation for applied scientific research, TNO. It contains gridded anthropogenic emissions for Europe for the period 2000–2011. The inventory was originally developed for the MACC project for use in atmospheric composition modelling. The emissions are based on reported emissions to EMEP, and checked and gap-filled with emissions reported to CEIP, the GAINS model, EDGAR and finally TNO's own calculations. Black carbon (as fine and coarse mode elemental carbon) emissions are included as country- and sector-specific share of $PM_{2.5}$.

ECLIPSEv5a is an emission dataset developed at the International Institute of Applied Systems Analysis (Klimont et al., 2017) with the GAINS (Greenhouse gas and Air pollution Interactions and Synergies) model (Amann et al., 2011). The dataset contains gridded global emissions from 1990 to 2010 with projections to 2050. Beyond ECLIPSE, the latest global GAINS emission dataset was also included in the comparison; the latter can be seen as an update of ECLIPSE since it makes use of most recent statistical data, includes new methodological developments, and for Europe also incorporates results of the Clean Air Outlook study (Amann et al., 2018). The GAINS emissions are developed to be used in air quality, climate modelling and health impact assessments, and have been used in the ECLIPSE project and beyond. In GAINS, the activity data are based on statistics from IEA, Eurostat, FAO, and several national sources. The emission factors are based on extensive and ongoing literature review.

3.3.1 Total emissions from independent inventories

Total black carbon emissions for the Arctic Council Member States and Observer States from the inventories are presented in Table 3.10 and Figure 3.17. $PM_{2.5}$ emissions are presented in Table 3.11 and Figure 3.18.

EDGAR had systematically the lowest black carbon emissions per country, partly due to differences in sectors included in the inventory. For example, large-scale biomass burning, super-emitting vehicles and resuspension, and traffic dust emissions. In contrast, TNO MACC-III had the highest emissions. The differences between EDGAR and TNO MACC-III were over 50% in each county except for the United Kingdom, and total emissions from European countries were 72% smaller in EDGAR. ECLIPSEv5a estimates were closest to the emissions reported to CLRTAP. The greatest variations country-wise were for Poland and Russia. China and India had the highest black carbon emissions, followed by the United States and Russia. Only EDGAR, ECLIPSE and GAINS include estimates for all Arctic Council Member States, and for them emissions from ECLIPSE were more than double those of EDGAR. For Observer States, emissions from ECLIPSE were 58% higher than from EDGAR.

Reported $PM_{2.5}$ emissions to CLRTAP for Canada presented in Table 3.11 and Figure 3.18 are for 2014. Although the total reported $PM_{2.5}$ emission was 1646 kt, Table 3.11 and Figure 3.18 show emissions excluding sources not accounted for in other countries. These were $PM_{2.5}$ from wind erosion, prescribed forest burning, paved and unpaved roads, construction dust, and crop production. These sectors accounted for 1310 kt of $PM_{2.5}$, and were taken out to increase the comparability of the numbers. The latest GAINS $PM_{2.5}$ emissions for Canada include emissions from the pulp industry that are overestimates, that will be corrected in the future.

[22] http://edgar.jrc.ec.europa.eu/overview.php?v=432_AP&SECURE=123

Table 3.10 Total black carbon emissions for 2010 (unless marked otherwise) in kilotons.

Country	CLRTAP	EDGAR 4.3.2	TNO MACC-III[a]	ECLIPSEv5a	GAINS
Canada	43.0[b]	26.1		48.0	49.7
China		1304.9		1914.3	1308.6
Denmark	5.6	2.4	7.9	4.8	4.6
Finland	6.3	5.1	15.3	6.9	7.6
France	48.3	22.9	75.0	60.7	56.4
Germany	20.8	18.6	45.2	30.3	27.5
Iceland	0.2	0.1	0.1	0.1	0.2
India		597.3		1030.7	1065.0
Italy	32.7	18.7	42.0	31.9	41.0
Japan	22.0[c]	23.1		29.4	23.6
Republic of Korea	13.4[b,c]	15.7		29.1	21.2
Netherlands	5.4	2.8	7.0	6.3	5.7
Norway	4.6	3.5	8.1	3.8	6.5
Poland	23.3	18.9	108.0	57.1	60.6
Russia		27.3	187.1	171.2	152.8
Singapore		1.9		3.7	2.2
Spain	43.9	18.0	33.7	33.3	34.4
Sweden	3.9	3.0	11.7	4.9	4.5
Switzerland	1.7	2.1	5.6	1.6	2.01
United Kingdom	27.2	14.0	23.3	20.4	28.2
United States	315.0[b]	137.9		200.8	217.7
Total		2264.3		3689.3	3098.6
Europe		157.3	569.7	433.4	431.9
Arctic Council		205.3		440.4	443.5
Observers		2058.9		3248.9	2655.2

[a]2011 emissions; [b]2014 emissions; [c]from national reports for the Arctic Council.

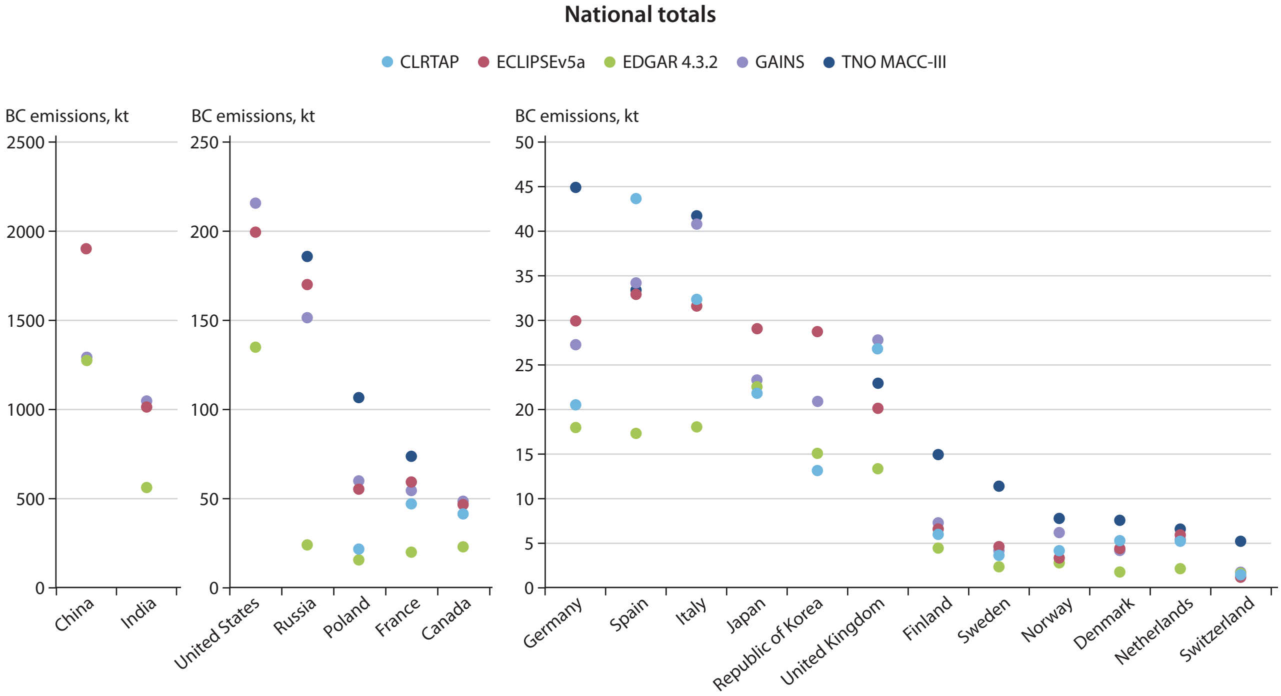

Figure 3.17 Total black carbon emissions. The data are for 2010, except for TNO MACC-III which used 2011 data and Canada and the Republic of Korea under CLRTAP which are for 2014. The United States CLRTAP value for 2014 (315 kt) is not shown on the graph.

Table 3.11 Total $PM_{2.5}$ emissions for 2010 (unless marked otherwise) in kilotons.

Country	CLRTAP	EDGAR 4.3.2	TNO MACC-III[a]	ECLIPSEv5a	GAINS
Canada	336.0[b]	225.1		238.0	715.9[c]
China		11104.7		16019.2	9489.3
Denmark	25.0	21.4	34.5	28.5	26.7
Finland	26.4	51.6	67.5	33.8	39.0
France	214.5	199.3	390.3	217.3	219.0
Germany	121.0	137.9	191.2	120.2	113.9
Iceland	1.4	1.6	1.8	1.3	1.4
India		5863.9		6109.8	6094.3
Italy	196.2	139.9	199.9	138.3	196.2
Japan	112.9[d]	146.8		159.6	140.7
Republic of Korea		130.2		146.9	115.3
Netherlands	17.0	15.0	27.1	21.5	19.6
Norway	37.9	27.9	39.1	43.3	41.3
Poland	162.9	216.5	319.9	261.9	292.9
Russia	349.1	363.0	1012.5	1371.3	1175.2
Singapore		15.3		15.2	7.1
Spain	141.1	100.1	151.7	132.0	154.4
Sweden	23.3	31.9	54.5	30.5	27.0
Switzerland	8.3	17.9	17.6	7.4	8.4
United Kingdom	121.9	79.8	79.3	79.8	109.7
United States	4088.0[e]	1313.9		1028.6	1260.0
Total		20203.7		26204.5	20131.9
Europe		1403.9	2587.0	2487.2	2424.7
Arctic Council		2036.5		2775.2	3286.5
Observers		18167.1		23429.3	16845.4

[a]2011 emissions; [b]2014 emissions, excluding reported emissions on wind erosion, prescribed forest burning, paved and unpaved roads, construction dust, and crop production; [c]includes overestimated emissions from pulp industry, will be corrected in future; [d]from national reports for the Arctic Council; [e]2014 emissions.

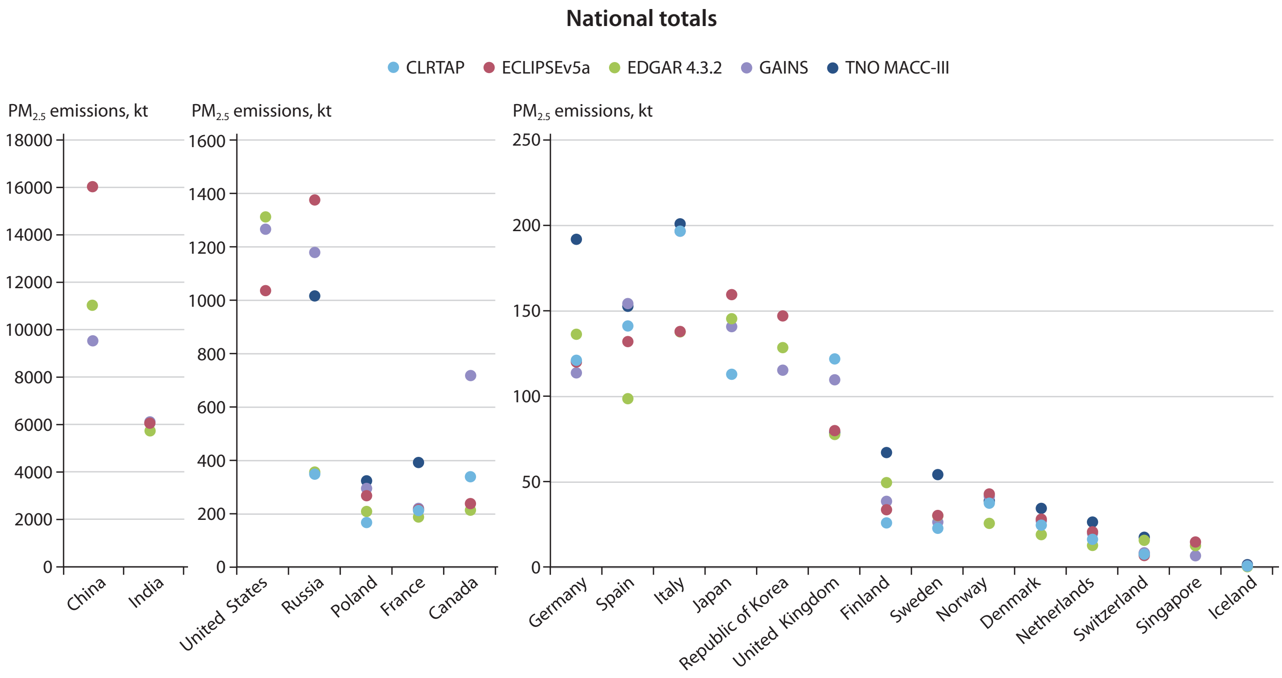

Figure 3.18 $PM_{2.5}$ emissions. The data are for 2010, except for TNO MACC-III which used 2011 data and Canada under CLRTAP which are for 2014. The United States CLRTAP value for 2014 (4088 kt) is not shown on the graph.

Appendix A3 to this report presents black carbon and $PM_{2.5}$ emissions globally and for several countries as reported by various studies, and collated by Klimont et al. (2017). The authors identified several important sectors that are addressed differently across studies. Kerosene lamps are included in the GAINS model, but often omitted in earlier studies. The inclusion of gas flaring, and the methods used in the emission calculation vary. Open waste burning emissions have large uncertainties, as well as large variability in the estimates. These sectors in particular require more attention from the scientific community and compilers of inventories in the future.

3.3.2 Analysis of sectoral emissions from independent inventories

The inventories available follow different source category nomenclatures. Emissions reported to CLRTAP are in NFR format, similar to EDGAR, but a slightly different version. TNO MACC–III emissions are summarised in SNAP (Selected Nomenclature for sources of Air Pollution) categories (ten sectors broadly compatible with aggregated GNFR level). The GAINS model (also used for ECLIPSEv5a) has its own very detailed structure, but for comparison purposes emissions can be exported in several formats including SNAP and NFR; for ECLIPSEv5a the aggregated sectors used for gridding were applied and these are compatible with the IPCC key sectors (nine categories similar to SNAP). This variability affects sectoral comparison, because some discrepancies are caused by the different source structure. In order to make comparison more consistent, emissions were aggregated into six sectors: road transport; machinery, energy and industry; residential combustion; flaring; and 'other' (such as agriculture, waste treatment and disposal, solvent use). For the TNO MACC-III dataset, emissions for flaring are included in SNAP sector 9 (waste), which as well as flaring contains waste treatment and disposal.

Black carbon emissions from road transport (Figure 3.19) showed the smallest variation between inventories, and the differences were mostly systematic. Emissions were consistently

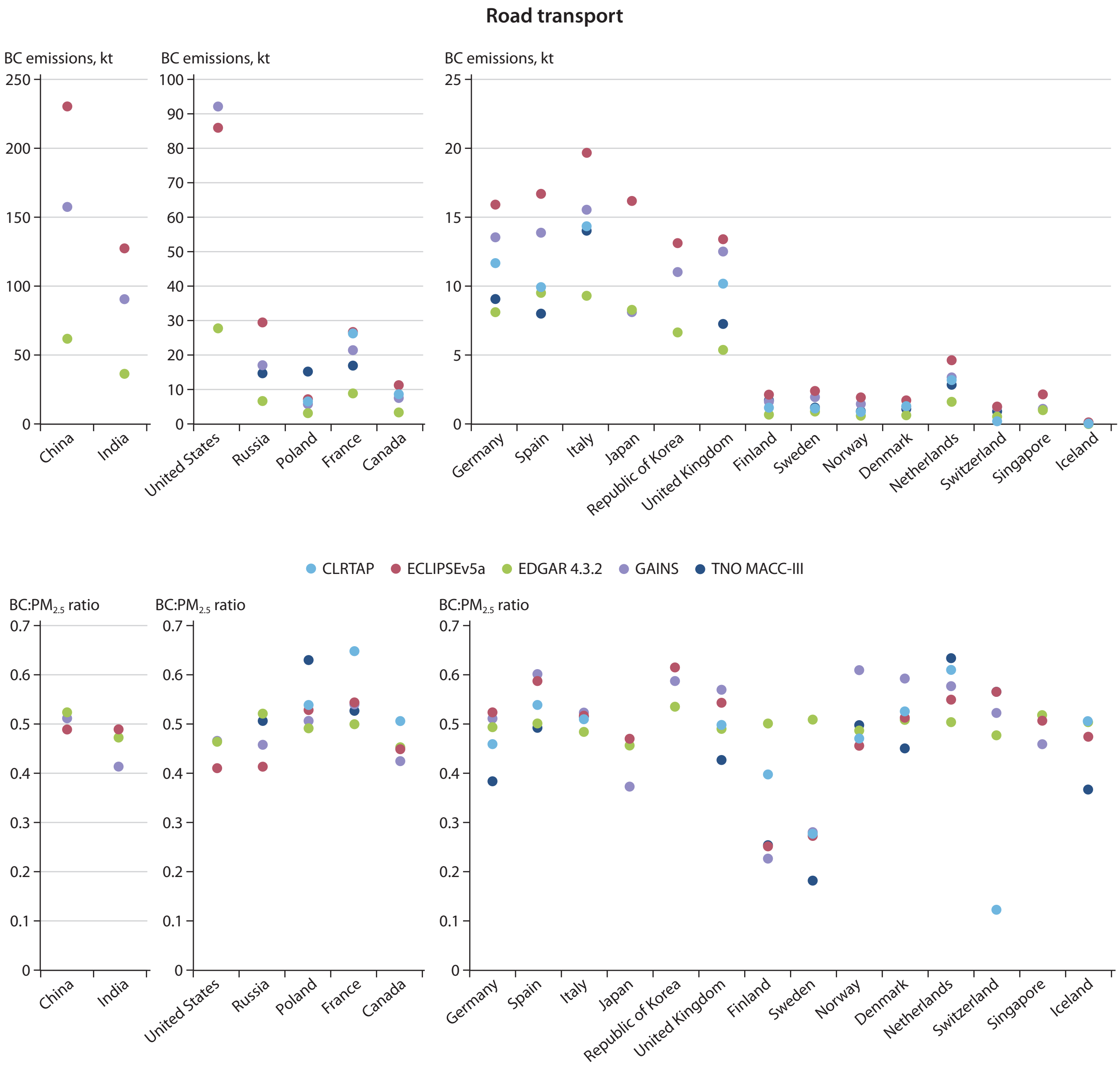

Figure 3.19 Comparison of 2010 black carbon emissions and $BC:PM_{2.5}$ ratios for road transport. The data are for 2010, except for TNO MACC-III which used 2011 data and Canada under CLRTAP which are for 2014.

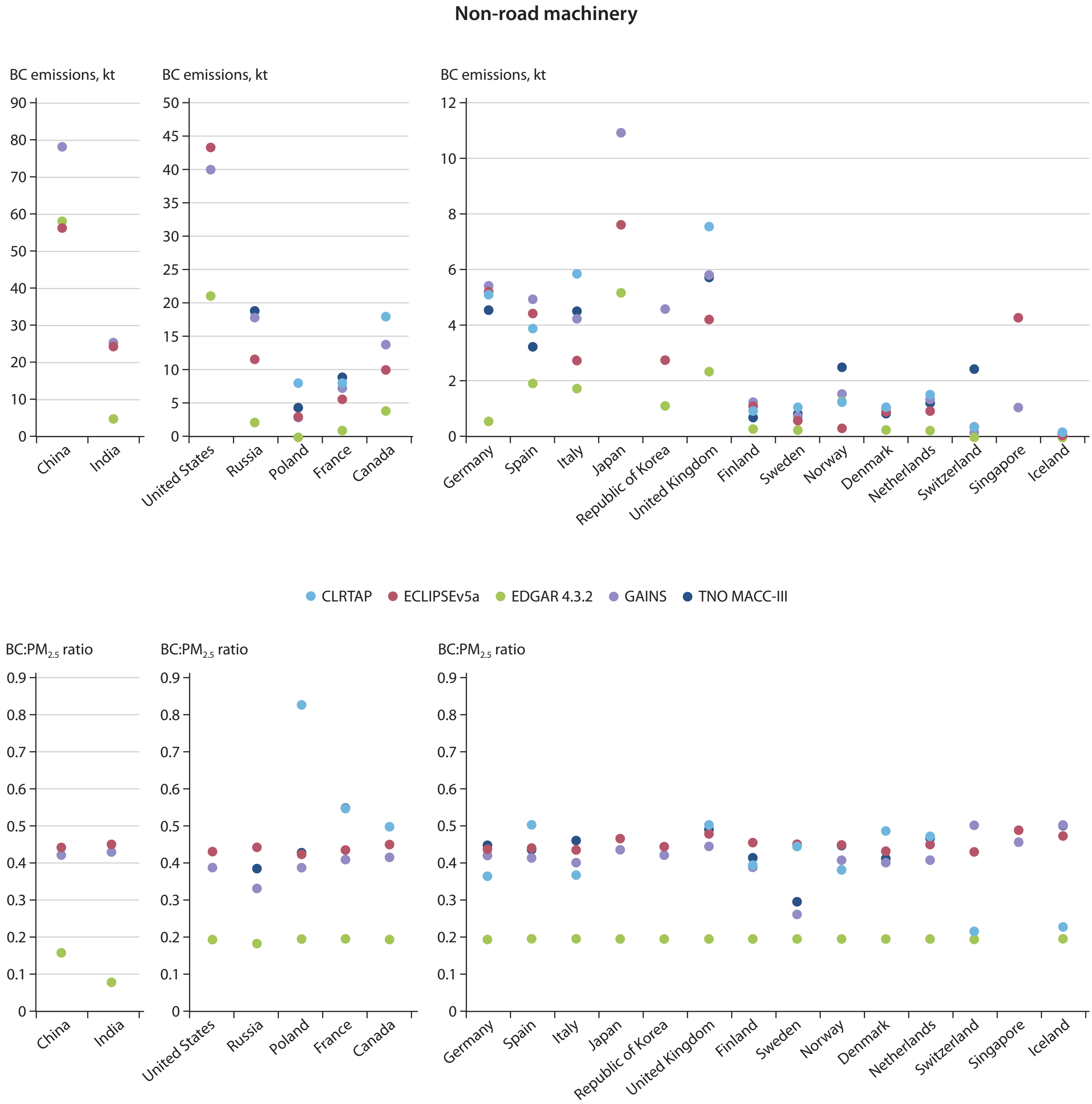

Figure 3.20 Comparison of 2010 black carbon emissions and BC:$PM_{2.5}$ ratios for non-road machinery. The data are for 2010, except for TNO MACC-III which used 2011 data and Canada under CLRTAP which are for 2014.

lower for EDGAR, but were otherwise relatively similar between inventories. *Higher Tier* methodologies are often used in road transport emission calculation, and similar estimates show the advantage of using *Higher Tier* methodologies over *Lower Tier* methodologies. An exception is Switzerland, for which reported CLRTAP emissions were four times lower than the next lowest estimation. As stated in Section 3.1.2.2.5, Switzerland used *Higher Tier* methodology for its road transport black carbon emission calculation, but the black carbon fraction used was unclear, so the reason for the difference is difficult to identify.

Black carbon emissions for non-road machinery show higher variation than road transport (cf. Figures 3.19 and 3.20). However, the differences between inventories were mostly systematic in this sector too. As seen from the BC:$PM_{2.5}$ ratios, those used by EDGAR were almost constant in each country (Figure 3.20), and lower than for the other inventories. GAINS also had lower variation in the BC:$PM_{2.5}$ ratios than for CLRTAP and EDGAR. This is partly due to limited availability of good emission factors for machinery. CLRTAP showed most variation. One outlier in the data was the BC:$PM_{2.5}$ ratio for Switzerland in TNO MACC-III. The coarse fraction (black carbon particles over 2.5 μm) was relatively high, causing the total black carbon emission to be higher than the total $PM_{2.5}$ from machinery. This was not seen in other countries, where black carbon emission was lower than $PM_{2.5}$. Allocating emissions to machinery may differ between inventories and even between country reports, because agricultural machinery might for example be included either in the machinery/off-road or agricultural sector.

For residential combustion (household heating, cooking, lighting, commercial and agricultural heating) the inventories showed a range of methods to estimate the activity (amount of combusted fuel) and allocation between technologies. EDGAR relied on IEA statistics on fuel use, and generic data from a

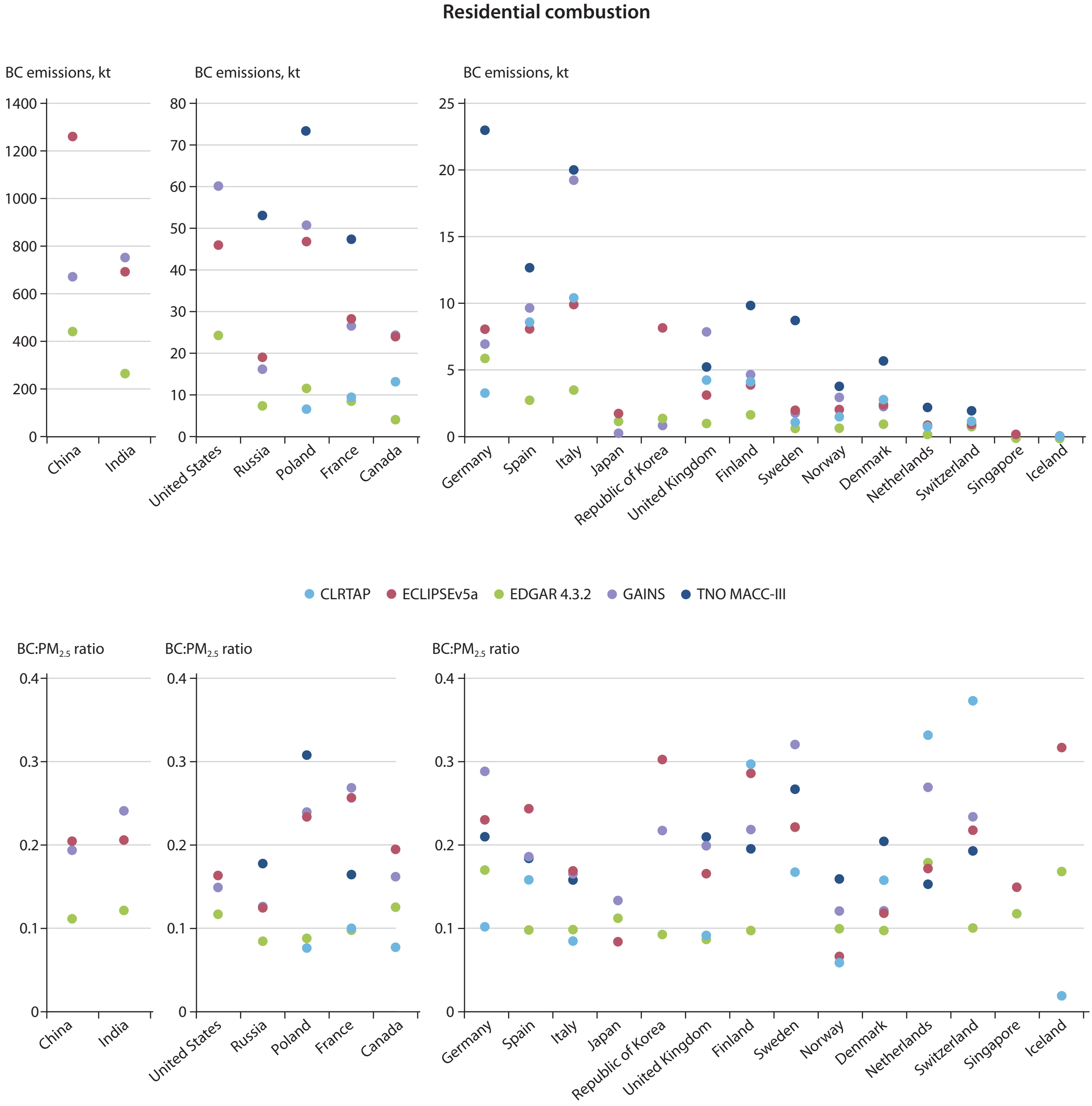

Figure 3.21 Comparison of 2010 black carbon emissions and BC:$PM_{2.5}$ ratios for residential combustion. The data are for 2010, except for TNO MACC-III which used 2011 data and Canada under CLRTAP which are for 2014.

small number of national statistics on the technological division. GAINS bases its estimates on a mix of sources (including international and national statistics) and their own assessment, and in Europe consultations with national experts were used. For wood fuel use and technology division, TNO MACC-III used the GAINS estimates, and IEA statistics when GAINS data were lacking, as a starting point. The activity data were modified using their own method based on their own wood availability assessment. The technology division used has a major impact on total emissions, since different appliances show large variation in terms of emission factors.

EDGAR had the lowest emissions from residential combustion (Figure 3.21), possibly at least partly due to its use of official statistics as activity data. Residential wood fuel use statistics in Europe do not show the full picture, as much of the wood can be obtained outside official vendors, and so is not shown in official statistics. TNO MACC-III had the highest emissions for most countries. The inventory's own wood fuel use estimation method seems to give higher activity values than other methods relying on statistics and national expert assessments. The CLRTAP emissions usually fell between the estimates given by the independent inventories, being often close to the GAINS numbers. TNO MACC-III and GAINS used appliance-specific emission factors based on literature reviews, while EDGAR relied on the 2013 EMEP/EEA Guidebook (EEA, 2013). On average, EDGAR had lower BC:$PM_{2.5}$ ratios than the other inventories, although for CLRTAP there was large variation in the ratio between different countries (Figure 3.21). The EMEP/EEA Guidebook offers general $PM_{2.5}$ emission factors for different residential combustion appliances, as well as BC:$PM_{2.5}$ ratios to derive black carbon emissions. However, the $PM_{2.5}$ emission factors do not reflect the differences between countries in terms of appliances used, and this uncertainty is carried through into the black carbon emissions due to the use of the black carbon fraction from $PM_{2.5}$.

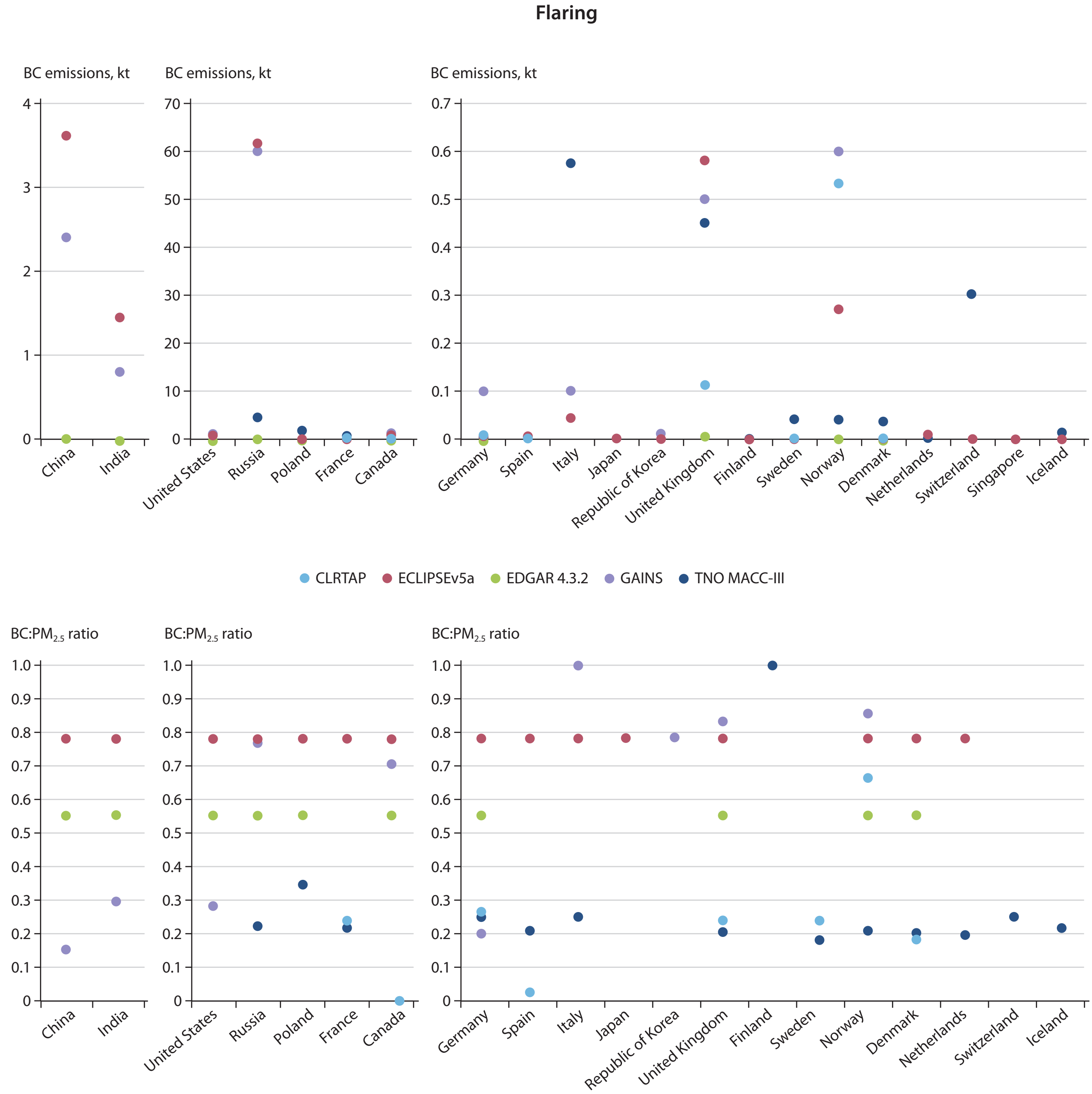

Figure 3.22 Comparison of 2010 black carbon emissions and BC:$PM_{2.5}$ ratios for flaring. The data are for 2010, except for TNO MACC-III which used 2011 data and Canada under CLRTAP which are for 2014.

For flaring, EDGAR uses NOAA satellite observations to estimate activity data (amount of gas flared). TNO MACC-III based its emission estimate on emissions reported to EMEP or GAINS (EDGAR is used for few countries outside the scope of this report), depending on availability. GAINS flaring activity data are based on data developed in the World Bank Group's Global Gas Flaring Reduction Partnership initiative, which is based on NOAA satellite observations and subsequent NASA MODIS Fire detection products (Elvidge et al., 2011).

Black carbon emissions from flaring showed large variation between inventories (Figure 3.22). ECLIPSE and GAINS had the highest emission estimates from flaring. CLRTAP emissions were mostly significantly lower than the GAINS estimates, if reported at all. There were also large differences between the activity (gas flared) estimates as well as the emission factors used. EDGAR had constant BC:$PM_{2.5}$ ratios for all countries (Figure 3.22), while the newer version of GAINS takes into account differences in the composition of gas flared and so the emission factor applied varies between regions. The official statistics for flared gas volumes are incomplete or uncertain, and inventories therefore rely on satellite observations to derive volume data. This method has uncertainties, for example due to how observations (infrared radiation intensity) are converted to gas volumes and how many flares are observed and identified correctly. An important component adding to overall uncertainty is that the emission factors lack comprehensive measurements for different gas compositions and flaring conditions, and are based on very few studies.

While the emissions are not consistent between inventories, it is valuable to have different estimates to compare and assess the differences. Independent inventories provide a range of values which helps to interpret the reported emissions and other estimates. Furthermore, investigating the causes of discrepancies between the various emissions estimates can help improve both official and independent inventory systems.

Table 3.12 Black carbon emissions from Arctic shipping from independent inventories and assessments.

Assessment	Year	Arctic definition	BC emission [kton]	Reference
Corbett	2004	Arctic Council, AMSA	1.23	Corbett et al. (2010)
Peters	2004	Extended AMAP definition	1.15	Peters et al. (2011)
RCP2.6	2005	>60°N	2.00	van Vuuren et al. (2007)
	2010		1.57	
Winther	2012	>58.95°N	0.71	Winther et al. (2017)
	2013		0.73	
	2014		0.86	
	2015		0.65	
	2016		0.56	
ICCT	2015	>58.95°N	1.45	Comer et al. (2017)
	2015	IMO Arctic	0.19	

3.3.3 Emissions from independent shipping inventories

International shipping emissions are often estimated separately from national emissions, because activity in international waters is not allocated to specific countries. There are several emission inventories including Arctic shipping as well as separate assessments. Definition of the Arctic area, coverage of the shipping activities and the subject year vary between the assessments, making comparisons difficult.

Five assessments with gridded emissions were compared in this report. Corbett et al. (2010) presented Arctic shipping emissions under existing and future scenarios up to 2050. Peters et al. (2011) considered shipping and petroleum activities in the Arctic now and projections for 2030 and 2050. The IPCC RCP2.6 scenario (van Vuuren et al., 2007) represents a pathway for global emissions to reach a radiative forcing of 2.6 W/m^2 by 2100. It includes global shipping emissions as part of the overall assessment. Winther et al. (2017) presents Arctic shipping emissions for the period 2012–2016 and future projections until 2050. The International Council on Clean Transportation (ICCT) (Comer et al., 2017) estimated heavy fuel oil and other fuel use and air pollution emissions in 2015 by ships operating in the Arctic, with three different definitions of Arctic region (two of which are included here).

Table 3.12 compares the spatial coverage and black carbon emissions from the five assessments. The most notable differences in terms of activity coverage were that Peters et al. (2011) did not include passenger and fishing vessels, and that Winther et al. (2017) included vessels using AIS (Automatic Information System). The AIS data provide ship-specific type, route and engine use information. With regard to spatial extent, Corbett et al. (2010) used the Arctic Council AMSA (Arctic Marine Shipping Assessment) definition of the Arctic, while Peters et al. (2011) followed that of the Arctic Monitoring and Assessment Programme (AMAP). Winther et al. (2017) defined the Arctic as those areas north of 58.95°N, which includes part of the Baltic Sea and excludes areas in the North Atlantic and south of the Bering Strait covered by the AMAP and AMSA definitions. ICCT (Comer et al., 2017) included areas north of 58.95°N as well as the International Maritime Organization (IMO) definition, which excludes the Baltic Sea and North Atlantic between Greenland and Scandinavia. RCP2.6 (van Vuuren et al., 2007) has global extent, and shipping emissions north of 60°N were included in the comparison. Furthermore, the subject year extended from 2004 to 2016.

The black carbon emissions for broader definitions of the Arctic varied between 0.7 and 2 kt. Winther et al. (2017) used the latest AIS data and incorporated fuel- and engine type as well as load-specific emission factors, giving lower total emissions than the other inventories. Because the AIS data offer actual ship-specific type, route and engine use information, they could be seen as best available activity data for international shipping. However, not all vessels incorporate these systems, for example smaller ships for fishing, and including these requires separate assessment.

4. Perspectives on the international frameworks for monitoring black carbon emissions

4.1 Current international landscape for emissions reporting

There are currently three international fora where official national inventory estimates of black carbon emissions are reported to a central body: UNECE-CLRTAP, the EU NEC Directive and the Arctic Council Framework on Enhanced Black Carbon and Methane Emissions Reductions. Where countries report to two or three of the above fora (e.g., the Scandinavian EU- and Arctic Council Member States), generally the same emissions data are reported (some EU Parties vary due to different definitions of geographic coverage under NEC and CLRTAP). Indeed, national black carbon emissions reported under NEC and/or the Arctic Council Framework are mostly submitted using the CLRTAP reporting template.

In all three fora, the reporting of national black carbon emissions data is not mandatory, but rather encouraged. Despite the absence of a mandatory reporting obligation, the level of black carbon emissions reporting under CLRTAP and the Arctic Council Framework may be considered high. Since 2015, when the new reporting templates including black carbon were made available to the CLRTAP Parties, the number of Parties submitting estimates of national total black carbon emissions under CLRTAP has been increasing. As of 2018, 41 of the 51 CLRTAP Parties had reported estimates for national total black carbon emissions. Of the 28 EU Member States, all of whom submit their data under NEC and CLRTAP, only two have yet to report estimates for national total black carbon emissions. Finally, under the Arctic Council Framework, all eight Arctic Council Member States submitted black carbon emissions during the first round of reporting in 2015, with 10 of the 13 Observer States also providing estimates. The level of reporting, which essentially constitutes voluntary reporting by the respective Parties, is thus encouraging.

Emissions inventories are fundamental to air pollution abatement efforts. Therefore, the degree of reporting observed here demonstrates that a large number of countries within CLRTAP, the Arctic Council and the European Union, view black carbon emissions as a significant environmental and human health issue which needs to be addressed. However, it is legitimate to ask whether these emissions inventories, and the systems within which they are reported, are fit for purpose. In other words, are these systems adequate for developing emissions reduction targets for black carbon and can they provide a transparent gauge for monitoring individual and collective progress on reducing black carbon emissions?

Evaluated against these criteria, a number of significant limitations in the CLRTAP black carbon reporting systems, and thus the Arctic Council and EU black carbon reporting systems, emerged from this review. First, in terms of the recommended inventory methods in the 2016 EMEP/EEA Guidebook (EEA, 2016), it is apparent that emission coefficients are lacking. For several source sectors where black carbon is emitted there are no black carbon fractions or emission factors given. Furthermore, in the 29 subchapters describing inventory methods for black carbon, roughly half provide Tier 1 black carbon fractions only (e.g., maritime shipping and gas flaring). The given emission coefficients, regardless of Tier are also typically associated with high relative uncertainty such as the Tier 2 black carbon fractions given for road transport. Although Parties are generally encouraged to develop and use country-specific emission factors, owing to limited resources the majority of the European countries rely heavily on the Guidebook methods and emission factors for estimates of air pollution emissions from most sectors. These gaps constitute a significant shortcoming which influences the completeness and accuracy of the national emissions estimates.

Another issue to emerge from the review was that of inconsistency between the reported black carbon emissions estimates. While national circumstances dictate which emission sources are relevant, the review revealed a significant variation in the number of source sectors (NFR categories) reported both between countries but also over the time series of certain countries. Therefore the degree to which the inventory is complete (i.e., covering all relevant source sectors) appears to vary substantially between countries and over the reported time series of countries. Black carbon emissions from the five priority source sectors (residential combustion, gas flaring, shipping, open burning of agricultural residues, road transport) were also reported to varying extents. With perhaps the exception of road transport, it was also observed that *Lower Tier* methods were being used by many countries for estimating black carbon emissions. Even for residential combustion, where the Guidebook provides Tier 2 black carbon fractions, it was judged that 16 of the 37 Parties reporting black carbon emissions from this sector were doing so using *Lower Tier* methods. There are also inherent limitations in CLRTAP leading to general reporting inconsistencies. Due to their geographical location outside the EMEP domain, the United States and Canada are not obliged to follow the reporting guidelines. As such, they do not have to report their emissions data in the same format and at the same source sector resolution (NFR category) as the other 49 Parties to the Convention. As a result, the NFR reporting template submitted by the United States includes only the national emissions totals for the mandatory pollutants and black carbon and not the source sector emissions estimates. Source sector emissions estimates for black carbon are however included in the United States *Informative Inventory Report* albeit using their own aggregated source sector split rather than the NFR system. In contrast, Canada reports its emissions of the mandatory pollutants using the recommended source sector split and reporting template. Canada's black carbon emissions are also reported using the NFR source-sector split in a separate data file submitted to CEIP later in the year after the 15 February submission deadline for the mandatory pollutants.

Finally, despite a large number of countries reporting at some level, it should be noted that those countries that have not yet reported black carbon emissions (Albania, Austria, Bosnia and Herzegovina, Liechtenstein, Luxembourg, Macedonia, Montenegro, Russia, Turkey, and Ukraine under CLRTAP; China, India and Singapore under the Arctic Council) constitute a considerable gap in the respective emissions reporting systems. In terms of monitoring the emissions of black carbon impacting the Arctic, the lack of routine Russian reporting represents a particularly significant gap. These Parties are of course in no violation of their reporting commitments because black carbon is not a mandatory pollutant to report. This leads to the final and perhaps most significant weakness of the reporting system under CLRTAP. As a voluntary pollutant, the emissions estimates for black carbon are not subject to rigorous review by CEIP. The emissions estimates are thus taken at face value and the reporting Parties are not externally prompted to correct errors or make methodological improvements.

4.2 Recommendations for improving emissions reporting under CLRTAP

The various limitations in the black carbon reporting system under CLRTAP indicate ample room for improvement. Substantial improvements in methods are required. Future revisions of the 2016 EMEP/EEA Guidebook (EEA, 2016) should look to further develop the methods for estimating black carbon emissions, focusing in particular on increasing the extent to which the relevant black carbon source sectors are provided with *Higher Tier* emission coefficients. To support this work, further experimental research is likely to be required to derive new emission factors and black carbon fractions and to reduce uncertainties in these parameters. This process is likely to be accelerated if the IPCC Task Force on National Greenhouse Gas Inventories does indeed begin work on further developing inventory methods for SLCFs. However, before embarking on a comprehensive update and expansion of the current methodologies, a reassessment of the validity of the current methods using black carbon fractions of $PM_{2.5}$ should be considered.

An improvement in methodology would provide the CLRTAP Parties (and countries within and beyond the European Union and Arctic Council) with the tools needed to develop and/or improve their own black carbon emissions inventories. However, improving the available inventory methodologies alone will not secure voluntary reporting of black carbon by those countries that do not currently prepare national inventories. Neither will it secure that those countries that do compile inventories take the steps to upgrade their inventories by collecting the activity data required for implementing *Higher Tier* inventory methods. As indicated by the Questionnaire responses in Appendix A2 to this report, improvements of national black carbon inventories are also restricted by financial resources and lack of higher-resolution activity data. Of course some countries are reporting and improving their inventories voluntarily; however, across-the-board reporting and improvements are needed if CLRTAP is to function as an effective system for monitoring black carbon emissions from its 51 Parties. In fact, substantial improvements in reporting can only be expected once reporting of black carbon emissions under CLRTAP becomes mandatory. If mandatory reporting were to be implemented, not only would Parties be then legally obliged to report their black carbon emissions, but also the emissions estimates would then be subject to the independent Stage 3 inventory reviews conducted by CEIP. These reviews could then identify and request action on sectors in the inventories where, for example, emissions estimates are not available or should have been estimated with *Higher Tier* methods. However, under such a scenario, Canada and the United States would not be subject to Stage 3 reviews due to differential reporting obligations under CLRTAP for these Parties.

Although the prospect of mandatory black carbon emissions reporting is not explicitly mentioned in the recently adopted longterm strategy for the Convention (UNECE, 2018b), which sets out a 2020–2030 vision for the Convention, the strategy recommends, in reference to a review of the amended Gothenburg Protocol, that recommendations in the policy review group report (UNECE, 2017), which includes, *inter alia*, proposals for mandatory black carbon emissions reporting, be taken into account. This EU Action on Black Carbon in the Arctic report strongly recommends that the future review (and potential update) of the amended Gothenburg Protocol considers mandatory black carbon emissions reporting; however, this report cautions that an update of the Gothenburg Protocol could likely only effect mandatory black carbon emissions reporting in the medium- to long term and that this reporting obligation would then only apply to the Parties to the Protocol rather than all 51 Parties to CLRTAP. As pointed out in Section 2.1.2.1, this would be a lengthy process involving a formal review of the Protocol, a period of preparation and discussion of draft amendments, adoption of the new amendment, and finally the time it takes for enough Parties to ratify the new Amendment for its entry into force. Furthermore, the process can only begin once the 2012 Amendment enters into force. As of 1 May 2019, only 16 Parties have ratified the 2012 Amendment[23]; a total of 18 ratifying Parties (two-thirds of the Protocol Parties) are needed before the Amendment can enter into force. At the aforementioned Executive Body meeting in December 2018, Parties were asked to report on their planned ratification of the Protocol and it was concluded that, based on the commitments made at the meeting, the 2012 amendment is very likely to reach the required number of ratifications by the end of 2019 (UNECE, 2018c). This EU Action on Black Carbon in the Arctic report therefore recommends that the Convention also considers alternative pathways for implementing mandatory black carbon emissions reporting. As described in Section 2.1.2.1, mandatory particulate matter emissions reporting was first implemented via Executive Body Decision 2002/10 (UNECE, 2002), a decade before the 2012 Gothenburg Protocol Amendment, which reaffirmed mandatory emissions reporting of particulate matter and outlined, *inter alia*, particulate matter emissions reduction commitments. As such, an update of Executive Body Decisions 2013/3 and 2013/4 (UNECE, 2013a,b), which together outline the current minimum reporting obligations for all 51 CLRTAP Parties, may be an option to effect mandatory black carbon emissions reporting in the near term. If the respective countries were willing, the update could maybe also address EMEP vs. non-EMEP discrepancies in the reporting obligations and review procedures.

[23] https://treaties.un.org/Pages/ViewDetails.aspx?src=TREATY&mtdsg_no=XXVII-1-k&chapter=27&clang=_en

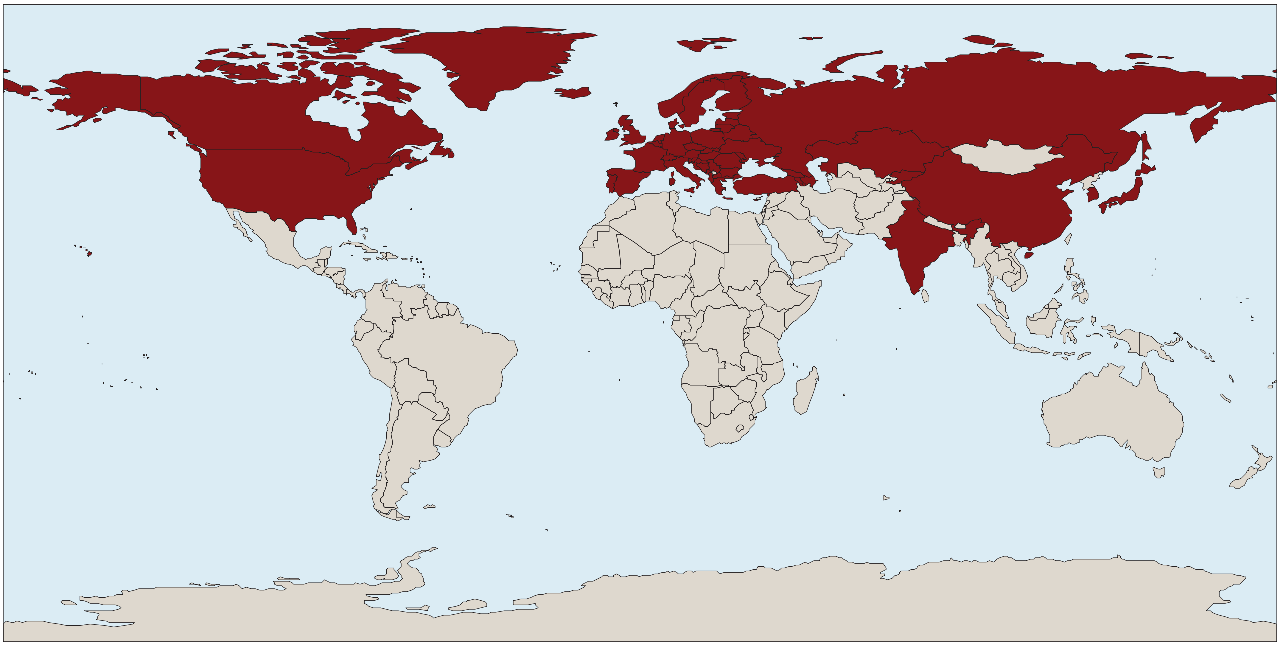

Figure 4.1 Combined geographical scope of CLRTAP and the Arctic Council.

4.3 Emission estimates from independent inventories to support national reporting

Outside the official reporting provided by the countries themselves, black carbon emissions are assessed in several independent emission inventories. The advantage of these inventories is that the methodology is consistent over a large area, whether the coverage is regional or global. Although the estimates from different inventories do not always agree, they do set a range of values, the comparison of which helps the development of emission estimation, as long as the reasons for the differences are understood. The inventories compared in this report show that there is variation in the inclusion and handling of important emission sectors, and also that *Lower Tier* methods do not incorporate the national and regional characteristics needed for detailed estimates. Further discussion between national and independent inventory experts is needed to improve the data and methodology in emission calculations. International fora such as Expert Groups under the Arctic Council offer possible platforms for such dialogue.

In addition to providing estimates where no national data are available, independent emissions inventories are also essential in filling sectoral gaps in the official reporting systems. The limited geographic scope of the EMEP grid and the current incomplete reporting of gridded black carbon emissions under CLRTAP both highlight the importance of spatially-disaggregated emissions estimates from independent inventories, particularly with respect to emissions from high-latitude gas flaring and shipping in Arctic waters. These emissions, which are potentially having a significant impact on the Arctic, are only partially reported under CLRTAP and the spatial extent and resolution of reported emissions is insufficient to monitor those emissions affecting the Arctic. The sectoral and geo-gridded estimates provided by independent global assessments are thus critical to assessing the role of black carbon emissions in accelerating Arctic warming.

4.4 Future scenario for monitoring the impact of national emissions on the Arctic

Hopes that black carbon emissions reporting would become established under the UNFCCC Paris Agreement were partly dashed by the agreed *Paris Rulebook* that emerged from the recent 24th Conference of the Parties in Katowice, Poland. The draft decision on the Paris Agreement transparency framework makes no mention of black carbon as a pollutant to be reported. The onus for international black carbon monitoring therefore remains on cooperation between CLRTAP-, Arctic Council- and EU reporting systems. This final section of the summary builds upon the preceding recommendations and describes a scenario whereby synergies between CLRTAP and the Arctic Council could create an enhanced inventory reporting system for monitoring black carbon emissions that impact the Arctic. Together, the two frameworks span a large part of the Northern Hemisphere (Figure 4.1) and furthermore cover many (but not all) of the countries whose black carbon emissions directly and/or indirectly have an effect on Arctic warming (AMAP, 2015).

The Arctic Council has long been an important presence within CLRTAP and could perhaps mobilise its influence to push for improvements in CLRTAP which benefit both the Convention and its own Framework on Enhanced Black Carbon and Methane Emissions Reductions. As previously described, the United States and Canada are not obliged to follow the Convention's reporting Guidelines and thus do not have to report their emissions data in same format and at the same source sector resolution (NFR categories) as the other 49 Parties to CLRTAP. Canada's reporting of the mandatory CLRTAP pollutants is nonetheless consistent with that expected of the EMEP countries, with Canada's black carbon emissions also reported using the NFR source sector split (albeit in a separate data file submitted to CEIP later than the 15 February submission deadline for mandatory pollutants). At a 2018 EU-Canada Stakeholder Meeting involving Canadian inventory representatives and experts from the EU Action on Black Carbon in the Arctic, Canadian officials indicated that they were considering whether to further harmonise the submission of their black carbon emissions estimates by submitting the black carbon data in the CLRTAP reporting template rather than as a separate data file. If the United States were to undertake similar steps, and in turn adapt its sector split for reporting, a significant step in harmonising the black carbon reporting systems within CLRTAP and the Arctic Council would be achieved. Some degree of harmonisation should be feasible, given that the United States has submitted sector level estimates to CLRTAP and the Arctic Council, albeit at a more aggregated level.

Russian engagement is also vital. Russia has yet to report black carbon emissions under CLRTAP and those emissions of pollutants it does provide are calculated for the European part of Russia only. Given its geography with respect to the Arctic and the potential magnitude of the black carbon emissions from its territory (particularly from gas flaring, as highlighted in the ECLIPSEv5a and GAINS independent inventories), the participation of Russia in the reporting systems is crucial. Perhaps, the Arctic Council may again represent an effective forum to facilitate Russian engagement in developing nationwide black carbon emissions estimates and regularly reporting the data.

The synergy between CLRTAP and the Arctic Council could also work in the other direction. As described in Section 2.2, the Arctic Council Framework is largely dependent on the black carbon emissions reported under CLRTAP to CEIP. However, emissions from Asian Observer States which are not Parties to CLRTAP, are not submitted to CEIP but directly to the Arctic Council. So if CEIP were to host, and potentially review the data, a great deal of further harmonisation of the Arctic Council's black carbon emissions reporting system could be achieved. Shared reporting mechanisms for voluntary submissions from countries external to the CLRTAP-Arctic Council-EU scope could be further considered in this respect. Such participation may be possible through the CCAC, which has been assisting Bangladesh, Chile, Colombia, Cote d'Ivoire, Ghana, the Maldives, Mexico, Morocco, Nigeria, Philippines and Togo in developing their own national black carbon inventories. These and the previous recommendations will be explored further during the course of this EU Action on Black Carbon in the Arctic and elaborated in an upcoming *Roadmap for International Cooperation on Black Carbon*.

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Appendix A1: Supplementary Figures and Tables

Table A1.1 Tier 1 emission coefficients for estimating black carbon emissions from residential combustion according to the 2016 EMEP/EEA Guidebook (EEA, 2016), Chapter 1.A.4 *Small combustion.*

Fuel type	Emission factor $PM_{2.5}$ [g GJ]	BC fraction [% of $PM_{2.5}$]	Guidebook tables(s)
Hard coal and brown coal	398	6.4	Table 3.3, p. 36
Gaseous fuels	1.2	5.4	Table 3.4, p. 37
Liquid fuels	1.9	8.5	Table 3.5, p. 38
Biomass	740	10	Table 3.6, p. 38

Table A1.2 Tier 2 emission coefficients for estimating black carbon emissions from residential combustion according to the 2016 EMEP/EEA Guidebook (EEA, 2016), Chapter 1.A.4 *Small combustion.*

Fuel type	Technology type	Emission factor $PM_{2.5}$ [g GJ]	BC fraction [% of $PM_{2.5}$]	Guidebook tables(s)
Solid fuels (except biomass)	Open fireplaces	330	9.839	Table 3.12, p. 47
Gaseous fuels	Partly closed/Closed fireplaces	2.2	5.4	Table 3.13, p. 48
Solid fuels (except biomass)	Conventional stoves	450	6.4	Table 3.14, p. 49
	Conventional boilers <50 kWth	201	6.4	Table 3.15, p. 50
Gaseous fuels	Conventional boilers <50 kWth	0.2	5.4	Table 3.16, p. 51
Gas oil	Conventional stoves	2.2	13	Table 3.17, p. 52
	Conventional boilers <50 kWth	1.5	3.9	Table 3.18, p. 53
Coal	Advanced / Ecolabelled stoves	220	6.4	Table 3.19, p. 54
Wood	Open fireplaces	820	7	Table 3.39, p. 82
	Conventional stoves	740	10	Table 3.40, p. 84
	High-efficiency stoves	370	16	Table 3.41, p. 85
	Advanced / Ecolabelled stoves and boilers	93	28	Table 3.42, p. 87
	Conventional boilers	470	16	Table 3.43, p. 88
Wood pellets	Pellet stoves and boilers	60	15	Table 3.44, p. 90

Table A1.3 Tier 1 emission coefficients for estimating black carbon emissions from gas flaring according to the 2016 EMEP/EEA Guidebook (EEA, 2016), Chapter 1.B.2.c *Venting and flaring.*

Flare type	Emission factor $PM_{2.5}$	BC fraction [% of $PM_{2.5}$]	Guidebook tables(s)
Oil and gas extraction	2.6 kg Mg^{-1}	24	Table 3.1, p. 9
Oil refinery	0.89 g GJ^{-1}	-	Table 3.4, p. 12

A dash indicates that this value was not estimated.

Table A1.4 Tier 1 emission coefficients for estimating black carbon emissions from shipping according to the 2016 EMEP/EEA Guidebook (EEA, 2016), Chapter 1.A.3.d *Navigation (shipping).*

Fuel type	Emission factor $PM_{2.5}$ [g $tonne^{-1}$]	BC fraction [% of $PM_{2.5}$]	Guidebook tables(s)
Bunker fuel oil	5.6	12	Table 3.1, p. 13
Marine diesel oil, marine gas oil	1.4	31	Table 3.4, p. 14
Gasoline	9.5	5	Table 3.5, p. 14

Table A1.5 Tier 2 emission coefficients for estimating black carbon emissions from shipping according to the 2016 EMEP/EEA Guidebook (EEA, 2016), Chapter 1.A.3.d *Navigation (shipping)*.

Fuel type	Engine type	Emission factor $PM_{2.5}$ [g $tonne^{-1}$]	BC fraction [% of $PM_{2.5}$]	Guidebook tables(s)
Bunker fuel oil	Gas turbine	0.3	12	Table 3.4, p. 16
	High-speed diesel	3.4	12	Table 3.4, p. 16
	Medium-speed diesel	3.4	12	Table 3.4, p. 16
	Slow-speed diesel	7.8	12	Table 3.4, p. 16
	Steam turbine	2.4	12	Table 3.4, p. 16
Marine diesel oil, marine gas oil	Gas turbine	0.0	31	Table 3.4, p. 16
	High-speed diesel	1.3	31	Table 3.4, p. 16
	Medium-speed diesel	1.3	31	Table 3.4, p. 16
	Slow-speed diesel	1.5	31	Table 3.4, p. 16
	Steam turbine	0.9	31	Table 3.4, p. 16
Diesel	Recreational boat (Conventional)	4.6	55	Table 3.5, p. 16
	Recreational boat (2003/44/EC)	3.71	55	Table 3.5, p. 16
Gasoline	Recreational boat; 2-stroke (Conventional)	12.6	5	Table 3.5, p. 16
	Recreational boat; 4-stroke (Conventional)	188	5	Table 3.5, p. 16
	Recreational boat; 2-stroke (2003/44/EC)	NE	5	Table 3.5, p. 16
	Recreational boat; 4-stroke (2003/44/EC)	188	5	Table 3.5, p. 16

Table A1.6 Tier 2 emission coefficients for estimating black carbon emissions from agricultural open burning according to the 2016 EMEP/EEA Guidebook (EEA, 2016), Chapter *3.F Field burning of agricultural wastes*.

Crop type	Emission factor black carbon [mg kg^{-1} dm]	Guidebook tables(s)
Wheat	500	Table 3.3, p. 7
Barley	1200	Table 3.4, p. 8
Maize	750	Table 3.5, p. 9
Rice	500	Table 3.6, p. 10

Table A1.7 Tier 1 emission coefficients for estimating black carbon emissions from road transport according to the 2016 EMEP/EEA Guidebook (EEA, 2016), Chapter 1.A.3.b.i-iv *Exhaust emissions from road transport*.

Vehicle category	Fuel type	Emission factor $PM_{2.5}$ [g kg^{-1}]	BC fraction [% of $PM_{2.5}$]	Guidebook tables(s)
Passenger cars	Petrol	0.03	12	Table 3.6, p. 23; Table 3.11, p. 24
	Diesel	1.10	57	Table 3.6, p. 23; Table 3.11, p. 24
	LPG	0.00	-	Table 3.6, p. 23
Light commercial vehicles	Petrol	0.02	5	Table 3.6, p. 23; Table 3.11, p. 24
	Diesel	1.52	55	Table 3.6, p. 23; Table 3.11, p. 24
Heavy duty vehicles	Diesel	0.94	53	Table 3.6, p. 23; Table 3.11, p. 24
	CNG (buses)	0.02	-	Table 3.6, p. 23
Two-wheel (L category)	Petrol	2.20	11	Table 3.6, p. 23; Table 3.11, p. 24

LPG: liquefied petroleum gas; CNG: compressed natural gas.

Table A1.8 Tier 2 emission coefficients for estimating black carbon emissions from road transport according to the 2016 EMEP/EEA Guidebook (EEA, 2016), Chapter 1.A.3.b.i-iv *Exhaust emissions from road transport*.

Vehicle category	Fuel and/or vehicle size	Engine technology	Emission factor $PM_{2.5}$ [g km^{-1}]	BC fraction [% of $PM_{2.5}$]	Guidebook tables(s)
Passenger cars	Petrol Mini	Euro 4 – 98/69/EC II	0.0011	15	Table 3.18 p. 31; Table 3.88, p. 104
		Euro 5 – EC 715/2007	0.0014	-	Table 3.18 p. 31
		Euro 6 up to 2016	0.0014	-	Table 3.18 p. 31
		Euro 6 2017–2019	0.0016	-	Table 3.18 p. 31
		Euro 6 2020+	0.0016	-	Table 3.18 p. 31
	Petrol Small	PRE ECE	0.0022	2	Table 3.18 p. 31; Table 3.88, p. 104
		ECE 15/00-01	0.0022	5	Table 3.18 p. 31; Table 3.88, p. 104
		ECE 15/02	0.0022	5	Table 3.18 p. 31; Table 3.88, p. 104
		ECE 15/03	0.0022	5	Table 3.18 p. 31; Table 3.88, p. 104
		ECE 15/04	0.0022	20	Table 3.18 p. 31; Table 3.88, p. 104
		Open Loop	0.0022	30	Table 3.18 p. 31; Table 3.88, p. 104
		Euro 1 – 91/441/EEC	0.0022	25	Table 3.18 p. 31; Table 3.88, p. 104
		Euro 2 – 94/12/EEC	0.0022	25	Table 3.18 p. 31; Table 3.88, p. 104
		Euro 3 – 98/69/EC I	0.0011	15	Table 3.18 p. 31; Table 3.88, p. 104
		Euro 4 – 98/69/EC II	0.0011	15	Table 3.18 p. 31; Table 3.88, p. 104
		Euro 5 – EC 715/2007	0.0014	-	Table 3.18 p. 31
		Euro 6 up to 2016	0.0014	-	Table 3.18 p. 31
		Euro 6 2017–2019	0.0016	-	Table 3.18 p. 31
		Euro 6 2020+	0.0016	-	Table 3.18 p. 31
	Petrol Medium	PRE ECE	0.0022	2	Table 3.18 p. 31; Table 3.88, p. 104
		ECE 15/00-01	0.0022	5	Table 3.18 p. 31; Table 3.88, p. 104
		ECE 15/02	0.0022	5	Table 3.18 p. 31; Table 3.88, p. 104
		ECE 15/03	0.0022	5	Table 3.18 p. 31; Table 3.88, p. 104
		ECE 15/04	0.0022	20	Table 3.18 p. 31; Table 3.88, p. 104
		Open Loop	0.0022	30	Table 3.18 p. 31; Table 3.88, p. 104
		Euro 1 – 91/441/EEC	0.0022	25	Table 3.18 p. 31; Table 3.88, p. 104
		Euro 2 – 94/12/EEC	0.0022	25	Table 3.18 p. 31; Table 3.88, p. 104
		Euro 3 – 98/69/EC I	0.0011	15	Table 3.18 p. 31; Table 3.88, p. 104
		Euro 4 – 98/69/EC II	0.0011	15	Table 3.18 p. 31; Table 3.88, p. 104
		Euro 5 – EC 715/2007	0.0014	-	Table 3.18 p. 31
		Euro 6 up to 2016	0.0014	-	Table 3.18 p. 31
		Euro 6 2017–2019	0.0016	-	Table 3.18 p. 31
		Euro 6 2020+	0.0016	-	Table 3.18 p. 31
	Petrol Large SUV Executive	PRE ECE	0.0022	2	Table 3.18 p. 31; Table 3.88, p. 104
		ECE 15/00-01	0.0022	5	Table 3.18 p. 31; Table 3.88, p. 104
		ECE 15/02	0.0022	5	Table 3.18 p. 31; Table 3.88, p. 104
		ECE 15/03	0.0022	5	Table 3.18 p. 31; Table 3.88, p. 104
		ECE 15/04	0.0022	20	Table 3.18 p. 31; Table 3.88, p. 104
		Euro 1 – 91/441/EEC	0.0022	25	Table 3.18 p. 31; Table 3.88, p. 104
		Euro 2 – 94/12/EEC	0.0022	25	Table 3.18 p. 31; Table 3.88, p. 104
		Euro 3 – 98/69/EC I	0.0011	15	Table 3.18 p. 31; Table 3.88, p. 104
		Euro 4 – 98/69/EC II	0.0011	15	Table 3.18 p. 31; Table 3.88, p. 104
		Euro 5 – EC 715/2007	0.0014	-	Table 3.18 p. 31
		Euro 6 up to 2016	0.0014	-	Table 3.18 p. 31
		Euro 6 2017–2019	0.0016	-	Table 3.18 p. 31
		Euro 6 2020+	0.0016	-	Table 3.18 p. 31

Vehicle category	Fuel and/or vehicle size	Engine technology	Emission factor $PM_{2.5}$ [g km^{-1}]	BC fraction [% of $PM_{2.5}$]	Guidebook tables(s)
	Diesel Small	Euro 4 – 98/69/EC II	0.0314	87	Table 3.18 p. 31; Table 3.88, p. 104
		Euro 5 – EC 715/2007	0.0021	-	Table 3.18 p. 31
		Euro 6 up to 2016	0.0015	-	Table 3.18 p. 31
		Euro 6 2017–2019	0.0015	-	Table 3.18 p. 31
		Euro 6 2020+	0.0015	-	Table 3.18 p. 31
	Diesel Medium	Conventional	0.2209	55	Table 3.18 p. 31; Table 3.88, p. 104
		Euro 1 – 91/441/EEC	0.0842	70	Table 3.18 p. 31; Table 3.88, p. 104
		Euro 2 – 94/12/EEC	0.0548	80	Table 3.18 p. 31; Table 3.88, p. 104
		Euro 3 – 98/69/EC I	0.0391	85	Table 3.18 p. 31; Table 3.88, p. 104
		Euro 4 – 98/69/EC II	0.0314	87	Table 3.18 p. 31; Table 3.88, p. 104
		Euro 5 – EC 715/2007	0.0021	-	Table 3.18 p. 31
		Euro 6 up to 2016	0.0015	-	Table 3.18 p. 31
		Euro 6 2017–2019	0.0015	-	Table 3.18 p. 31
		Euro 6 2020+	0.0015	-	Table 3.18 p. 31
	Diesel Large SUV Executive	Conventional	0.2209	55	Table 3.18 p. 31; Table 3.88, p. 104
		Euro 1 – 91/441/EEC	0.0842	70	Table 3.18 p. 31; Table 3.88, p. 104
		Euro 2 – 94/12/EEC	0.0548	80	Table 3.18 p. 31; Table 3.88, p. 104
		Euro 3 – 98/69/EC I	0.0391	85	Table 3.18 p. 31; Table 3.88, p. 104
		Euro 4 – 98/69/EC II	0.0314	87	Table 3.18 p. 31; Table 3.88, p. 104
		Euro 5 – EC 715/2007	0.0021	-	Table 3.18 p. 31
		Euro 6 up to 2016	0.0015	-	Table 3.18 p. 31
		Euro 6 2017–2019	0.0015	-	Table 3.18 p. 31
		Euro 6 2020+	0.0015	-	Table 3.18 p. 31
	LPG	Conventional	0.0022	-	Table 3.18 p. 31
		Euro 1 – 91/441/EEC	0.0022	-	Table 3.18 p. 31
		Euro 2 – 94/12/EEC	0.0022	-	Table 3.18 p. 31
		Euro 3 – 98/69/EC I	0.0011	-	Table 3.18 p. 31
		Euro 4 – 98/69/EC II	0.0011	-	Table 3.18 p. 31
	2-Stroke	Conventional	n.a.	-	Table 3.18 p. 31
	Hybrid Petrol Small	Euro 4 – 98/69/EC II	n.a.	-	Table 3.18 p. 31
	Hybrid Petrol Medium	Euro 4 – 98/69/EC II	n.a.	-	Table 3.18 p. 31
	Hybrid Petrol Large	Euro 4 – 98/69/EC II	n.a.	-	Table 3.18 p. 31
	E85	Euro 4 – 98/69/EC II	0.0011	-	Table 3.18 p. 31
	CNG	Euro 4 – 98/69/EC II	0.0011	-	Table 3.18 p. 31
Light commercial vehicles	Petrol	Conventional	0.0023	-	Table 3.20 p. 33
		Euro 1 – 93/59/EEC	0.0023	25	Table 3.20 p. 33; Table 3.88, p. 104
		Euro 2 – 96/69/EEC	0.0023	25	Table 3.20 p. 33; Table 3.88, p. 104
		Euro 3 – 98/69/EC I	0.0011	15	Table 3.20 p. 33; Table 3.88, p. 104
		Euro 4 – 98/69/EC II	0.0011	15	Table 3.20 p. 33; Table 3.88, p. 104
		Euro 5 – EC 715/2007	0.0014	-	Table 3.20 p. 33
		Euro 6 up to 2017	0.0012	-	Table 3.20 p. 33
		Euro 6 2018–2020	0.0012	-	Table 3.20 p. 33
		Euro 6 2021+	0.0012	-	Table 3.20 p. 33

Vehicle category	Fuel and/or vehicle size	Engine technology	Emission factor $PM_{2.5}$ [g km^{-1}]	BC fraction [% of $PM_{2.5}$]	Guidebook tables(s)
	Diesel	Conventional	0.356	55	Table 3.20 p. 33; Table 3.88, p. 104
		Euro 1 – 93/59/EEC	0.117	70	Table 3.20 p. 33; Table 3.88, p. 104
		Euro 2 – 96/69/EEC	0.117	80	Table 3.20 p. 33; Table 3.88, p. 104
		Euro 3 – 98/69/EC I	0.0783	85	Table 3.20 p. 33; Table 3.88, p. 104
		Euro 4 – 98/69/EC II	0.0409	87	Table 3.20 p. 33; Table 3.88, p. 104
		Euro 5 – EC 715/2007	0.001	-	Table 3.20 p. 33
		Euro 6 up to 2017	0.0009	-	Table 3.20 p. 33
		Euro 6 2018–2020	0.0009	-	Table 3.20 p. 33
		Euro 6 2021+	0.0009	-	Table 3.20 p. 33
Heavy-duty vehicles	Petrol >3.5 t	Conventional	0	-	Table 3.22 p. 34
	Diesel ≤7.5 t	Conventional	0.333	50	Table 3.22 p. 34; Table 3.88, p. 104
		Euro I – 91/542/EEC I	0.129	65	Table 3.22 p. 34; Table 3.88, p. 104
		Euro II – 91/542/EEC II	0.061	65	Table 3.22 p. 34; Table 3.88, p. 104
		Euro III – 2000	0.0566	70	Table 3.22 p. 34; Table 3.88, p. 104
		Euro IV – 2005	0.0106	75	Table 3.22 p. 34; Table 3.88, p. 104
		Euro V – 2008	0.0106	75	Table 3.22 p. 34; Table 3.88, p. 104
		Euro VI	0.0005	15	Table 3.22 p. 34; Table 3.88, p. 104
		Conventional	0.3344	50	Table 3.22 p. 34; Table 3.88, p. 104
	Diesel 7.5–16 t	Euro I – 91/542/EEC I	0.201	65	Table 3.22 p. 34; Table 3.88, p. 104
		Euro II – 91/542/EEC II	0.104	65	Table 3.22 p. 34; Table 3.88, p. 104
		Euro III – 2000	0.0881	70	Table 3.22 p. 34; Table 3.88, p. 104
		Euro IV – 2005	0.0161	75	Table 3.22 p. 34; Table 3.88, p. 104
		Euro V – 2008	0.0161	75	Table 3.22 p. 34; Table 3.88, p. 104
		Euro VI	0.0008	15	Table 3.22 p. 34; Table 3.88, p. 104
	Diesel 16–32 t	Conventional	0.418	50	Table 3.22 p. 34; Table 3.88, p. 104
		Euro I – 91/542/EEC I	0.297	65	Table 3.22 p. 34; Table 3.88, p. 104
		Euro II – 91/542/EEC II	0.155	65	Table 3.22 p. 34; Table 3.88, p. 104
		Euro III – 2000	0.13	70	Table 3.22 p. 34; Table 3.88, p. 104
		Euro IV – 2005	0.0239	75	Table 3.22 p. 34; Table 3.88, p. 104
		Euro V – 2008	0.0239	75	Table 3.22 p. 34; Table 3.88, p. 104
		Euro VI	0.0012	15	Table 3.22 p. 34; Table 3.88, p. 104
	Diesel >32 t	Conventional	0.491	50	Table 3.22 p. 34; Table 3.88, p. 104
		Euro I – 91/542/EEC I	0.358	65	Table 3.22 p. 34; Table 3.88, p. 104
		Euro II – 91/542/EEC II	0.194	65	Table 3.22 p. 34; Table 3.88, p. 104
		Euro III – 2000	0.151	70	Table 3.22 p. 34; Table 3.88, p. 104
		Euro IV – 2005	0.0268	75	Table 3.22 p. 34; Table 3.88, p. 104
		Euro V – 2008	0.0268	75	Table 3.22 p. 34; Table 3.88, p. 104
		Euro VI	0.0013	15	Table 3.22 p. 34; Table 3.88, p. 104
Buses	Urban CNG Buses	Euro I – 91/542/EEC I	0.02	-	Table 3.24 p. 35
		Euro II – 91/542/EEC II	0.01	-	Table 3.24 p. 35
		Euro III – 2000	0.01	-	Table 3.24 p. 35
		EEV	0.005	-	Table 3.24 p. 35
	Urban Buses Standard	Conventional	0.909	50	Table 3.24 p. 35; Table 3.88, p. 104
		Euro I – 91/542/EEC I	0.479	65	Table 3.24 p. 35; Table 3.88, p. 104
		Euro II – 91/542/EEC II	0.22	65	Table 3.24 p. 35; Table 3.88, p. 104
		Euro III – 2000	0.207	70	Table 3.24 p. 35; Table 3.88, p. 104
		Euro IV – 2005	0.0462	75	Table 3.24 p. 35; Table 3.88, p. 104
		Euro V – 2008	0.0462	75	Table 3.24 p. 35; Table 3.88, p. 104
		Euro VI	0.0023	15	Table 3.24 p. 35; Table 3.88, p. 104

Vehicle category	Fuel and/or vehicle size	Engine technology	Emission factor $PM_{2.5}$ [g km^{-1}]	BC fraction [% of $PM_{2.5}$]	Guidebook tables(s)
	Coaches Standard	Conventional	0.47	50	Table 3.24 p. 35; Table 3.88, p. 104
		Euro I – 91/542/EEC I	0.362	65	Table 3.24 p. 35; Table 3.88, p. 104
		Euro II – 91/542/EEC II	0.165	65	Table 3.24 p. 35; Table 3.88, p. 104
		Euro III – 2000	0.178	70	Table 3.24 p. 35; Table 3.88, p. 104
		Euro IV – 2005	0.0354	75	Table 3.24 p. 35; Table 3.88, p. 104
		Euro V – 2008	0.0354	75	Table 3.24 p. 35; Table 3.88, p. 104
		Euro VI	0.0018	15	Table 3.24 p. 35; Table 3.88, p. 104
Motorcycles and mopeds	2-stroke <50 cm^3	Conventional	0.176	10	Table 3.26 p. 36; Table 3.88, p. 104
		Mop – Euro 1	0.045	20	Table 3.26 p. 36; Table 3.88, p. 104
		Mop – Euro 2	0.026	20	Table 3.26 p. 36; Table 3.88, p.104
		Mop – Euro 3 and on	0.018	-	Table 3.26 p. 36
	4-stroke <50 cm^3	Conventional	0.176	10	Table 3.26 p. 36; Table 3.88, p. 104
		Mop – Euro 1	0.04	20	Table 3.26 p. 36; Table 3.88, p. 104
		Mop – Euro 2	0.007	20	Table 3.26 p. 36; Table 3.88, p. 104
		Mop – Euro 3 and on	0.004	-	Table 3.26 p. 36
	2-stroke >50 cm^3	Conventional	0.16	15	Table 3.26 p. 36; Table 3.88, p. 104
		Mot – Euro 1	0.064	25	Table 3.26 p. 36; Table 3.88, p. 104
		Mot – Euro 2	0.032	25	Table 3.26 p. 36; Table 3.88, p. 104
		Mot – Euro 3 and on	0.0096	25	Table 3.26 p. 36; Table 3.88, p. 104
	4-stroke <250 cm^3	Conventional	0.014	15	Table 3.26 p. 36; Table 3.88, p. 104
		Mot – Euro 1	0.014	25	Table 3.26 p. 36; Table 3.88, p. 104
		Mot – Euro 2 and on	0.0035	25	Table 3.26 p. 36; Table 3.88, p. 104
	4-stroke 250–750 cm^3	Conventional	0.014	15	Table 3.26 p. 36; Table 3.88, p. 104
		Mot – Euro 1	0.014	25	Table 3.26 p. 36; Table 3.88, p. 104
		Mot – Euro 2 and on	0.0035	25	Table 3.26 p. 36; Table 3.88, p. 104
	4-stroke >750 cm^3	Conventional	0.014	15	Table 3.26 p. 36; Table 3.88, p. 104
		Mot – Euro 1	0.014	25	Table 3.26 p. 36; Table 3.88, p. 104
		Mot – Euro 2 and on	0.0035	25	Table 3.26 p. 36; Table 3.88, p. 104

A dash indicates that this value was not estimated. LPG: liquefied petroleum gas; CNG: compressed natural gas.

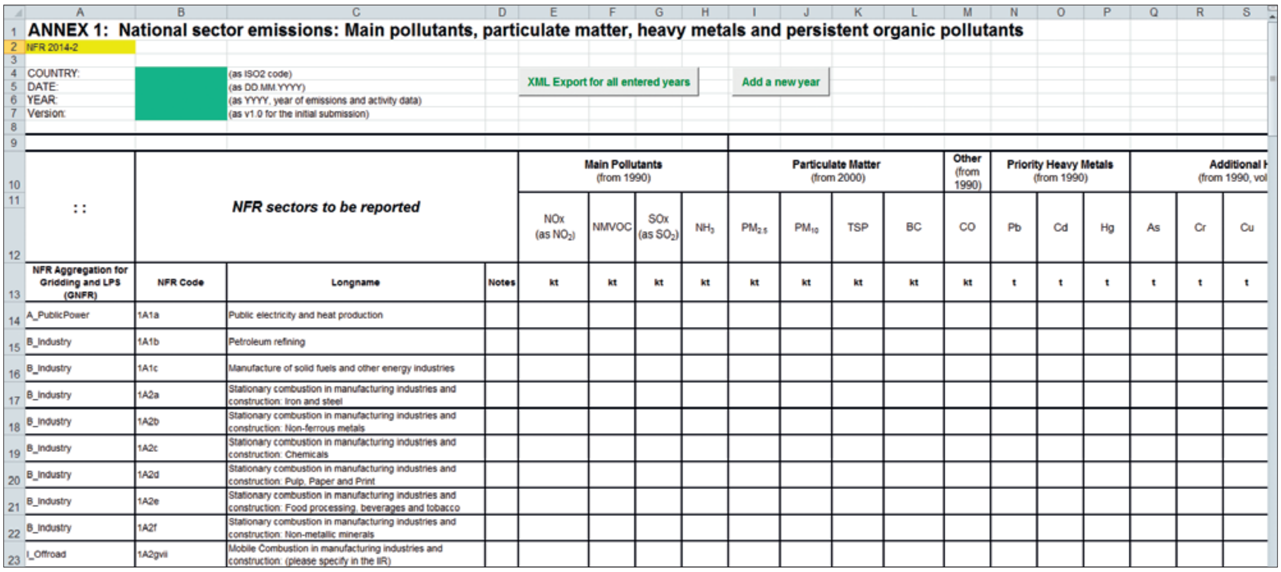

Figure A1.1 Emissions reporting template currently used by the CLRTAP Parties to submit their emissions data to CEIP. The current template allows the Parties, *inter alia*, to submit their inventory estimates of black carbon emissions for the various source sectors (NFR sectors) as well as their respective national total emissions.

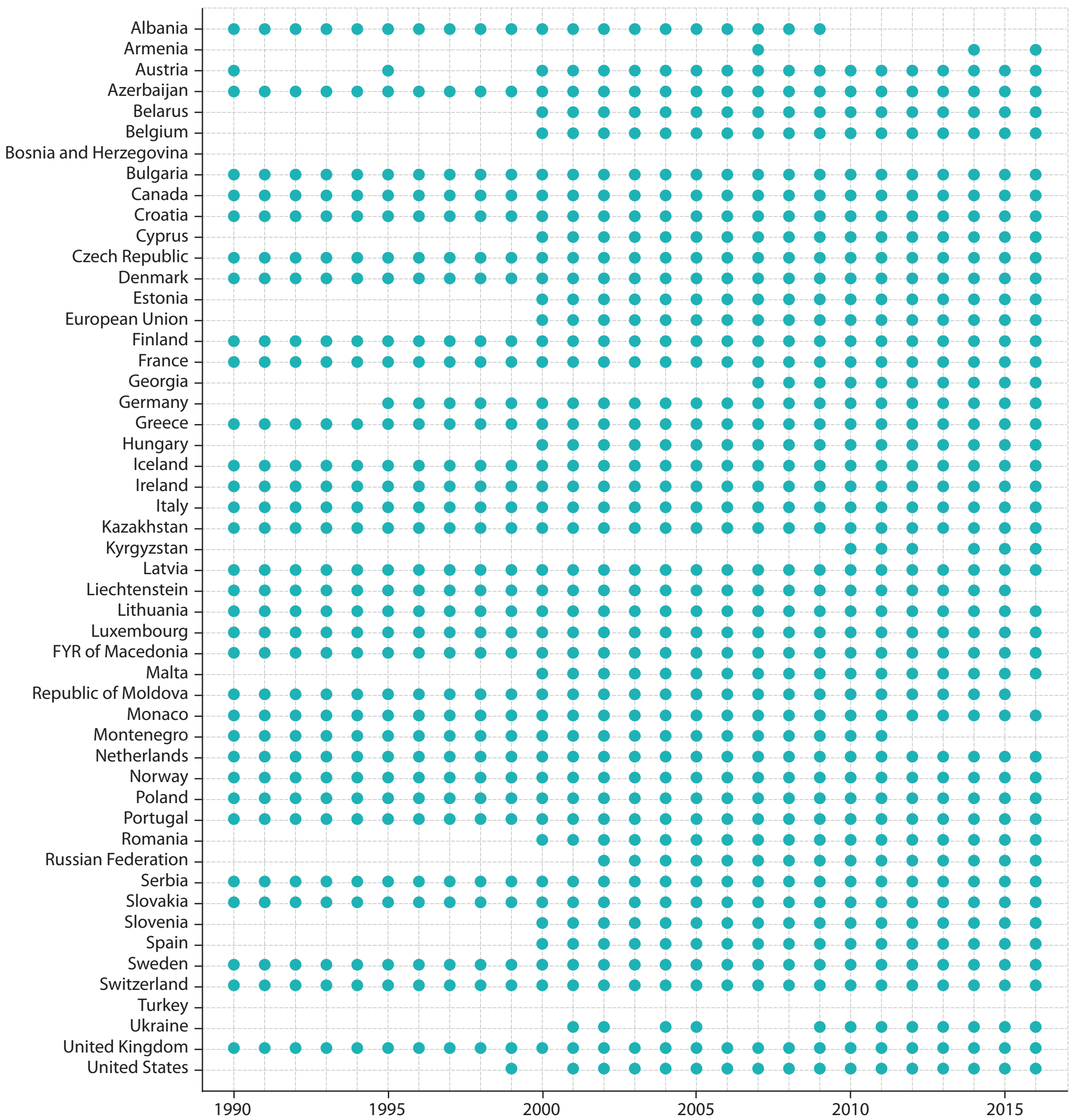

Figure A1.2 Reporting of annual total emissions of $PM_{2.5}$ by CLRTAP Parties. Dots mark the years for which $PM_{2.5}$ emissions were reported.

Table A1.9 Spatially gridded GNFR aggregated source sector black carbon emissions reported (green) or not reported (red) by those CLRTAP Parties submitting spatially disaggregated black carbon emissions estimates for the year 2015. Gridded emissions estimates for the year 2016 were used for Malta.

Country	A_PublicPower	B_Industry	C_OtherStationaryComb	D_Fugitive	E_Solvents	F_RoadTransport	G_Shipping	H_Aviation	I_Offroad	J_Waste	L_AgriOther	M_Other	N_Natural	O_AviCruise	P_IntShipping
Belgium	green	green	green	green	green	green	green	green	green	green	red	red	red	red	green
Bulgaria	red	red	red	red	red	green	red	red	red	red	red	red	red	red	red
Croatia	green	green	green	green	green	green	green	green	green	green	red	red	red	green	green
Czech Republic	green	green	green	red	red	green	green	green	green	green	red	red	red	red	red
Finland	green	green	green	red	green	green	green	red	green	green	green	red	red	red	red
France	green	green	green	green	green	green	green	green	green	green	green	red	red	red	red
Georgia	green	green	green	green	green	red	red	red	red	green	red	red	red	red	red
Greece	green	red	red	red	red	red	red	red	red	red	red	red	red	red	red
Hungary	green	green	green	green	green	green	green	green	green	green	red	red	red	red	red
Ireland	green	green	green	red	red	green	green	green	green	green	red	red	red	green	green
Italy	green	red	red	red	red	red	red	red	red	red	red	red	red	red	red
Latvia	green	green	green	red	red	green	green	green	green	green	red	red	red	red	red
Lithuania[a]	red	red	red	red	red	red	red	red	red	red	red	red	red	red	red
FYR of Macedonia	green	green	green	red	green	red	red	red	green	green	red	red	red	red	red
Malta	green	red	red	red	red	green	red	red	red	red	red	red	red	red	red
Monaco	green	red	green	red	red	green	green	red	red	red	red	red	red	red	green
Netherlands	red	green	green	red	red	green	green	green	green	red	red	red	red	red	green
Norway	green	green	green	green	green	green	green	green	green	green	green	red	red	red	green
Poland	green	green	green	green	green	green	green	green	green	green	green	red	red	red	red
Portugal	green	green	green	green	red	green	green	green	green	green	green	red	green	red	red
Romania	green	green	green	green	green	red	red	red	green	green	green	red	red	red	red
Slovakia	red	green	red	green	red	green	green	green	green	green	red	red	red	red	red
Slovenia	green	green	green	green	red	green	red	red	green	green	red	red	red	red	green
Spain	green	green	green	green	red	green	green	green	green	green	green	red	red	red	red
Sweden	green	green	green	red	green	green	green	green	green	green	red	red	red	red	red
Switzerland	green	green	green	green	green	green	green	green	green	green	red	green	red	red	red
United Kingdom	green	green	green	green	red	green	green	red	green	green	red	green	green	red	green

[a]Lithuania reported only gridded national total black carbon emissions and not GNFR source emissions.

Table A1.10 Code names of the NFR sectors for source sector level emissions reporting under CLRTAP and the aggregated sectors (GNFR) to which they belong.

GNFR Code	NFR Code	NFR Long name	Additional notes
A_PublicPower	1A1a	Public electricity and heat production	
B_Industry	1A1b	Petroleum refining	
B_Industry	1A1c	Manufacture of solid fuels and other energy industries	
B_Industry	1A2a	Stationary combustion in manufacturing industries and construction: Iron and steel	
B_Industry	1A2b	Stationary combustion in manufacturing industries and construction: Non-ferrous metals	
B_Industry	1A2c	Stationary combustion in manufacturing industries and construction: Chemicals	
B_Industry	1A2d	Stationary combustion in manufacturing industries and construction: Pulp, Paper and Print	
B_Industry	1A2e	Stationary combustion in manufacturing industries and construction: Food processing, beverages and tobacco	
B_Industry	1A2f	Stationary combustion in manufacturing industries and construction: Non-metallic minerals	
I_Offroad	1A2gvii	Mobile Combustion in manufacturing industries and construction: (please specify in the IIR)	
B_Industry	1A2gviii	Stationary combustion in manufacturing industries and construction: Other (please specify in the IIR)	
H_Aviation	1A3ai(i)	International aviation LTO (civil)	
H_Aviation	1A3aii(i)	Domestic aviation LTO (civil)	
F_RoadTransport	1A3bi	Road transport: Passenger cars	
F_RoadTransport	1A3bii	Road transport: Light duty vehicles	
F_RoadTransport	1A3biii	Road transport: Heavy duty vehicles and buses	
F_RoadTransport	1A3biv	Road transport: Mopeds & motorcycles	
F_RoadTransport	1A3bv	Road transport: Gasoline evaporation	
F_RoadTransport	1A3bvi	Road transport: Automobile tyre and brake wear	
F_RoadTransport	1A3bvii	Road transport: Automobile road abrasion	
I_Offroad	1A3c	Railways	
G_Shipping	1A3di(ii)	International inland waterways	
G_Shipping	1A3dii	National navigation (shipping)	
I_Offroad	1A3ei	Pipeline transport	
I_Offroad	1A3eii	Other (please specify in the IIR)	
C_OtherStationaryComb	1A4ai	Commercial/institutional: Stationary	
I_Offroad	1A4aii	Commercial/institutional: Mobile	
C_OtherStationaryComb	1A4bi	Residential: Stationary	
I_Offroad	1A4bii	Residential: Household and gardening (mobile)	
C_OtherStationaryComb	1A4ci	Agriculture/Forestry/Fishing: Stationary	
I_Offroad	1A4cii	Agriculture/Forestry/Fishing: Off-road vehicles and other machinery	
I_Offroad	1A4ciii	Agriculture/Forestry/Fishing: National fishing	
C_OtherStationaryComb	1A5a	Other stationary (including military)	
I_Offroad	1A5b	Other, Mobile (including military, land based and recreational boats)	
D_Fugitive	1B1a	Fugitive emission from solid fuels: Coal mining and handling	
D_Fugitive	1B1b	Fugitive emission from solid fuels: Solid fuel transformation	
D_Fugitive	1B1c	Other fugitive emissions from solid fuels	
D_Fugitive	1B2ai	Fugitive emissions oil: Exploration, production, transport	
D_Fugitive	1B2aiv	Fugitive emissions oil: Refining / storage	
D_Fugitive	1B2av	Distribution of oil products	
D_Fugitive	1B2b	Fugitive emissions from natural gas (exploration, production, processing, transmission, storage, distribution and other)	

GNFR Code	NFR Code	NFR Long name	Additional notes
D_Fugitive	1B2c	Venting and flaring (oil, gas, combined oil and gas)	
D_Fugitive	1B2d	Other fugitive emissions from energy production	
B_Industry	2A1	Cement production	
B_Industry	2A2	Lime production	
B_Industry	2A3	Glass production	
B_Industry	2A5a	Quarrying and mining of minerals other than coal	
B_Industry	2A5b	Construction and demolition	
B_Industry	2A5c	Storage, handling and transport of mineral products	
B_Industry	2A6	Other mineral products (please specify in the IIR)	
B_Industry	2B1	Ammonia production	
B_Industry	2B2	Nitric acid production	
B_Industry	2B3	Adipic acid production	
B_Industry	2B5	Carbide production	
B_Industry	2B6	Titanium dioxide production	
B_Industry	2B7	Soda ash production	
B_Industry	2B10a	Chemical industry: Other (please specify in the IIR)	
B_Industry	2B10b	Storage, handling and transport of chemical products (please specify in the IIR)	
B_Industry	2C1	Iron and steel production	
B_Industry	2C2	Ferroalloys production	
B_Industry	2C3	Aluminium production	
B_Industry	2C4	Magnesium production	
B_Industry	2C5	Lead production	
B_Industry	2C6	Zinc production	
B_Industry	2C7a	Copper production	
B_Industry	2C7b	Nickel production	
B_Industry	2C7c	Other metal production (please specify in the IIR)	
B_Industry	2C7d	"Storage, handling and transport of metal products (please specify in the IIR)"	
E_Solvents	2D3a	Domestic solvent use including fungicides	
B_Industry	2D3b	Road paving with asphalt	
B_Industry	2D3c	Asphalt roofing	
E_Solvents	2D3d	Coating applications	
E_Solvents	2D3e	Degreasing	
E_Solvents	2D3f	Dry cleaning	
E_Solvents	2D3g	Chemical products	
E_Solvents	2D3h	Printing	
E_Solvents	2D3i	Other solvent use (please specify in the IIR)	
E_Solvents	2G	Other product use (please specify in the IIR)	
B_Industry	2H1	Pulp and paper industry	
B_Industry	2H2	Food and beverages industry	
B_Industry	2H3	Other industrial processes (please specify in the IIR)	
B_Industry	2I	Wood processing	
B_Industry	2J	Production of POPs	
B_Industry	2K	"Consumption of POPs and heavy metals (e.g. electrical and scientific equipment)"	
B_Industry	2L	Other production, consumption, storage, transportation or handling of bulk products (please specify in the IIR)	
K_AgriLivestock	3B1a	Manure management - Dairy cattle	
K_AgriLivestock	3B1b	Manure management - Non-dairy cattle	

GNFR Code	NFR Code	NFR Long name	Additional notes
K_AgriLivestock	3B2	Manure management - Sheep	
K_AgriLivestock	3B3	Manure management - Swine	
K_AgriLivestock	3B4a	Manure management - Buffalo	
K_AgriLivestock	3B4d	Manure management - Goats	
K_AgriLivestock	3B4e	Manure management - Horses	
K_AgriLivestock	3B4f	Manure management - Mules and asses	
K_AgriLivestock	3B4gi	Manure mangement - Laying hens	
K_AgriLivestock	3B4gii	Manure mangement - Broilers	
K_AgriLivestock	3B4giii	Manure mangement - Turkeys	
K_AgriLivestock	3B4giv	Manure management - Other poultry	
K_AgriLivestock	3B4h	Manure management - Other animals (please specify in IIR)	
L_AgriOther	3Da1	Inorganic N-fertilizers (includes also urea application)	
L_AgriOther	3Da2a	Animal manure applied to soils	
L_AgriOther	3Da2b	Sewage sludge applied to soils	
L_AgriOther	3Da2c	"Other organic fertilisers applied to soils (including compost)"	
L_AgriOther	3Da3	Urine and dung deposited by grazing animals	
L_AgriOther	3Da4	Crop residues applied to soils	
L_AgriOther	3Db	Indirect emissions from managed soils	
L_AgriOther	3Dc	Farm-level agricultural operations including storage, handling and transport of agricultural products	
L_AgriOther	3Dd	Off-farm storage, handling and transport of bulk agricultural products	
L_AgriOther	3De	Cultivated crops	
L_AgriOther	3Df	Use of pesticides	
L_AgriOther	3F	Field burning of agricultural residues	
L_AgriOther	3I	Agriculture other (please specify in the IIR)	
J_Waste	5A	Biological treatment of waste - Solid waste disposal on land	
J_Waste	5B1	Biological treatment of waste - Composting	
J_Waste	5B2	Biological treatment of waste - Anaerobic digestion at biogas facilities	
J_Waste	5C1a	Municipal waste incineration	
J_Waste	5C1bi	Industrial waste incineration	
J_Waste	5C1bii	Hazardous waste incineration	
J_Waste	5C1biii	Clinical waste incineration	
J_Waste	5C1biv	Sewage sludge incineration	
J_Waste	5C1bv	Cremation	
J_Waste	5C1bvi	Other waste incineration (please specify in the IIR)	
J_Waste	5C2	Open burning of waste	
J_Waste	5D1	Domestic wastewater handling	
J_Waste	5D2	Industrial wastewater handling	
J_Waste	5D3	Other wastewater handling	
J_Waste	5E	Other waste (please specify in IIR)	
M_Other	6A	Other (included in national total for entire territory) (please specify in IIR)	
O_AviCruise	1A3ai(ii)	International aviation cruise (civil)	Memo item
O_AviCruise	1A3aii(ii)	Domestic aviation cruise (civil)	Memo item
P_IntShipping	1A3di(i)	International maritime navigation	Memo item
z_Memo	1A5c	Multilateral operations	Memo item
z_Memo	1A3	Transport (fuel used)	Memo item
z_Memo	6B	Other not included in national total of the entire territory (please specify in the IIR)	Memo item

Appendix A2: Questionnaire

On 10 October 2018, a questionnaire was sent to CEIP national contact points for each CLRTAP Party. Figure A2.1 shows the section questionnaire relevant technical issues of black carbon emissions to CLRTAP. By the end of 2018, completed questionnaires were received from CEIP national contact points representing ten CLRTAP Parties. Tables A2.1 to A2.3 synthesise the responses given by the CEIP national contact points for each CLRTAP Party.

Questionnaire

The EU Action on Black Carbon in the Arctic (EUA-BC)[1] is working closely with UNECE CLRTAP institutions to bring about improvements in national black carbon (BC) emissions inventories and increase BC reporting under CLRTAP. To help improve *the knowledge base on black carbon emissions* and identify the key obstacles limiting the submission/improvement of BC inventory estimates reported under CLRTAP, we kindly ask you, the CLRTAP national contact point for your country, to fill out the following questionnaire.

Name:	
Organization:	
Email:	
Country:	

Mark with "X" the key issues restricting the submission/improvement of your country's national BC emissions inventory:

Limited availability of activity data	Limited availability of emission factors	Absence of reporting obligation	Other (specify): ____

Mark with "X" the key sources for BC emission factors/inventory methods which your country used to develop its national BC emissions inventory model:

EMEP/EEA Inventory Guidebook 2016	International scientific literature	National studies	Other (specify): ____	Other (specify): ____	Other (specify): ____

Mark with "X" the key issues restricting the submission/improvement of inventory estimates of BC emissions from the following sources in your country's national BC emissions inventory:

Sources	Limited availability of activity data[a]	Lack of data about sector structure[b]	Limited availability of emission factors	Lack of time/financial resources
Residential coal combustion				
Residential wood combustion				
Gas flaring				
Shipping				
Road transport				
Non-road transport				
Open burning of agricultural waste				

[a]Statistical data or other estimates of coal, wood use, gas flare, other fuel consumption, etc.

[b]Especially relevant for residential sector where information about the share of boilers, stoves, fireplaces and their types, e.g., manual, automatic, pellet, EcoDesign conform is often more difficult to obtain compared to total fuel consumption

Figure A2.1 Section of the questionnaire sent to CEIP national contact points.

Table A2.1 Responses to questionnaire element *Mark with '×' the key issues restricting the submission/improvement of your country's national BC emissions inventory*.

Country	Limited availability of activity data	Limited availability of emission factors	Absence of reporting obligation	Other (specify):
Austria			×	High uncertainty of Guidebook methods and lack of financial resources
Canada		×		
Czech Republic	×	×		
Denmark		×		
Finland				Finland has reported a BC emissions inventory since the 2014 submission
Germany		×		Quality of EF available; Absence of a consistent measurement standard
Netherlands		×		
Slovakia		×		
Sweden		×		
United Kingdom				Note that the BC factors used for the UK are drawn from the EMEP/EEA Inventory Guidebook. These are dawn from a variety of sources and measurement approaches. Uncertainty is high and comparability between emission factors (and between ambient air measurements) may be limited.

Table A2.2 Responses to questionnaire element *Mark with '×' the key sources for BC emission factors/inventory methods which your country used to develop its national BC emissions inventory model.*

Country	EMEP/EEA Inventory Guidebook 2016	International scientific literature	National studies	Other (specify):
Canada		×	×	US EPA's Speciate database
Czech Republic	×			
Denmark	×	×		
Finland	×[1]	×[2]	×	[1]2013 Version; [2]Regional Reports
Germany	×			
Netherlands	×	×		
Slovakia	×			
Sweden	×		×	
United Kingdom	×			

Table A2.3 Responses to questionnaire element *Mark with '×' the key issues restricting the submission/improvement of inventory estimates of BC emissions from the following sources in your country's national BC emissions inventory*.

Country	Sources	Limited availability of activity data	Lack of data about sector structure	Limited availability of emission factors	Lack of time/ financial resources
Canada	Residential coal combustion				
	Residential wood combustion	×	×	×	
	Gas flaring			×	
	Shipping			×	
	Road transport				
	Non-road transport			×	
	Open burning of agricultural waste			×	
Czech Republic	Residential coal combustion			×	×
	Residential wood combustion			×	×
	Gas flaring	×			
	Shipping				
	Road transport				
	Non-road transport				
	Open burning of agricultural waste				
Denmark	Residential coal combustion			×	
	Residential wood combustion			×	
	Gas flaring			×	
	Shipping			×	
	Road transport			×	
	Non-road transport			×	
	Open burning of agricultural waste			×	
Finland	Residential coal combustion				
	Residential wood combustion				
	Gas flaring				
	Shipping				
	Road transport				
	Non-road transport				
	Open burning of agricultural waste				
Germany	Residential coal combustion			×	
	Residential wood combustion			×	
	Gas flaring	×		×	
	Shipping			×	
	Road transport			×	
	Non-road transport			×	
	Open burning of agricultural waste			×	
Netherlands	Residential coal combustion		×		
	Residential wood combustion	×	×		
	Gas flaring		×		
	Shipping			×	
	Road transport				
	Non-road transport			×	
	Open burning of agricultural waste	×			

Country	Sources	Limited availability of activity data	Lack of data about sector structure	Limited availability of emission factors	Lack of time/ financial resources
Slovakia	Residential coal combustion		×	×	×
	Residential wood combustion		×	×	×
	Gas flaring	×	×		
	Shipping	×			
	Road transport	×			
	Non-road transport	×			
	Open burning of agricultural waste	×			×
Sweden	Residential coal combustion				
	Residential wood combustion	×	×		
	Gas flaring			×	
	Shipping			×	
	Road transport			×	
	Non-road transport			×	
	Open burning of agricultural waste				
United Kingdom	Residential coal combustion		×		
	Residential wood combustion		×		
	Gas flaring	×		×	
	Shipping				
	Road transport				
	Non-road transport	×	×		
	Open burning of agricultural waste	×			

Appendix A3: Black carbon and $PM_{2.5}$ emissions from the literature

Table A3.1 Comparison of regional estimates for anthropogenic[a] emissions of black carbon and $PM_{2.5}$ (Gg y^{-1}), adapted from Klimont et al. (2017).

Region - (Source) - Year	Black carbon	$PM_{2.5}$
Global		
(**Klimont et al., 2017**) - 1995	6206	43762
(Bond et al., 2004) - 1996	4997	
(**Klimont et al., 2017**) - 2000	6595	44613
(Bond et al., 2013) - 2000	4870	
(**Klimont et al., 2017**) - 2010	7264	47843
HTAP_v2 (Janssens-Maenhout et al., 2015) - 2010	5525	32761
China		
(**Klimont et al., 2017**) - 2000	1646	13554
(Cao et al., 2006) - 2000	1496	
(Streets et al., 2003) - 2000	1049	
(Klimont et al., 2009) - 2000	1345	
(Lu et al., 2011) - 2000	1244	
(Ohara et al., 2007) - 2000	1093	
(Bond et al., 2013) - 2000	1200[b]	
(Zhang et al., 2006) - 2001		12100
(**Klimont et al., 2017**) - 2005	1813	15593
(Zhang et al., 2009) - 2006	1811	13266
(Klimont et al., 2009) - 2005	1366	
(**Klimont et al., 2017**) - 2010	1915	16019
(Lu et al., 2011) - 2010	1838	
(Kurokawa et al., 2013) - 2008	1589	14514
(Guan et al., 2014) - 2010		12100
HTAP_v2 (Janssens-Maenhout et al., 2015) - 2010	1764	12199
(Kondo et al., 2011) - 2008	1940	
India		
(**Klimont et al., 2017**) - 2000	884	6472
(Streets et al., 2003) - 2000	600	
(Ohara et al., 2007) - 2000	795	
(Klimont et al., 2009) - 2000	842	
(Lu et al., 2011) - 2000	736	
(Bond et al., 2013) - 2000	500[b]	
(Reddy and Venkataraman, 2002a,b) - 1998-99	380	4300
(**Klimont et al., 2017**) - 2005	908	5957
(Zhang et al., 2009) - 2006	344	3111
(Klimont et al., 2009) - 2005	1029	
(**Klimont et al., 2017**) - 2010	1022	6032
(Lu et al., 2011) - 2010	996	
HTAP_v2 (Janssens-Maenhout et al., 2015) - 2010	1019	6230
(Kurokawa el al., 2013) - 2008	713	4884

Region - (Source) - Year	Black carbon	$PM_{2.5}$
Europe[c]		
(Klimont et al., 2017) - 1995	675	4584
(Kupiainen and Klimont, 2007) - 1995	717	
(Schaap et al., 2004) - 1995	760	
(Bond et al., 2004) - 1996	768	
(Klimont et al., 2017) - 2000	618	3843
(Kupiainen and Klimont, 2007) - 2000	680	
(Kupiainen and Klimont, 2004) - 2000	672	
(Klimont et al., 2017) - 2010	562	3471
TNO-MACCII (Kueuen et al., 2014) - 2009	548	3199
HTAP_v2 (Janssens-Maenhout et al., 2015)[d] - 2010	382	2133
CLRTAP reporting (wwwceip.at) - 2010		3250
Russian Federation		
(Klimont et al., 2017) - 2010	170	1368
HTAP_v2 (Janssens-Maenhout et al., 2015) - 2010	60	313
(Huang et al., 2015) - 2010	224	
Russian Federation - European part only		
(Klimont et al., 2017) - 2010	71	734
CLRTAP reporting (www.ceip.at) - 2010		367
United States		
(Klimont et al., 2017) - 2000	289	1296
(Battye et al., 2002) - 1999	430	
(Reff et al., 2009) - 2000	440	
(Bond et al., 2013) - 2000	350[b]	
(Klimont et al., 2017) - 2010	201	1027
HTAP_v2 (Janssens-Maenhout et al., 2015) - 2010	295	1640
(US EPA, 2016)[e] - 2011		1909
(US EPA, 2016)[e] - 2014	280	1875

[a]Based on the information available in the quoted studies, all presented estimates exclude forest fires but include agricultural burning, unless stated otherwise; [b]excluding agricultural burning; [c]includes European part of Russian Federation (except HTAP_v2); [d]excluding any territories of Russian Federation; [e]excluding wildfires and prescribed burning, unpaved roads, and construction dust.

Glossary

AMAP	Arctic Monitoring and Assessment Programme
AMSA	Arctic Marine Shipping Assessment
BC	Black carbon
CCAC	Climate and Clean Air Coalition
CEIP	EMEP Centre on Emission Inventories and Projections
CLRTAP	Convention on Long-range Transboundary Air Pollution
COP	Conference of the Parties
dm	Dry matter
EEA	European Environment Agency
EMEP	European Monitoring and Evaluation Programme
EU	European Union
GHG	Greenhouse gas
GNFR	Gridded Nomenclature for Reporting
IEA	International Energy Agency
IIR	Informative Inventory Report
IMO	International Maritime Organization
INDC	Intended Nationally Determined Contribution
IPCC	Intergovernmental Panel on Climate Change
IPPU	Industrial processes and product use (sector)
kWth	Kilowatt (thermal)
NDC	Nationally Determined Contribution
NEC	EU National Emission Ceilings (NEC) Directive 2016/2284
NFR	Nomenclature for Reporting
NH_3	Ammonia
NMVOCs	Non-methane volatile organic compounds
NO_X	Nitrogen oxides
$PM_{2.5}$	Particulate matter, or particles with an aerodynamic diameter equal to or less than 2.5 micrometres (µm)
SLCF	Short-lived climate forcer
SNAP	(Page 19) Supporting National Action and Planning
SNAP	(Page 41) Selected Nomenclature for sources of Air Pollution
SO_X	Sulphur oxides
UNECE	United Nations Economic Commission for Europe
UNFCCC	United Nations Framework Convention on Climate Change

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