DOMESTIC COMBUSTION MODEL MIGRATION

NAEI Methodology Report

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CONTENTS

Appendices

1. FOREWORD

The work described in this report was completed in 2022, and the methodology proposed was subsequently implemented into the NAEI for the first time in NAEI21, published in February 2023. Where the text in this report refers to the current/latest data, this relates to NAEI20, published in February 2022. Since February 2023, the methodology has been further developed, and these improvements are described in the final section of this report. The reader may also wish to refer to the most recent publication of the UK's Informative Inventory Report for the most up to date information.

For information relating to the current (at the time of writing) UK-specific emission factors, the reader should refer to reports produced as part of the Emission Factors for Domestic Solid Fuels (EFDSF) project:

EFDSF Work package 1

EFDSF Work package 2

EFDSF Work package 3

2. EXECUTIVE SUMMARY

As part of the 2021/22 NAEI Improvement Program Defra have funded an item to consolidate the domestic fuel models into one singular inventory system. This is for three main reasons:

- To incorporate the findings of the Defra burning survey carried out by Kantar in 2019 into the NAEI.
- To implement a flexible system that is able to easily accept data from the ongoing domestic combustion projects, including the Emission Factors for Domestic Solid Fuels project.
- To ensure that assumptions regarding appliance mix are consistent across all relevant activities.

As a result of carrying out the task, the UK has now moved to using a Tier 2 model for many pollutants and activities, whereas prior to this exercise, Tier 2 was limited to pollutants from the burning of wood, a selection of pollutants from mineral solid fuels, and NO_X emissions from the usage of natural gas.

At the sectoral level of NFR 1A4bi (Stationary domestic combustion) the emission estimates output of NECR pollutants (NH_3, NO_X, PM_{10}, $PM_{2.5}$, NMVOC) from the new model are largely consistent with the previous suite of approaches, as seen in Table ES-1. SO_2 is excluded from the model due to more detailed country specific factors being applied based on data on the sulphur content of fuels provided by UK fuel manufacturers and suppliers.

Table ES-1 Comparison of emissions of NECR pollutants (excluding SO_2) for 1990, 2005 and 2020 between the previous model suite and the newly implemented model.

ShortPollName	Units	EmissionYear	New model	NAEI20	Raw Difference	% Change
NH_3	kt	1990	5.12E-01	4.24E-01	8.81E-02	21%
NH_3	kt	2005	5.32E-01	4.94E-01	3.78E-02	8%
NH_3	kt	2020	7.85E-01	8.96E-01	-1.11E-01	-12%
NOx	kt	1990	8.70E+01	9.15E+01	-4.58E+00	-5%
NOx	kt	2005	4.97E+01	4.59E+01	3.72E+00	8%
NOx	kt	2020	3.06E+01	3.08E+01	-2.01E-01	-1%
PM_{10}	kt	1990	4.82E+01	4.71E+01	1.09E+00	2%
PM_{10}	kt	2005	1.86E+01	1.91E+01	-5.16E-01	-3%
PM_{10}	kt	2020	1.96E+01	2.02E+01	-6.47E-01	-3%
$PM_{2.5}$	kt	1990	4.72E+01	4.63E+01	9.69E-01	2%
$PM_{2.5}$	kt	2005	1.82E+01	1.87E+01	-5.29E-01	-3%
$PM_{2.5}$	kt	2020	1.91E+01	1.98E+01	-6.57E-01	-3%
VOC	kt	1990	6.76E+01	6.45E+01	3.09E+00	5%
VOC	kt	2005	2.12E+01	2.11E+01	1.32E-01	1%
VOC	kt	2020	2.19E+01	2.36E+01	-1.66E+00	-7%

It should be noted that the information and data presented in this report was correct at the time of writing. Since the date of writing of this report, (two submissions following the work), the following improvements have been made:

- Incorporating emission factors from the Emission Factors for Domestic Solid Fuels project for wood logs for all pollutants except Particulate Matter.
- Improving the accuracy of the use of fuels in newer, Eco-Design stoves through allocating the growth in residential wood use to newly installed appliances.

Further improvements to the domestic combustion system will be documented in the Informative Inventory Reports which accompany annual emission submissions.

3. BACKGROUND

The UK National Atmospheric Emissions Inventory (NAEI) comprises annual pollutant emission estimates from 1970 to the most current inventory year for the majority of pollutants. Some pollutants are estimated from 1990 or 2000 to the most current inventory year. The NAEI is maintained by Ricardo Energy & Environment on behalf of Defra and BEIS and is used fulfil international reporting obligations under the Convention on Long-Range Transboundary Air Pollution (CLRTAP) and National Emissions Ceilings Regulations (NECR) 2018 (which transposed the EU National Emission Ceilings Directive 2016/2284/EU into UK law). In addition, the NAEI includes the UK Greenhouse Gas (GHG) Inventory which is used to monitor progress in achieving GHG emission reductions.

The NAEI is also a key reference data source for Defra, BEIS and other government departments for policy development and tracking progress in achieving emission reduction targets.

Domestic (residential) combustion is a key source for many pollutants in the NAEI. In particular, residential combustion contributes about 25% of UK $PM_{2.5}$ emissions – much of this from combustion of wood.

A number of projects have been undertaken or are in progress to improve emission estimates for residential combustion including:

- A survey of residential burning activity (completed), to be repeated again in 2022/2023.
- Research into new and emerging fuels (ongoing)
- Research into emission factors for wood and other solid fuels (ongoing)
- Development of an improved model within the NAEI for residential combustion (this NAEI improvement project)

The survey of residential burning activity resulted in a major reduction in estimates for wood burned in residential combustion and provided information on technology for wood and solid fuel combustion in the UK. A key aim of this NAEI improvement project is to incorporate the outputs of the residential burning survey in an improved emission estimation model.

Another aim of the improved emission estimation model is to enable incorporation of future outputs (emission factors) from the solid fuels emission factor project, including emission factors for wet wood. Further, incorporation of data from future residential burning surveys has been a key consideration.

4. CURRENT MODEL

Currently, domestic combustion calculations are spread across several models within the NAEI. These models are aligned to different fuel types and pollutants. These models all use a top down approach utilising national energy statistics (DUKES) as the primary activity data and combining them with emission factors that are mainly from the EMEP/EEA Guidebook 2019 but with some being sourced from other literature.

4.1 RESIDENTIAL WOOD

A survey of solid fuel use in the residential sector was published by Defra[1] in 2020 which has led to a large reduction in the estimates for use of wood in the residential sector in the UK[2] in the DUKES 2021 publication. The adoption of the Defra research has led to a new timeseries of activity data in DUKES, revising the residential wood use activity from 2003 onwards. The NAEI has also derived a new timeseries for residential wood use between 1998 and 2003, to address an inconsistency in wood calorific values across the early years in the timeseries.

These recalculations to the wood activity data have had a notable impact on the level and trend of emission estimates from the UK residential sector compared to earlier inventories. The most notable impact is that the recalculated DUKES activity data present a large decrease in wood use in later years of the timeseries, and this leads to much lower reported emissions (notably of particulate matter) from the sector.

Note that the Department of Energy & Climate Change, DECC (now BEISDESNZ) conducted research during 2014-15 into the use of wood for residential heating[3]. This led to a very substantial increase in the estimated use of wood in the residential sector within the DUKES 2015 publication, compared to previous UK energy statistics. The new research incorporated in DUKES 2021 has removed this increase. The Defra survey adopted a different approach to the DECC survey in particular around the time period that householders were asked about their use of heating appliances. The Defra survey asked respondents whether they had burned any fuel in the previous week rather than over a season. Users' recollection of activity over a longer period was felt to be a key uncertainty in the DECC survey, in particular around accurate recollection of when an appliance wasn't in use.

Activity data for this source category remain highly uncertain; the accurate assessment of wood use in the residential sector is extremely difficult due to the lack of comprehensive fuel sales data, this is due, in part, to a substantial component of wood fuel sourced outside conventional fuel markets.

The DECC research[3] enabled some improved assumptions regarding the use of wood in different appliance types over time. Most of the wood burned in 2014 was in non-automatic appliances including about half in open appliances. Although the DECC and recent Defra surveys are a 'snapshot' and primarily intended to provide information on fuel consumption, they also included information on appliance type and age. The Defra survey indicates a lower percentage of fuel burned in open fires than the DECC research. This NAEI Improvement project aims to incorporate appliance information from the Defra survey.

The appliance population across the timeseries is currently modelled assuming that the proportion of wood fuel used in open appliances from 1970-1990 compared to closed appliances was 3:1. Between 1990 and 2014 the ratio was interpolated between 3:1 (1990) and about 1:1 (2014 to 2020). The DECC survey information on appliance age is used to allocate EMEP/EEA Guidebook emission factors for different stove technologies to appliance ages.

Combustion on open fires is less controlled, and therefore typically emits higher levels of many pollutants; the assumptions made on appliance technologies have a large impact on the emission estimates.

Although most of the emissions from wood combustion are calculated using a Tier 2 methodology, ammonia emissions are calculated at a Tier 1 level. Following review of the NAEI during the 2017 submission cycle, the

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[1] Burning in UK Homes and Gardens, Dec 2020 report by Kantar for Defra available here : http://randd.defra.gov.uk/Default.aspx?Module=More&Location=None&ProjectID=20159

[2] The DUKES analysis of residential wood use is provided here https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/976039/Domestic_wood_consumption_new_baseline.pdf

[3] Summary results of domestic wood survey here : https://www.gov.uk/government/publications/summary-results-of-the-domestic-wood-use-survey

ammonia emission factors in the latest EMEP/EEA Guidebook were assessed and determined to be based on wildland fires and consequently highly uncertain for burning in residential appliances. The decision was therefore made to use a Tier 1 factor based on the original reference.

Particulate matter emissions for residential wood combustion in the NAEI are based on emission factors for total particulate matter (filterable and condensable).

4.2 SOLID MINERAL FUELS

Emissions from residential combustion of coal and coal-based solid fuels are estimated from national energy statistics for coal, anthracite, manufactured solid fuels, coke and petroleum coke and EMEP/EEA Guidebook emission factors that take into account the various types of appliances used in the UK. The proportions of each type of appliance using each fuel are estimated, based primarily on information from the 2007 report '*Preparatory Study for Eco-design Requirements of EuPs, Lot 15: Solid fuel small combustion installations: Task 3*'[4], with some more detailed splits utilising expert judgment. The appliance technology assumptions currently are held constant over the 1970-2020 timescale of the inventory. Emissions are calculated using EMEP/EEA Guidebook Tier 2 (for PM fractions, NO_X and CO) and Tier 1 emission factors. Country-specific emission factors are applied for PM species for 'smokeless' fuels Authorised under the Clean Air Act 1993 (anthracite, coke and manufactured solid fuels), based on research on smokeless fuels.

The Defra burning survey provides information on the technology mix used in the UK and this NAEI Improvement project aims to incorporate appliance information from the Defra survey.

4.3 GASEOUS FUELS

Emissions from residential combustion of gaseous fuels are estimated from national energy statistics. For natural gas, EMEP/EEA Guidebook Tier 1 emission factors are applied for all pollutants except for NO_X. The NAEI applies a modelled approach for NO_X emissions to reflect changes in boiler appliance technologies. The method assumes the following emission factors for new boilers in the following four periods:

- 1970-1989 70 g NO_X/GJ net
- 1990-2004 24 g NO_X/GJ net
- >2004 19.4 g NO_X/GJ net
- >2017 15.6 g NO_X/GJ net

The four emission factors chosen are, respectively:

1. the 2009 EMEP/EEA Guidebook default Tier 2 factor (Table 3-20) for domestic natural gas combustion - note that the latest EMEP/EEA Guidebook default Tier 2 factor is lower (42 g/GJ[5]) but is believed to represent more modern boilers;
2. a factor taken from the Ecodesign Directive preparatory studies on central heating boilers (Lot 1) and water heaters (Lot 2) and derived from the GEMIS database for natural gas boilers;
3. the Class 5 standard for new natural gas-fired boilers introduced in EN 483;
4. The Ecodesign ELV of 56 mg/kWh fuel input on a gross basis, introduced in Commission Regulation 814/2013.

An age profile is applied for gas boilers. The age profile is based on a survey of 44,000 homes as part of the RE:NEW home energy retrofit scheme in London in 2012[6] and indicates that about 50% of boilers are up to five years old but 11% were more than 15 years old.

[4] Available here: http://www.eceee.org/ecodesign/products/solid-fuel-small-combustion-installations/ (website checked 22 February 2022)

[5] 2019 EMEP/EEA guidebook chapter *1.A.4 Small combustion 2019*, table 3.16

[6] https://www.london.gov.uk/sites/default/files/domestic_boiler_emission_testing_report.pdf

4.4 LIQUID FUELS

For residential oil combustion, national energy statistics provide activity data. Tier 1 emission factors for CO, NO_X and PM_{10} are taken from the latest EMEP/EEA Guidebook, whereas factors for SO_X and metals are based on UK-specific data on fuel composition.

4.5 SUMMARY OF PROPOSED IMPROVEMENT

The aim of this improvement project is to combine the various models used in the NAEI into one single model utilising R. As part of this, profiles of appliance ages and their technology levels can be used for all fuel types. Currently, this approach is only used for wood combustion and natural gas. In parallel to developing the model, stakeholder consultation has been undertaken to allow testing and revision of assumptions and parameters with any information that sectoral experts could provide. Furthermore, a literature review of available emission factor data was conducted to ascertain if any improvements could be made to the emission factors currently used in the NAEI models.

5. SCOPE OF NEW MODEL

The new Domestic Combustion Model Suite produces estimates of emission factors for a range of solid, liquid and gaseous fuel appliances used in the domestic sector. The model is split into three modules covering solid, gaseous and liquid fuels. Projections have been built into the model, such that the same methodology is used to estimate emissions through to 2040, by incorporating the trends in activity data quoted in EEP. For clarity of comparison to the 2022 submission, the emissions from 2021 to 2040 are not displayed in this report.

Table 5-1, Table 5-2 and Table 5-3 set out the scope of each module.

Projections have been built into the model, such that the same methodology is used to estimate emissions through to 2040, by incorporating the trends in activity data quoted in EEP. For clarity of comparison to the 2022 submission, the emissions from 2021 to 2040 are not displayed in this report.

Table 5-1 Scope of the Solid Fuel Module

Parameter	Scope
Fuels	Anthracite, Coal, Coke, Peat, Charcoal, Petroleum Coke, Smokeless Solid Fuel, Wood
Years	1990-2040
Appliances	Open Fireplaces; Closed Stoves; Boilers; Outdoor
Pollutants	All (Tier 2), except SO_x, NH_3

Table 5-2 Scope of the Gaseous Fuel Module

Parameter	Scope
Fuels	Natural Gas, LPG
Years	1990-2040
Appliances	Gas boilers, Roomheaters & Water boilers; Gas cookers; LPG boilers & Roomheaters
Pollutants	NO_x (Tier 2), all others, Tier 1

Table 5-3 Scope of the Liquid Fuel Module

Parameter	Scope
Fuels	Burning oil, Gas oil
Years	1990-2040
Appliances	Boilers; Space heaters
Pollutants	All (Tier 2), except SO_x

6. SOLID FUELS

Solid fuels include wood, coal, anthracite, petroleum coke, manufactured solid fuels (including coke in the historic inventory), peat and charcoal. The solid fuel section is the most complex module in the new model, this is due to there being a need to take account of a combination of different types of appliance, each of which may have multiple technologies and associated emission factors, and also are capable of burning a range of fuels. In comparison, Liquid and Gaseous technologies have much more limited variation in fuel type and combustion technology.

6.1 APPLIANCE TYPES

Three appliance types are taken account of within the Solid Fuel module – open fireplaces, closed stoves and 'other', which predominantly refers to boilers. Within each of the appliance types, there are a range of technologies that are taken account of, relating generally to changing emission controls and efficiencies over time. Table 6-1 shows the appliances taken account of in the Solid Fuel module and the years in which they have been manufactured and installed in people's homes.

The choice in technologies used is designed to be compatible with ongoing Emission Factors development work (the Emission Factors for Domestic Solid Fuels project) and the range of emission factors that are present within the EMEP/EEA 2019 Guidebook.

Table 6-1 Solid Fuel Appliances, technologies and years manufactured.

Appliance	Technology detail	Start year	End year
Open fireplace	Default fireplace	1970	2040
Closed stove	Basic stove	1970	2000
Closed stove	Upgraded stove	2001	2021
Closed stove	Ecodesign stove	2017	2040
Other	Boiler	1970	2040

The module is scalable, such that if a further technology is developed or planned to be implemented in the future, it can be included in the model by defining the appliance type, the years in which it is manufactured (and installed) in, and relevant emission factors. In most cases in all modules, it is assumed that the final year of manufacture of an old technology and the first year of a new technology occur in consecutive years without overlap for simplicity. If this is not the case, and there is indeed an overlap, for example in the transition from Upgraded Stoves to Ecodesign Stoves, then if there is no further information, a linear interpolation is modelled. In the case of the migration from Upgraded to Ecodesign stoves, following recent discussions with the Stove Industry Alliance, we are set to receive sales data showing the split between Upgraded and Ecodesign stoves in these overlap years. This information is expected to be available for incorporation into the model in time for compilation for the 2023 inventory submission, however the data is anticipated to be generally in line with the assumption of a linear transition.

6.2 AGE PROFILES

For each technology, in particular stoves, which is where the majority of technological development has occurred, it is key for the NAEI to estimate the proportions of different-aged technologies in use across the UK. As previously mentioned (see Section 4), in the current NAEI, the 2014 DECC residential wood survey was used as the full basis for appliance ages. The Defra burning survey provides a more recent (2019) data point for the appliance ages. In the respective publications, there is an indication of the proportion of appliances which were installed in a certain time period. The raw percentages obtained from the publications are displayed in Table 6-2 and Table 6-3.

Table 6-2 Proportion of Solid Fuel Appliances by Age in 2014 (BEIS residential wood survey)

Appliance	0-1 Years	1-2 Years	2-5 Years	5-15 Years	15+ Years	Undefined
Open Fireplace, %	3	4	4	14	68	7
Closed Stove, %	14	13	29	24	12	8
Pellet Stove, %	33	11	22	11	22	0
Manual Boiler, %	29	14	0	43	0	14

Table 6-3 Proportion of Solid Fuel Appliance by Age in 2019 (Defra residential burning survey)

Appliance	Installed between 2009-2019	Installed between 2000-2009	Installed before 2000
Open Fireplace, %	4	9	81
Closed Stove, %	71	19	10

These datasets are converted into age profiles by first spreading the percentage in each year bracket evenly, and by setting the earliest that an appliance can be installed being 1970. Subsequently, a profile is generated for each appliance in 2014 and 2019 by using a Locally Estimated Scatterplot Smoothing (LOESS) model. The profiles generated for closed stove appliances can be seen in Figure 6-1 and Figure 6-2.

Figure 6-1 Closed Stove Age Profile for 2014

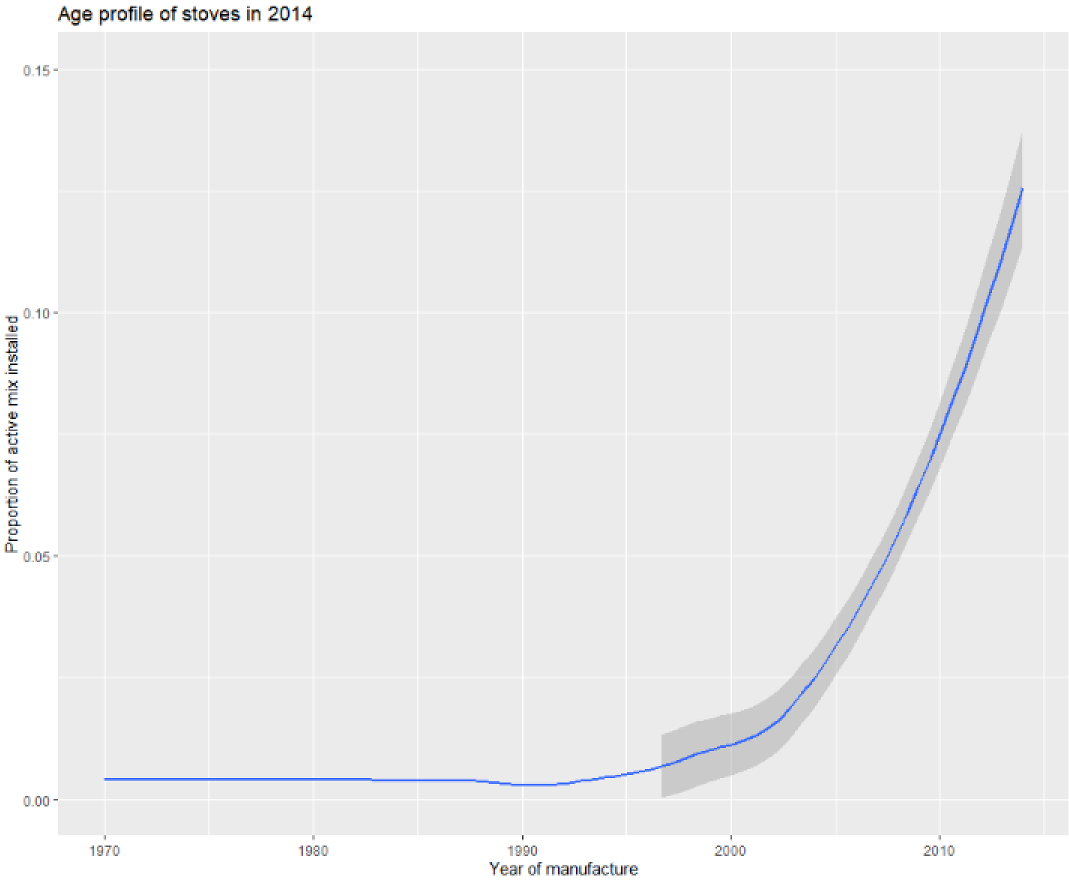
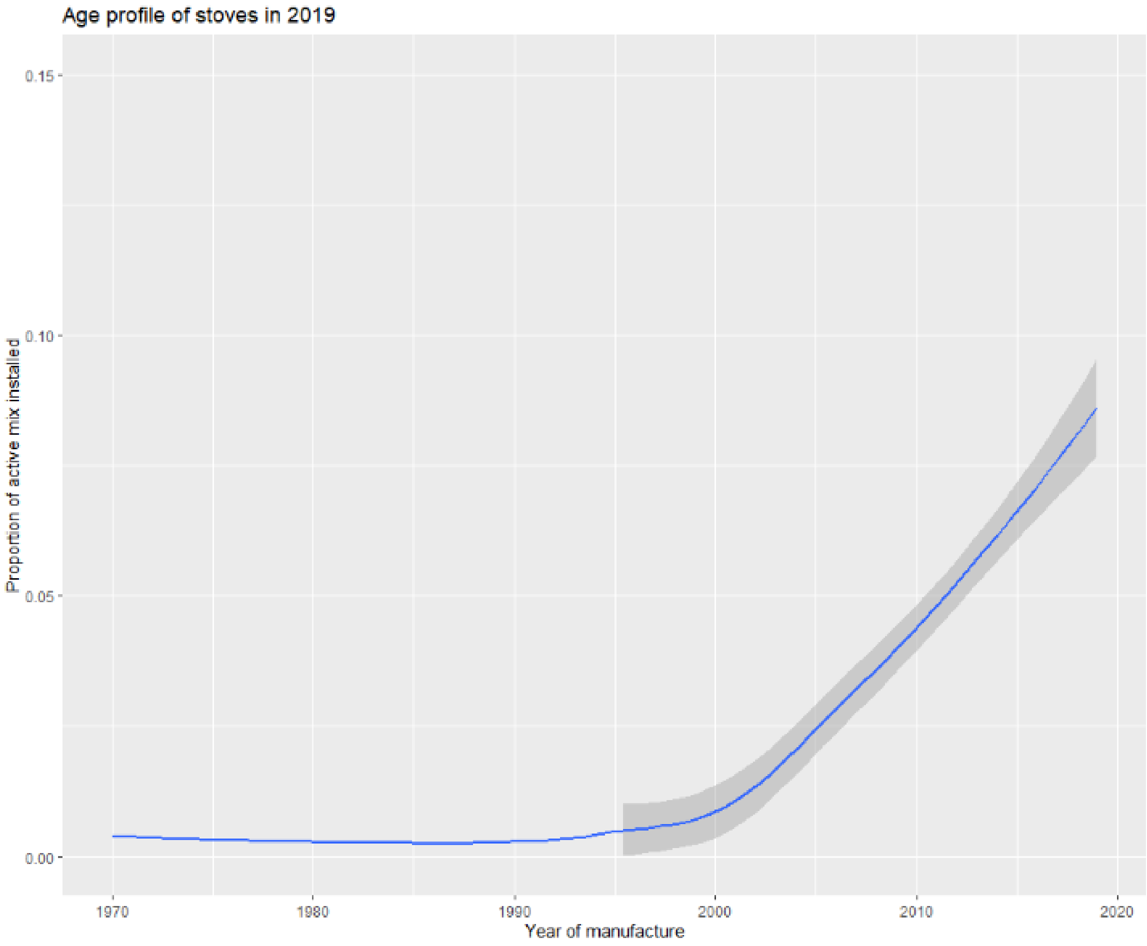


Figure 6-2 Closed Stove Age Profile for 2019



Both the 2014 and 2019 studies indicate an exponential decay in appliance age – with a much higher proportion of newer stoves in use at the point of time that the surveys were carried out, followed by a steep decline to a small proportion of older appliances in use. Data from the 2014 study suggests that the median age of stoves surveyed was 8 years old, whilst the Defra burning survey in 2019 calculates the median age of 10. It is encouraging that these profiles are broadly consistent with one another, and from discussions with the SIA, it has been confirmed that these are realistic.

In the absence of other data, the 2014 age profile is applied for years prior to 2014; for years beyond 2019, the 2019 age profiles are assumed to be the best available data. For intervening years, the 2014 and 2019 age profiles are interpolated.

As mentioned in Table 6-1, the assignations of appliance age can be mapped onto the detailed technology of the appliance, and subsequently, appropriate emission factors can be applied. This is covered in further detail in Section 6.5.

6.3 APPLIANCE USE

Activity data for the domestic sector is obtained directly from DUKES. The data provided however, is high level, and only split out by fuel type. It is therefore necessary to estimate the split of each fuel type between appliance types. Within the model, this is done first by estimating the proportion in populations of appliance types, for example open fires and closed stoves. The technology proportions are developed from 4 sets of data from regular time intervals and as a result capture evolution in technology use better than other areas of the model. Assumptions on the split in populations are provided in Table 6-4. Outdoor appliances are populated with a proportion of ‘1’ to enable data to be calculated as anticipated, as the system does not accept a NULL value.

Table 6-4 Population Proportions of Solid Fuel Appliances

Appliance	Profile Start Year	Population Proportion	Data Source
Open Fireplace	1990	56	British Coal (1990)
Closed Stove	1990	30	British Coal (1990)
other	1990	13	British Coal (1990)
Outdoor	1990	1	Arbitrary input for completeness
Open Fireplace	1999	67	UK Model (2011)
Closed Stove	1999	25	UK Model (2011)
other	1999	7	UK Model (2011)
Outdoor	1999	1	Arbitrary input for completeness
Open Fireplace	2007	67	UK Model (2011)
Closed Stove	2007	25	UK Model (2011)
other	2007	7	UK Model (2011)
Outdoor	2014	1	Arbitrary input for completeness
Open Fireplace	2014	43	BEIS (2014)
Closed Stove	2014	52	BEIS (2014)
other	2014	3	BEIS (2014)
Outdoor	2014	1	Arbitrary input for completeness
Open Fireplace	2019	32	Kantar (2019)
Closed Stove	2019	60	Kantar (2019)
other	2019	7	Kantar (2019)
Outdoor	2019	1	Arbitrary input for completeness

The population proportions are then weighted by the average amount of time per week that appliances are used based on survey data from 2014 and 2019. The assumptions of these are documented in Table 6-5.

Table 6-5 Average Hours per week of use by Solid Fuel Appliance

Appliance	Year	Hours
Open Fireplace	2014	26
Closed Stove	2014	38
other	2014	47
Open Fireplace	2019	66
Closed Stove	2019	71

As with the age profiles, if there is a lack of data between two intervening years, it is interpolated to produce a steady trend. If there is no further data available, for instance, beyond 2019, then the data for the latest year is rolled forward.

6.4 FUEL USE

Once the activity has been split by appliance type, it is necessary to determine the proportions that different fuels are used within the appliances. In the solid fuel module, this has been carried out in two parts:

1) Determine the split between mineral and wood fuels
2) Split wood and mineral activity further

Carrying out the disaggregation is required to be done in two steps due to the availability of the data that has been identified. To produce a broad split of wood-mineral fuel use in domestic appliances, data displayed in Figure 4.7 of the Defra survey is utilised as separate data are provided for open fireplaces and closed stoves – the two main appliance types used to burn solid fuel domestically. This split is show in Table 6-6; which is allocated, in lieu of further data and evidence, against the proportions shown for all years of the time series.

Table 6-6 Proportions of wood and mineral fuel used in Open Fireplaces and Closed Stoves

Fuel Mix	Open Fireplaces, %	Closed Stoves, %
Wood only	8	28
Wood mix[7] only	20	31
Wood and coal	26	18
Wood mix[7] and coal	38	20
Coal	7	2
Other	2	1

Following the application of proportions shown in Table 6-6, activity of each fuel mix is separated further using splits derived from:

1) The Defra burning survey (Annex B, Table 4.1) to calculate the proportion to attribute to wood and mineral fuels in each of with 'wood and coal' and 'wood mix and coal' groups;
2) British Coal (1990) to disaggregate the coal activity into: Anthracite, House Coal, Coke, Petroleum Coke, Smokeless Solid Fuel

The proportions by which the high level Fuel Mixes are broken down by is shown in Table 6-7. From this data, the following key observations can be made:

i) There is no assumed activity regarding the burning of anthracite in open fireplaces, this is following research that has been carried out as part of the Emission Factors for Domestic Solid Fuels project, where it was found that anthracite required a disproportionate amount of user attention to remain burning in open fires.

ii) The split between wood and mineral fuels is based on data derived from the Defra Burning Survey, this provides a snapshot of the most recent years, but may not be as accurate for historical years.

iii) The disaggregation of mineral fuels has been carried out using data from British Coal in 1990, and so is likely to be more uncertain when applied to current use. Stakeholders to help address this issue have been identified and it is hoped that consultation will allow refinement of assumptions prior to the 2023 submission.

[7] 'Wood mix' is defined in the 1st Burning Survey as logs, pellets, briquettes and/or wood chips] and/or either waste wood or garden wood.

Table 6-7 Breakdown of Fuel Mixes into Detailed Activities

Fuel Mix	Parent Fuel	Detail Fuel	Open Fireplaces	Closed Stoves	Outdoor
Wood only	Wood	Wood	100	100	NA
Wood mix only	Wood	Wood	100	100	NA
Wood and coal	Wood	Wood	35.3	66.7	NA
Wood and coal	Coal	Anthracite	NA	14.2	NA
Wood and coal	Coal	Coal	44.9	3.5	NA
Wood and coal	Coal	Coke	5.3	5.2	NA
Wood and coal	Coal	Petroleum Coke	5.3	5.2	NA
Wood and coal	Coal	Smokeless Solid Fuel	5.3	5.2	NA
Wood and coal	Coal	Peat	3.8	NA	NA
Wood mix and coal	Wood	Wood	35.3	66.7	NA
Wood mix and coal	Coal	Anthracite	NA	14.2	NA
Wood mix and coal	Coal	Coal	44.9	3.5	NA
Wood mix and coal	Coal	Coke	5.3	5.2	NA
Wood mix and coal	Coal	Petroleum Coke	5.3	5.2	NA
Wood mix and coal	Coal	Smokeless Solid Fuel	5.3	5.2	NA
Wood mix and coal	Coal	Peat	3.8	NA	NA
Coal	Coal	Anthracite	NA	42.7	NA
Coal	Coal	Coal	79.5	10.6	13.3
Coal	Coal	Coke	8.2	15.6	NA
Coal	Coal	Petroleum Coke	8.2	15.6	NA
Coal	Coal	Smokeless Solid Fuel	8.2	15.6	NA
Coal	Coal	Peat	5.9	NA	NA
Coal	Coal	Charcoal	NA	NA	86.7

Note that wood use outdoors is assumed to be waste wood and covered under small-scale waste burning (5C2) in the NAEI. To determine the allocation of activity by appliance type, the data in Table 6-4, Table 6-5, Table 6-6 and Table 6-7 are combined and the product is calculated to produce a weighting. This weighting is then multiplied by the overall activity data for each fuel that has been calculated via other data streams within the NAEI – in all cases at present, this refers to the figures quoted within DUKES. To ensure that all of the DUKES activity is captured a check is made to ensure that the fuel sums are equivalent, and if not the activity is normalised as appropriate.

One further area of the module to have been developed, but not yet incorporated is the ability to take into account different moisture contents of wood. This will be incorporated following the determination and acceptance of suitable emission factors derived from the Defra Emission Factors for Domestic Solid Fuels project. At present, only one year's worth of data is available to proportion wood fuel usage across differing moisture contents from the Defra Burning Survey and is presented in Table 6-8.

Table 6-8 Proportions of Different Moisture Contents of Wood used in Domestic Burning

Wood Type	Moisture Content (%)	Proportion (%)
Kiln-Dried	10	18
Seasoned	20	56
Wet	30	26

6.5 EMISSION FACTORS

One key outcome from this improvement project has been the ease in migrating to a higher Tier method for a large range of pollutants. As mentioned in Section 4, in the current NAEI models, only a selection of the most important pollutants for domestic combustion were modelled using the Tier 2 model, the remaining pollutants utilised a standard Tier 1 method of Activity Data x Default EF.

For the Solid Fuel module, almost all EFs are now obtained from the 2019 EMEP/EEA Guidebook, Chapter 1A4, Small Combustion, the specific tables of which are documented in Table 6-9.

Table 6-9 Solid Fuel Emission Factor Sources

Appliance	Technology	Fuel	Source[a]	Notes
Open Fireplace	Default Fireplace	Coal	Table 3.12	
Open Fireplace	Default Fireplace	Wood	Table 3.39	
Open Fireplace	Default Fireplace	Petroleum Coke	Table 3.12	(b)
Open Fireplace	Default Fireplace	Smokeless Solid Fuel	Table 3.12	(b)
Open Fireplace	Default Fireplace	Coke	Table 3.12	(b)
Closed Stove	Basic Stove	Anthracite	Table 3.14	
Closed Stove	Basic Stove	Coal	Table 3.14	
Closed Stove	Basic Stove	Wood	Table 3.40	
Closed Stove	Basic Stove	Petroleum Coke	Table 3.14	(b)
Closed Stove	Basic Stove	Smokeless Solid Fuel	Table 3.14	(b)
Closed Stove	Basic Stove	Coke	Table 3.14	(b)
Closed Stove	Upgraded Stove	Anthracite	Table 3.14	
Closed Stove	Upgraded Stove	Coal	Table 3.14	

Appliance	Technology	Fuel	Source[a]	Notes
Closed Stove	Upgraded Stove	Wood	Table 3.41	
Closed Stove	Upgraded Stove	Petroleum Coke	Table 3.14	(b)
Closed Stove	Upgraded Stove	Smokeless Solid Fuel	Table 3.14	(b)
Closed Stove	Upgraded Stove	Coke	Table 3.14	(b)
Closed Stove	Ecodesign Stove	Anthracite	Table 3.19	
Closed Stove	Ecodesign Stove	Coal	Table 3.19	
Closed Stove	Ecodesign Stove	Wood	Table 3.42	
Closed Stove	Ecodesign Stove	Petroleum Coke	Table 3.19	(b)
Closed Stove	Ecodesign Stove	Smokeless Solid Fuel	Table 3.19	(b)
Closed Stove	Ecodesign Stove	Coke	Table 3.19	(b)
other	boiler	Coal	Table 3.15	
other	boiler	Anthracite	Table 3.15	
other	boiler	Petroleum Coke	Table 3.15	(b)
other	boiler	Smokeless Solid Fuel	Table 3.15	(b)
other	boiler	Coke	Table 3.15	(b)

[a] All tables refer to Chapter 1A4 – Small Combustion in the 2019 EMEP/EEA Guidebook https://www.eea.europa.eu/publications/emep-eea-guidebook-2019/part-b-sectoral-guidance-chapters/1-energy/1-a-combustion/1-a-4-small-combustion/view

[b] Emission Factors relating to Particulate Matters are one-fifth of that quoted in the EMEP/EEA Guidebook table based on UK country-specific research on emission limits for Authorised fuels approved for use in Smoke Control Areas under the Clean Air Act 1993 (as applied in the current NAEI models).

Not all EFs are directly obtained from the guidebook, for some pollutants, we have used country-specific evidence to deviate; these are provided as notes to Table 6-9 and as follows:

SO_2 EFs for mineral fuels – We are opting not to use the default EFs from the guidebook because the UK Inventory Agency has detailed data on the sulphur content of coal and other mineral fuels and, in most cases, SO_2 emissions are driven by the sulphur content of the fuel rather than technology, especially on the domestic scale where no abatement measures are applied for SO_2. There may be some sulphur retained in ash and the proportion can vary for different combustion technologies) but these are generally minor differences.

NH_3 EF for wood – The Guidebook EFs for NH_3 from wood combustion are derived from a source that provides EFs of NH_3 from wildfires, and hence this is believed to not be appropriate for use in the domestic sector, where the burning is controlled. As a result, we are proposing to use the current NAEI method of applying a ratio of 0.0073 (based on a US EPA report[8]) to the CO emission factor.

Metals petroleum coke – Due to the manufacturing methods of petroleum coke, small amount of the catalysts used may be included in the final product, and hence the concentrations of the metals emissions are higher

[8] Development of Emissions Inventory Methods for Wildland Fire Final Report, February 2002, Prepared for: U.S. Environmental Protection Agency, Research Triangle Park, North Carolina 27711, EPA Contract No. 68-D-98-046, Work Assignment No. 5-03. Prepared by: William Battye, Rebecca Battye, EC/R Incorporated. Available here : https://www3.epa.gov/ttnchie1/ap42/ch13/related/firerept.pdf

than would be the case in other mineral fuels. In the new model the Guidebook EFs have been used but, it is planned to use the same methodology as the 2022 submission.

PAH Mineral fuels – The factors presented in APARG (Air Pollution Abatement Review Group) are disaggregated by fuel types which are represented in DUKES, as opposed to the Guidebook which only presents general mineral fuel factors. In the new model, the factors from the 2019 EMEP/EEA Guidebook are applied however, it is planned to use the same methodology as the 2022 submission and align the EFs with the APARG report.

NMVOC Mineral fuels – Following research into the current NAEI data source (Brain et al, 1994), the model uses the EMEP/EEA Guidebook EF for NMVOC for coal and other solid mineral fuels will apply a ratio between coal and other solid mineral fuels from Brain et al to other solid mineral fuels.

It is anticipated that the Emission Factors for Domestic Solid Fuels project will produce EFs in time for adoption in the 2023 submission for wood fuels burnt in stoves, with mineral fuels to follow in the subsequent compilation cycle. Emission factors for wood will be determined for a large range of pollutants across three different moisture contents, aligning to the activity data split in Annex A, Table 1 of the Defra Burning Survey. The Solid Fuel module has been constructed in such a way that it will be simple to implement these new UK-specific emission factors, thereby improving the understanding of the uncertainty.

6.6 RESULTS

Presented in this section are a summary of the emissions calculated from the new solid fuel module compared to the estimates produced for the 2022 submission, as displayed in Table 6-10 together with a list of reasons for change for each pollutant in Table 6-11. For graphs displaying the comparison in emissions for each pollutant, please refer to Appendix 1.

Table 6-10 Comparison of Emissions estimated from the new model vs 2022 Submission Outputs

ShortPollName	Units	EmissionYear	New model	NAEI20	Raw Difference	% Change
As	kt	1990	4.91E-04	2.94E-03	-2.45E-03	-83%
As	kt	2005	1.02E-04	6.43E-04	-5.41E-04	-84%
As	kt	2020	6.11E-05	5.45E-04	-4.84E-04	-89%
B[a]p	kg	1990	3.29E+04	6.97E+03	2.59E+04	372%
B[a]p	kg	2005	8.80E+03	2.59E+03	6.21E+03	239%
B[a]p	kg	2020	7.48E+03	2.83E+03	4.65E+03	164%
Benzo[b]fluoranthene	kg	1990	4.02E+04	2.04E+03	3.81E+04	1868%
Benzo[b]fluoranthene	kg	2005	1.04E+04	1.91E+03	8.49E+03	444%
Benzo[b]fluoranthene	kg	2020	8.95E+03	2.26E+03	6.69E+03	296%
Benzo[k]fluoranthene	kg	1990	1.86E+04	7.24E+02	1.79E+04	2472%
Benzo[k]fluoranthene	kg	2005	4.59E+03	7.17E+02	3.87E+03	540%
Benzo[k]fluoranthene	kg	2020	3.86E+03	8.31E+02	3.03E+03	364%
Black Carbon	kt	1990	3.99E+00	4.23E+00	-2.39E-01	-6%
Black Carbon	kt	2005	1.52E+00	1.47E+00	4.81E-02	3%
Black Carbon	kt	2020	1.92E+00	1.74E+00	1.83E-01	11%
Cd	kt	1990	4.65E-04	3.58E-04	1.07E-04	30%

ShortPollName	Units	EmissionYear	New model	NAEI20	Raw Difference	% Change
Cd	kt	2005	2.85E-04	2.47E-04	3.88E-05	16%
Cd	kt	2020	3.91E-04	4.24E-04	-3.31E-05	-8%
CO	kt	1990	9.02E+02	9.13E+02	-1.06E+01	-1%
CO	kt	2005	2.46E+02	2.48E+02	-1.91E+00	-1%
CO	kt	2020	2.26E+02	2.44E+02	-1.84E+01	-8%
Cr	kt	1990	2.40E-03	6.28E-03	-3.88E-03	-62%
Cr	kt	2005	8.31E-04	1.96E-03	-1.13E-03	-58%
Cr	kt	2020	9.13E-04	2.18E-03	-1.26E-03	-58%
Cu	kt	1990	4.17E-03	1.44E-03	2.73E-03	190%
Cu	kt	2005	9.48E-04	5.51E-04	3.97E-04	72%
Cu	kt	2020	7.08E-04	6.14E-04	9.39E-05	15%
Dioxins	g-ITEq	1990	1.07E+02	1.49E+02	-4.22E+01	-28%
Dioxins	g-ITEq	2005	3.31E+01	4.20E+01	-8.85E+00	-21%
Dioxins	g-ITEq	2020	2.86E+01	3.75E+01	-8.88E+00	-24%
HCB	kg	1990	1.85E-01	1.10E-01	-2.82E-03	67%
HCB	kg	2005	1.11E-01	8.74E-02	-2.80E-04	27%
HCB	kg	2020	1.54E-01	1.57E-01	-2.79E-02	-2%
Hg	kt	1990	7.55E-04	7.09E-04	4.58E-05	6%
Hg	kt	2005	1.67E-04	1.94E-04	-2.68E-05	-14%
Hg	kt	2020	1.20E-04	1.84E-04	-6.36E-05	-35%
Indeno[123-cd]pyrene	kg	1990	1.61E+04	4.73E+03	1.14E+04	241%
Indeno[123-cd]pyrene	kg	2005	4.47E+03	1.58E+03	2.89E+03	182%
Indeno[123-cd]pyrene	kg	2020	4.09E+03	1.66E+03	2.43E+03	146%
NH_3	kt	1990	5.12E-01	4.24E-01	-6.99E-02	21%
NH_3	kt	2005	5.32E-01	4.94E-01	-1.05E-02	8%
NH_3	kt	2020	7.85E-01	8.96E-01	-2.02E-01	-12%
Ni	kt	1990	2.40E-03	1.23E-02	-9.91E-03	-81%
Ni	kt	2005	5.21E-04	6.00E-02	-5.95E-02	-99%
Ni	kt	2020	3.56E-04	6.77E-02	-6.73E-02	-99%
NOx	kt	1990	1.82E+01	2.32E+01	-4.99E+00	-21%
NOx	kt	2005	4.63E+00	5.68E+00	-1.04E+00	-18%

ShortPollName	Units	EmissionYear	New model	NAEI20	Raw Difference	% Change
NOx	kt	2020	4.25E+00	5.99E+00	-1.74E+00	-29%
Pb	kt	1990	2.41E-02	1.83E-02	5.85E-03	32%
Pb	kt	2005	5.34E-03	3.26E-03	2.07E-03	64%
Pb	kt	2020	3.75E-03	2.92E-03	8.30E-04	28%
PCB	kg	1990	2.90E+01	2.15E+01	7.26E+00	35%
PCB	kg	2005	6.04E+00	3.35E+00	1.35E+00	80%
PCB	kg	2020	4.19E+00	2.61E+00	5.64E-01	61%
PM_{10}	kt	1990	4.78E+01	4.57E+01	2.05E+00	4%
PM_{10}	kt	2005	1.82E+01	1.74E+01	7.23E-01	4%
PM_{10}	kt	2020	1.92E+01	1.89E+01	3.20E-01	2%
$PM_{2.5}$	kt	1990	4.69E+01	4.49E+01	1.93E+00	4%
$PM_{2.5}$	kt	2005	1.78E+01	1.70E+01	7.09E-01	4%
$PM_{2.5}$	kt	2020	1.88E+01	1.84E+01	3.10E-01	2%
Se	kt	1990	2.63E-04	2.69E-03	-2.43E-03	-90%
Se	kt	2005	6.33E-05	7.87E-04	-7.24E-04	-92%
Se	kt	2020	5.12E-05	7.34E-04	-6.83E-04	-93%
TPM	kt	1990	5.14E+01	4.97E+01	1.66E+00	3%
TPM	kt	2005	1.92E+01	1.85E+01	6.89E-01	4%
TPM	kt	2020	2.03E+01	2.00E+01	2.26E-01	1%
VOC	kt	1990	6.57E+01	6.16E+01	4.11E+00	7%
VOC	kt	2005	1.90E+01	1.75E+01	1.41E+00	8%
VOC	kt	2020	2.01E+01	2.08E+01	-6.58E-01	-3%
Zn	kt	1990	4.88E-02	2.15E-02	2.73E-02	127%
Zn	kt	2005	1.75E-02	1.19E-02	5.60E-03	47%
Zn	kt	2020	1.97E-02	1.86E-02	1.07E-03	6%

Table 6-11 Reasons for Change of Emission Estimates for Solid Fuels

Pollutant	Reason For Change
As	Change driven by migration of mineral fuel EFs from T1 to T2, previously the vast majority of EFs were obtained from Perry, 2002.
B[a]P	Driven by migration of mineral fuel EFs from T1 to T2, previously EFs were obtained from APARG, 1995 and Smith, 1984.
Benzo[b]fluoranthene	Driven by migration of mineral fuel EFs from T1 to T2, previously EFs were obtained from APARG, 1995 and Smith, 1984.
Benzo[k]fluoranthene	Driven by migration of mineral fuel EFs from T1 to T2, previously EFs were obtained from APARG, 1995 and Smith, 1984.

Pollutant	Reason For Change
Black Carbon	Revision due to assuming that no anthracite is burnt in open fires, increasing emissions in a number of years, offset by a decrease in emissions from the improved modelling system.
Cd	Increase in the first part of the time series due to the assumption that anthracite is not used in open fireplaces, but only closed stoves, thereby using a higher emission factor.
CO	Small revisions across a range of fuels as a result of the implementation of the new method.
Cr	Change driven by migration of mineral fuel EFs from T1 to T2, previously the vast majority of EFs were obtained from Perry, 2002.
Cu	Change driven by migration of mineral fuel EFs from T1 to T2, previously the vast majority of EFs were obtained from Perry, 2002.
Dioxins	Change driven by migration of mineral fuel EFs from T1 to T2, previously a T1 factor from the 2019 EMEP/EEA Guidebook was used.
HCB	Emissions estimated from fuels other than coal and wood for the first time.
Hg	Change driven by migration of mineral fuel EFs from T1 to T2, previously the vast majority of EFs were obtained from Perry, 2002, and a general factor for petroleum coke was used.
Indeno[123-cd]pyrene	Driven by migration of mineral fuel EFs from T1 to T2, previously EFs were obtained from APARG, 1995 and Smith, 1984.
NH_3	Migration to Tier 2 method for coal based fuels.
Ni	Revision almost exclusively due to migrating the EF for petroleum coke to using the 2019 EMEP/EEA Guidebook as opposed to a general factor from previous metal analysis.
NO_X	Revisions due to changes in the modelling approach.
Pb	Change driven by migration of mineral fuel EFs from T1 to T2, previously the vast majority of EFs were obtained from Perry, 2002.
PCB	Emissions estimated for petroleum coke for the first time.
PM_{10}	Revision due to assuming that no anthracite is burnt in open fires, increasing emissions in a number of years, offset by a decrease in wood emissions as a result of the improved modelling system.
$PM_{2.5}$	Revision due to assuming that no anthracite is burnt in open fires, increasing emissions in a number of years, offset by a decrease in wood emissions as a result of the improved modelling system.
Se	Change driven by migration of mineral fuel EFs from T1 to T2, previously the vast majority of EFs were obtained from Perry, 2002, and a general factor for petroleum coke was used.
TPM	Revision due to assuming that no anthracite is burnt in open fires, increasing emissions in a number of years, offset by a decrease in wood emissions as a result of the improved modelling system.
VOC	Migration from factors from Brain (1994) to the 2019 EMEP/EEA Guidebook.
Zn	Change driven by migration of mineral fuel EFs from T1 to T2, previously the vast majority of EFs were obtained from Perry, 2002.

6.7 LIMITATIONS AND UNCERTAINTIES

The limitations and uncertainties of the methods used to calculate emissions from solid fuel use in the domestic sector have largely been documented previously throughout Section 6, and are summarised within this sub-section.

i) Age Profiles – Presently, only two point in time surveys have been able to be used in the module representing the state of the sector in 2014 and 2019. These have been verified by industry experts to be appropriate for the time period in question, but there will remain uncertainty regarding historic data in particular. For projections too, the age profiles have to be considered more uncertain. Current (2022) high energy costs for gas and oil-based domestic heating systems could increase use of solid-fuel stoves used in the UK in the coming years. Due to fuel use being normalised to DUKES overall, the age and share of appliances are the most sensitive areas of the model as the age determines the technology in use and hence the emission factor to be used.

ii) Wood/Mineral Split – To estimate the proportions of wood vs mineral fuel used in appliances, data is only available from the Defra Burning Survey and pertains to the status in 2019. This is unlikely to be the same for all years as it will have changed over time with the development of different stove technologies. However, this is likely to have a reduced impact as overall fuel use is aligned with DUKES national activity data.

iii) Mineral Fuel Split – The data used to disaggregate total mineral fuel usage into individual fuels such as coal, anthracite and Smokeless Solid Fuel is currently based on British Coal data from 1990. During stakeholder consultation, it was commented that this split is likely to be unreasonable for recent years. Further stakeholder meetings are being arranged to address this prior to the 2023 inventory cycle.

iv) Wood Moisture Content – The proportion or wet and seasoned wood has been estimated from data in the Defra burning survey which is assumed to apply across all years. This is a highly uncertain (but most appropriate, based on the current information) assumption to make, particularly for historic data, and any sizeable change in the split would likely alter emission estimates.

6.8 FUTURE IMPROVEMENTS

The solid fuel module is set to undergo further improvements, both before the 2023 submission, and in the following years as subsequent funded items are completed and integrated inro the NAEI. The items that are expected to feed into and improve the module and the timescales are as follows:

i) Improved wood emission factors – The Emission Factors for Domestic Solid Fuel project will produce emission factors for wood of differing moisture contents burnt in a range of appliances and technologies. This is expected to feed into the module in time for the **2023 submission**.

ii) Improved mineral fuel emission factors - The Defra Emission Factors for Domestic Solid Fuel project will produce emission factors several mineral fuels burnt in a range of appliances and technologies. This is expected to feed into the module in time for the **2025 submission**.

iii) Additional point in time data for appliance age, usage, and fuel mix – The Defra burning survey, from which the results were reported in 2020 is anticipated to be repeated. The current timeline for this to be completed is **for fieldwork to be completed in 2023 and to feed in to the 2025 submission**.

iv) Inclusion of novel fuels – There is a project being carried out presently to investigate the extent to which novel fuels e.g. coffee logs are burnt domestically. This is expected to feed into the **2025 submission at the earliest**.

- Expansion to non-LRTAP pollutants – The NAEI calculates emissions for a range of other minor pollutants that are not reported under NECR or LRTAP, e.g. beryllium, naphthalene. Presently, these are estimated via a simple T1 method, however it would be possible to estimate T2 EFs by scaling and EF for a similar pollutant based on the old ratio and including these within the model. This is possible to include in the solid fuel module in the **future**.

v) Stakeholder consultation – To further improve the accuracy of the solid fuel module, the Inventory Agency intend to continue to have regular contact with key stakeholders such as the Stove Industry Alliance. This will be **ongoing amongst all future submissions**.

vi) Outdoor wood use – The Defra burning survey reported indoor and outdoor solid fuel use. The proposed model includes some outdoor fuel use (and outdoor waste-burning is covered elsewhere in the NAEI) but it is recommended that the Defra burning survey outdoor data are further reviewed to assure that activity and emissions are not double-counted or omitted from the NAEI.

7. GASEOUS FUELS

7.1 OVERVIEW

The gaseous fuels module replaces the section of the NAEI 'combustion' mastersheet that produces emission factors for natural gas boilers, but also implements a Tier 2 method to calculate LPG emissions.

Whilst the current NAEI model outputs a single output for domestic use of natural gas, the new model will disaggregate this in line with the ECUK (Energy Consumption in the UK) disaggregation and output individual estimates for:

- Space Heating and roomheaters
- Water boilers
- Cooking hobs and other appliances

Emissions for domestic LPG technologies are also output from the new system, currently as a single technology line as 'domestic'.

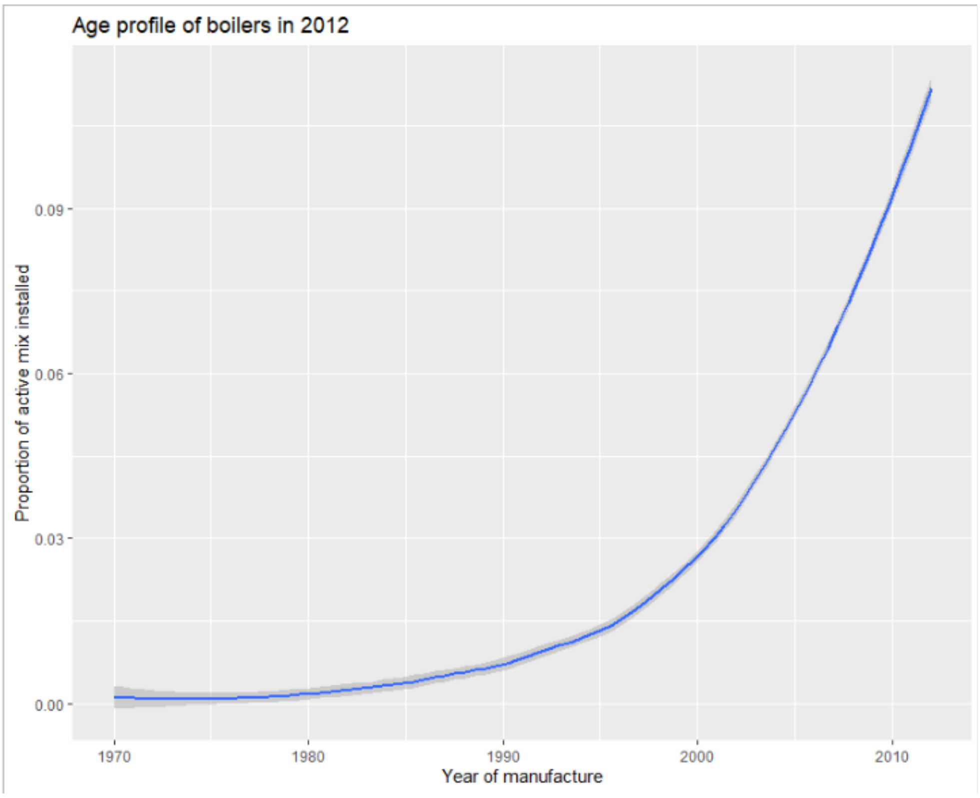
7.2 GASEOUS BOILERS

For emissions attributed to space heating, an age profile is used to estimate the proportions of technologies in use across the UK, and hence, produce a weighted emission factor. For natural gas boilers and roomheaters, the age profile is based on a smoothed version of on an age profile from a survey of boilers in 44,000 homes as part of the RE:NEW home energy retrofit scheme in London in 2012 (GLA, 2018). This smoothed profile can be seen in Table 7-1 and the full profile used, when extended to take account of technologies installed through to 1970 can be seen in Figure 7-1.

Table 7-1 Age Profile of Gaseous Boiler Technologies

Age of boiler (years)	<1	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Percentage	12	11	10	9	8	7	6	5	4	4	4	3	3	3	2	2	2	2	1	1	1

Figure 7-1 Plotted Age Profile of Gas Boilers



As part of this improvement item, we have contacted relevant stakeholders regarding the age profile assumption and their relevancy across the time series. However, we have not received feedback. We intend to continue engaging with stakeholders such that any feedback can be incorporated in time for the 2023 submission.

In lieu of more accurate data, the age profile is used across the time series, such that in any year, it is currently assumed that 50% of all boilers are 5 years old or younger.

As in the Solid Fuel module, it is necessary to associate the boiler technology with the year it was manufactured in order to produce a weighted emission factor. A list of technologies and associated NO_X EFs are seen in Table 7-2.

Table 7-2 NOx Emission Factors by Appliance and Technology type

Appliance	Technology	Start year	End year	NO_X EF (g/GJ net)	Data Source
Natural Gas boiler	All	1970	1989	70	2009 EMEP/EEA Guidebook Table 3-20[9]
Natural Gas boiler	EuP_Lot_1/2	1990	2004	24	Ecodesign Directive preparatory studies
Natural Gas boiler	EN_483_class_5	2005	2017	19.4	EN 483 documentation
Natural Gas boiler	Ecodesign_ELV	2018	2050	17.2	European Commission Regulation 814/2013

[9] The 2009 guidebook is used for historic appliances as it is believed that more recent documentation only represents modern boilers

Appliance	Technology	Start year	End year	NO_X EF (g/GJ net)	Data Source
Water boiler	All	1970	1989	70	2009 EMEP/EEA Guidebook Table 3-20[9]
Water boiler	EuP_Lot_1/2	1990	2004	24	Ecodesign Directive preparatory studies
Water boiler	EN_483_class_5	2005	2017	19.4	EN 483 documentation
Water boiler	Ecodesign_ELV	2018	2050	17.2	European Commission Regulation 814/2013
Cooking/Other	All	1970	2050	60	2019 EMEP/EEA Guidebook Table 3-13
LPG boiler	All	1970	2017	42	2019 EMEP/EEA Guidebook Table 3-20
LPG boiler	Ecodesign_ELV	2018	2050	17.2	European Commission Regulation 814/2013
LPG Roomheater	All	1970	2017	42	2019 EMEP/EEA Guidebook Table 3-20
LPG Roomheater	Ecodesign ELV	2018	2050	17.2	European Commission Regulation 814/2013

7.3 LPG BOILERS

Emissions associated with LPG boilers are calculated in a similar manner to those from gaseous boilers; in-lieu of more applicable data the natural gas boiler age profile is used although accounting for different boiler technologies and accompanying emission factors as shown in Table 7-2.

The emission factor for the pre-Ecodesign technology type is taken from the EMEP/EEA 2019 guidebook figure for household boilers burning natural gas. The emission factor for the 'Ecodesign_ELV' technology is simply a conversion of the emission limit value specified in Ecodesign Regulations. As of yet we have been unable to discern emission factors specifically for burning of LPG.

7.4 RESULTS

Presented in this section are a summary of the emissions calculated from the updated model for gaseous fuel combustion compared to the estimates produced for the 2022 submission, as displayed in Table 7-3 and Table 7-5 for Natural Gas and LPG respectively. A list of reasons for change for each pollutant are given in Table 7-4 and Table 7-6.

A comparison in NO_X emissions between the model outputs and the 2022 submission for both natural gas and liquid technologies is shown in Figure 7-2. Graphs showing the comparison of total gaseous fuel between the model outputs and the 2022 submission are shown in Appendix 2.

Table 7-3 Comparison of Emissions from Natural Gas combustion estimated from the new model vs 2022 Submission Outputs

ShortPollName	Units	EmissionYear	New model	NAEI20	Raw Difference	% Change
As	kt	1990	1.17E-04	NE	NA	NA
As	kt	2005	1.49E-04	NE	NA	NA
As	kt	2020	1.17E-04	NE	NA	NA
B[a]p	kg	1990	5.47E-01	5.47E-01	-1.05E-09	<0.01%
B[a]p	kg	2005	6.95E-01	6.95E-01	1.11E-16	<0.01%

ShortPollName	Units	EmissionYear	New model	NAEI20	Raw Difference	% Change
B[a]p	kg	2020	5.45E-01	5.45E-01	-1.11E-16	<0.01%
Benzo[b]fluoranthene	kg	1990	8.20E-01	8.20E-01	-1.57E-09	<0.01%
Benzo[b]fluoranthene	kg	2005	1.04E+00	1.04E+00	0.00E+00	<0.01%
Benzo[b]fluoranthene	kg	2020	8.17E-01	8.17E-01	1.11E-16	<0.01%
Benzo[k]fluoranthene	kg	1990	8.20E-01	8.20E-01	-1.57E-09	<0.01%
Benzo[k]fluoranthene	kg	2005	1.04E+00	1.04E+00	0.00E+00	<0.01%
Benzo[k]fluoranthene	kg	2020	8.17E-01	8.17E-01	1.11E-16	<0.01%
Black Carbon	kt	1990	4.05E-02	6.33E-02	-2.27E-02	-36%
Black Carbon	kt	2005	4.12E-02	8.04E-02	-3.92E-02	-49%
Black Carbon	kt	2020	3.65E-02	6.30E-02	-2.65E-02	-42%
Cd	kt	1990	2.44E-07	NE	NA	NA
Cd	kt	2005	3.10E-07	NE	NA	NA
Cd	kt	2020	2.43E-07	NE	NA	NA
CO	kt	1990	2.37E+01	2.54E+01	-1.68E+00	-7%
CO	kt	2005	2.94E+01	3.23E+01	-2.90E+00	-9%
CO	kt	2020	2.33E+01	2.53E+01	-1.96E+00	-8%
Cr	kt	1990	7.42E-07	NE	NA	NA
Cr	kt	2005	9.43E-07	NE	NA	NA
Cr	kt	2020	7.39E-07	NE	NA	NA
Cu	kt	1990	7.42E-08	NE	NA	NA
Cu	kt	2005	9.43E-08	NE	NA	NA
Cu	kt	2020	7.39E-08	NE	NA	NA
Dioxins	g-ITEq	1990	1.46E+00	1.46E+00	-2.81E-09	<0.01%
Dioxins	g-ITEq	2005	1.86E+00	1.86E+00	2.22E-16	<0.01%
Dioxins	g-ITEq	2020	1.46E+00	1.46E+00	3.33E-15	<0.01%
Hg	kt	1990	9.76E-05	NE	NA	NA
Hg	kt	2005	1.24E-04	NE	NA	NA
Hg	kt	2020	9.72E-05	NE	NA	NA
Indeno[123-cd]pyrene	kg	1990	8.20E-01	8.20E-01	-1.57E-09	<0.01%
Indeno[123-cd]pyrene	kg	2005	1.04E+00	1.04E+00	0.00E+00	<0.01%
Indeno[123-cd]pyrene	kg	2020	8.17E-01	8.17E-01	1.11E-16	<0.01%
Ni	kt	1990	4.98E-07	NE	NA	NA
Ni	kt	2005	6.33E-07	NE	NA	NA

ShortPollName	Units	EmissionYear	New model	NAEI20	Raw Difference	% Change
Ni	kt	2020	4.96E-07	NE	NA	NA
NOx	kt	1990	5.87E+01	6.35E+01	-4.84E+00	-8%
NOx	kt	2005	4.16E+01	3.43E+01	7.30E+00	21%
NOx	kt	2020	2.68E+01	1.98E+01	7.02E+00	35%
Pb	kt	1990	1.46E-06	NE	NA	NA
Pb	kt	2005	1.86E-06	NE	NA	NA
Pb	kt	2020	1.46E-06	NE	NA	NA
PM_{10}	kt	1990	7.51E-01	1.17E+00	-4.21E-01	-36%
PM_{10}	kt	2005	7.64E-01	1.49E+00	-7.26E-01	-49%
PM_{10}	kt	2020	6.77E-01	1.17E+00	-4.90E-01	-42%
$PM_{2.5}$	kt	1990	7.51E-01	1.17E+00	-4.21E-01	-36%
$PM_{2.5}$	kt	2005	7.64E-01	1.49E+00	-7.26E-01	-49%
$PM_{2.5}$	kt	2020	6.77E-01	1.17E+00	-4.90E-01	-42%
Se	kt	1990	1.07E-05	NE	NA	NA
Se	kt	2005	1.37E-05	NE	NA	NA
Se	kt	2020	1.07E-05	NE	NA	NA
SO_2	kt	1990	2.93E-01	2.93E-01	-5.62E-10	<0.01%
SO_2	kt	2005	3.72E-01	3.72E-01	0.00E+00	<0.01%
SO2	kt	2020	2.92E-01	2.92E-01	-3.89E-16	<0.01%
TPM	kt	1990	7.51E-01	1.17E+00	-4.21E-01	-36%
TPM	kt	2005	7.64E-01	1.49E+00	-7.26E-01	-49%
TPM	kt	2020	6.77E-01	1.17E+00	-4.90E-01	-42%
VOC	kt	1990	1.81E+00	2.66E+00	-8.45E-01	-32%
VOC	kt	2005	2.29E+00	3.38E+00	-1.09E+00	-32%
VOC	kt	2020	1.80E+00	2.65E+00	-8.49E-01	-32%
Zn	kt	1990	1.46E-06	NE	NA	NA
Zn	kt	2005	1.86E-06	NE	NA	NA
Zn	kt	2020	1.46E-06	NE	NA	NA

Table 7-4 Reason for change for emissions estimates for Natural Gas

Pollutant	Reason For Change
Black Carbon	Driven by migration from Tier 1 to Tier 2 EFs and their utilisation in the new technology weighted EF calculations. A more appropriate
CO	Driven by migration from Tier 1 to Tier 2 EFs and their utilisation in the new technology weighted EF calculations.
NOx	Change is due to a re-evaluation of the activity split provided by ECUK, meaning that more activity is attributed to non-boiler units, which have an increased EF, particularly in recent years.

Pollutant	Reason For Change
PM10	Driven by migration from Tier 1 to Tier 2 EFs and their utilisation in the new technology weighted EF calculations.
PM2.5	Driven by migration from Tier 1 to Tier 2 EFs and their utilisation in the new technology weighted EF calculations.
TPM	Driven by migration from Tier 1 to Tier 2 EFs and their utilisation in the new technology weighted EF calculations.
VOC	Driven by migration from Tier 1 to Tier 2 EFs and their utilisation in the new technology weighted EF calculations. Also migration from US EPA, 2004 EF to Tier 2 EF from 2019 EMEP/EEA Guidebook.
Metals	Not estimated in current NAEI models.

Table 7-5 Comparison of Emissions from LPG combustion estimated from the new model vs 2022 Submission Outputs

ShortPollName	Units	Emission Year	New model	NAEI20	Raw Difference	% Change
As	kt	1990	1.84E-06	NE	NA	NA
As	kt	2005	1.49E-06	NE	NA	NA
As	kt	2020	1.31E-06	NE	NA	NA
B[a]p	kg	1990	8.60E-03	8.60E-03	6.94E-18	<0.01%
B[a]p	kg	2005	6.97E-03	6.97E-03	-2.26E-17	<0.01%
B[a]p	kg	2020	6.11E-03	6.11E-03	3.47E-18	<0.01%
Benzo[b]fluoranthene	kg	1990	1.29E-02	1.29E-02	4.34E-17	<0.01%
Benzo[b]fluoranthene	kg	2005	1.05E-02	1.05E-02	-5.55E-17	<0.01%
Benzo[b]fluoranthene	kg	2020	9.16E-03	9.16E-03	8.67E-18	<0.01%
Benzo[k]fluoranthene	kg	1990	1.29E-02	1.29E-02	4.34E-17	<0.01%
Benzo[k]fluoranthene	kg	2005	1.05E-02	1.05E-02	-5.55E-17	<0.01%
Benzo[k]fluoranthene	kg	2020	9.16E-03	9.16E-03	8.67E-18	<0.01%
Black Carbon	kt	1990	1.66E-04	1.57E-03	-1.40E-03	-89%
Black Carbon	kt	2005	1.34E-04	1.27E-03	-1.14E-03	-89%
Black Carbon	kt	2020	1.18E-04	1.11E-03	-9.95E-04	-89%
Cd	kt	1990	3.84E-09	NE	NA	NA
Cd	kt	2005	3.11E-09	NE	NA	NA
Cd	kt	2020	2.73E-09	NE	NA	NA
CO	kt	1990	3.38E-01	3.99E-01	-6.14E-02	-15%
CO	kt	2005	2.74E-01	3.24E-01	-4.98E-02	-15%
CO	kt	2020	2.40E-01	2.84E-01	-4.36E-02	-15%
Cr	kt	1990	1.17E-08	NE	NA	NA
Cr	kt	2005	9.46E-09	NE	NA	NA
Cr	kt	2020	8.29E-09	NE	NA	NA
Cu	kt	1990	1.17E-09	NE	NA	NA
Cu	kt	2005	9.46E-10	NE	NA	NA
Cu	kt	2020	8.29E-10	NE	NA	NA
Dioxins	g-ITEq	1990	2.30E-02	2.30E-02	5.20E-17	<0.01%
Dioxins	g-ITEq	2005	1.87E-02	1.87E-02	-9.71E-17	<0.01%

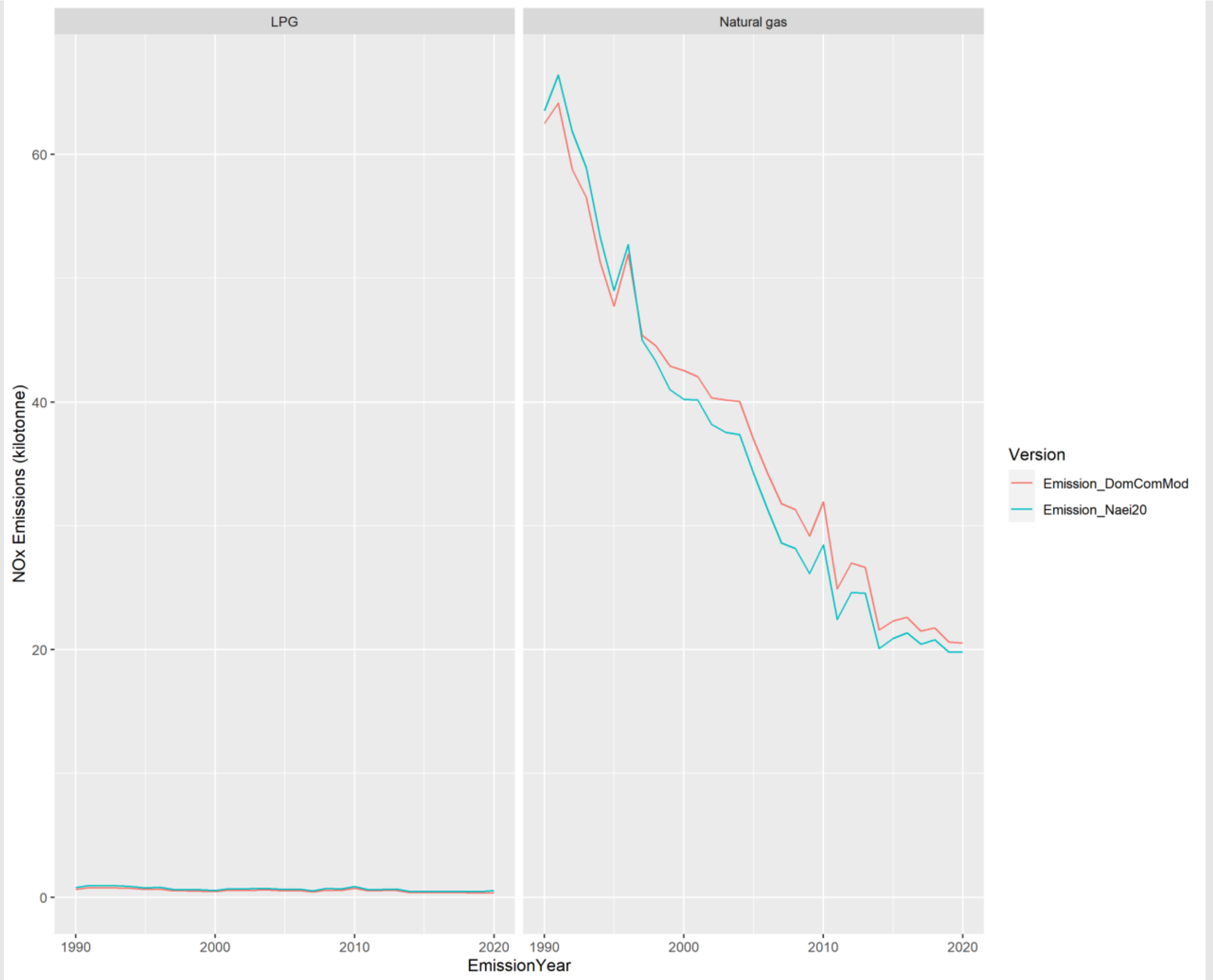
ShortPollName	Units	Emission Year	New model	NAEI20	Raw Difference	% Change
Dioxins	g-ITEq	2020	1.64E-02	1.64E-02	5.20E-17	<0.01%
Hg	kt	1990	1.54E-06	NE	NA	NA
Hg	kt	2005	1.24E-06	NE	NA	NA
Hg	kt	2020	1.09E-06	NE	NA	NA
Indeno[123-cd]pyrene	kg	1990	1.29E-02	1.29E-02	4.34E-17	<0.01%
Indeno[123-cd]pyrene	kg	2005	1.05E-02	1.05E-02	-5.55E-17	<0.01%
Indeno[123-cd]pyrene	kg	2020	9.16E-03	9.16E-03	8.67E-18	<0.01%
Ni	kt	1990	7.83E-09	NE	NA	NA
Ni	kt	2005	6.35E-09	NE	NA	NA
Ni	kt	2020	5.56E-09	NE	NA	NA
NOx	kt	1990	6.45E-01	7.83E-01	-1.38E-01	-18%
NOx	kt	2005	5.23E-01	6.35E-01	-1.12E-01	-18%
NOx	kt	2020	3.73E-01	5.56E-01	-1.83E-01	-33%
Pb	kt	1990	2.30E-08	NE	NA	NA
Pb	kt	2005	1.87E-08	NE	NA	NA
Pb	kt	2020	1.64E-08	NE	NA	NA
PM_{10}	kt	1990	3.07E-03	1.84E-02	-1.54E-02	-83%
PM_{10}	kt	2005	2.49E-03	1.49E-02	-1.24E-02	-83%
PM_{10}	kt	2020	2.18E-03	1.31E-02	-1.09E-02	-83%
$PM_{2.5}$	kt	1990	3.07E-03	1.84E-02	-1.54E-02	-83%
$PM_{2.5}$	kt	2005	2.49E-03	1.49E-02	-1.24E-02	-83%
$PM_{2.5}$	kt	2020	2.18E-03	1.31E-02	-1.09E-02	-83%
Se	kt	1990	1.69E-07	NE	NA	NA
Se	kt	2005	1.37E-07	NE	NA	NA
Se	kt	2020	1.20E-07	NE	NA	NA
SO_2	kt	1990	4.61E-03	4.61E-03	0.00E+00	<0.01%
SO_2	kt	2005	3.73E-03	3.73E-03	-9.97E-18	<0.01%
SO_2	kt	2020	3.27E-03	3.27E-03	0.00E+00	<0.01%
TPM	kt	1990	3.07E-03	1.84E-02	-1.54E-02	-83%
TPM	kt	2005	2.49E-03	1.49E-02	-1.24E-02	-83%

ShortPollName	Units	Emission Year	New model	NAEI20	Raw Difference	% Change
TPM	kt	2020	2.18E-03	1.31E-02	-1.09E-02	-83%
VOC	kt	1990	2.76E-02	6.71E-02	-3.95E-02	-59%
VOC	kt	2005	2.24E-02	5.46E-02	-3.22E-02	-59%
VOC	kt	2020	1.96E-02	4.78E-02	-2.81E-02	-59%
Zn	kt	1990	2.30E-08	NE	NA	NA
Zn	kt	2005	1.87E-08	NE	NA	NA
Zn	kt	2020	1.64E-08	NE	NA	NA

Table 7-6 Reason for change for emissions estimates for LPG

Pollutant	Reason For Change
Black Carbon	Migration of EF from Tier 1 to Tier 2 method to account for technology type. Previous Tier 1 EF was average of Tier 2 EFs for all technology types.
CO	Migration of EF from Tier 1 to Tier 2 method to account for technology type. Previous Tier 1 EF was average of Tier 2 EFs for all technology types.
NOx	Driven by migration from Tier 1 to Tier 2 EFs and their utilisation in the new technology weighted EF calculations. Greatest difference in recent years as model accounts for lower emission factors associated with increased Ecodeisgn technology use in recent years in line with Ecodesign directives.
PM_{10}	Migration of EF from Tier 1 to Tier 2 method to account for technology type. Previous Tier 1 EF was average of Tier 2 EFs for all technology types.
$PM_{2.5}$	Migration of EF from Tier 1 to Tier 2 method to account for technology type. Previous Tier 1 EF was average of Tier 2 EFs for all technology types.
TPM	Migration of EF from Tier 1 to Tier 2 method to account for technology type. Previous Tier 1 EF was average of Tier 2 EFs for all technology types.
VOC	Migration from US EPA, 2004 EF to 2019 EMEP/EEA Guidebook.
Metals	Not estimated in current NAEI model.

Figure 7-2 Comparison of NOx emissions estimates in natural gas and LPG boilers



7.5 LIMITATIONS AND UNCERTAINTIES

The limitations and uncertainties of the methods used to calculate emissions from gaseous fuel use are summarised within this sub-section.

i) Age Profiles – Presently, only one point in time survey has been used in the module representing the boiler age in London, this has also been applied on the national scale. There remains significant uncertainty that this age profile is applicable to past and for future years (and for LPG), it is hoped to address this in future through stakeholder consultation.

ii) Allocation of activity data to technologies – Currently there is a limited ability to split activity data using the ECUK proportions into technologies which are impacted by Ecodesign limits,

iii) LPG Emission Factors – The emission factors used for the two LPG technology types represented in the model are not specific to LPG but rather reflect emissions from the burning of gas fuels in general.

iv) Technology representation – Lack of technology diversity represented in the model may also introduce some uncertainty. It is likely that between 1970 and the implementation of the Ecodesign directive, technology types with differing emissions were in use although current data limitations have confined our model to only pre-Ecodesign and Ecodesign technology types.

7.6 FUTURE IMPROVEMENTS

Improvement of the gaseous fuel module will depend on engagement and input from stakeholders. No further improvement is anticipated before the 2023 submission. The following are suggested areas for improvement :

i) Differentiation of natural gas and LPG emission factors – Current LPG emission factors are not LPG specific but rather based on combustion of 'gas fuels' in general. It is recommended that further work is undertaken to obtain more applicable emission factors through continued literature review.

ii) Inclusion of new gaseous fuels – use of biomethane and bio-LPG should not impact emission estimates as the fuels are chemically the same as the fossil equivalent. Use of pure or blended hydrogen is anticipated to be important in future years but no EFs for air quality pollutants were identified in this study – it is recommended that further work is undertaken to identify and implement appropriate EFs.

iii) Stakeholder consultation – To further improve the accuracy of the gaseous fuel module, the Inventory Agency intend to continue seeking regular contact with key stakeholders. This will be **ongoing amongst all future submissions**.

iv) Disaggregation of non-combustion fuel use – In the NAEI methodology to estimate emissions of methane from gas boilers, an amount of gas leakage prior to combustion is calculated. It was chosen not to use this method in the new model, as assumptions are highly dependent on historical expert judgement. It is recommended that future engagement with stakeholders be used allow a more robust estimation of the quantity of gas which is not combusted and apply this to the new model.

8. LIQUID FUELS

8.1 OVERVIEW

A liquids fuel model has been developed to estimate emissions from domestic oil heating applications in the UK. The developed model focuses on the emissions as the result of the amount of liquid fuel that has been combusted in boilers and space heaters over the period of 1990 to 2020.

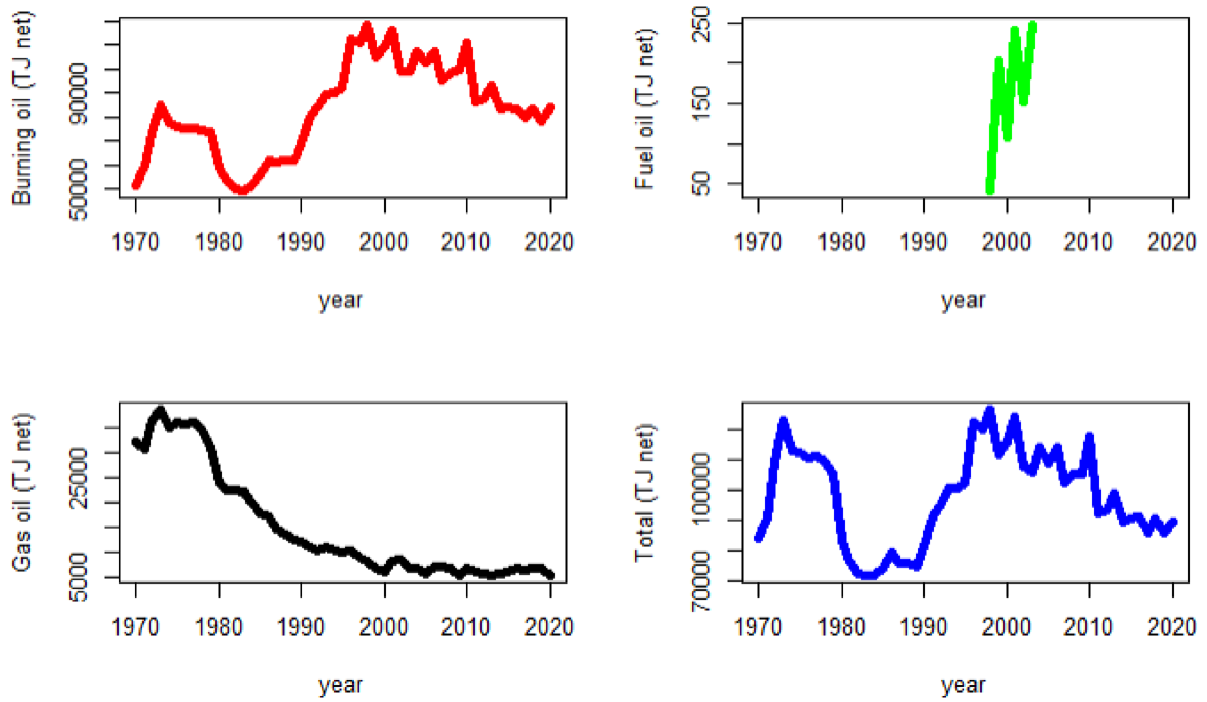
The emission factors obtained from the literature were used to estimate the emissions from fuel consumption data.

8.2 METHODOLOGY

A combination of the relevant activity data on oil consumption and the relevant emission factors were used to estimate the amount of emissions from domestic combustion of liquid fuels.

The activity data for this modelling exercise has been obtained from DUKES. The relevant dataset for this modelling exercise contains oil consumption data for burning oil, fuel oil and gas oil. Although the consumption of fuel oil in domestic settings is limited to the late 1990s and early 2000s. The data are provided in gross kilotonne of oil equivalent (ktoe) and are adjusted to net heat input (in GJ) in order to make the activity data compatible with the emissions factors provided in the EMEP/EEA Guidebook. The activity data of oil consumption is provided in Figure 8-1.

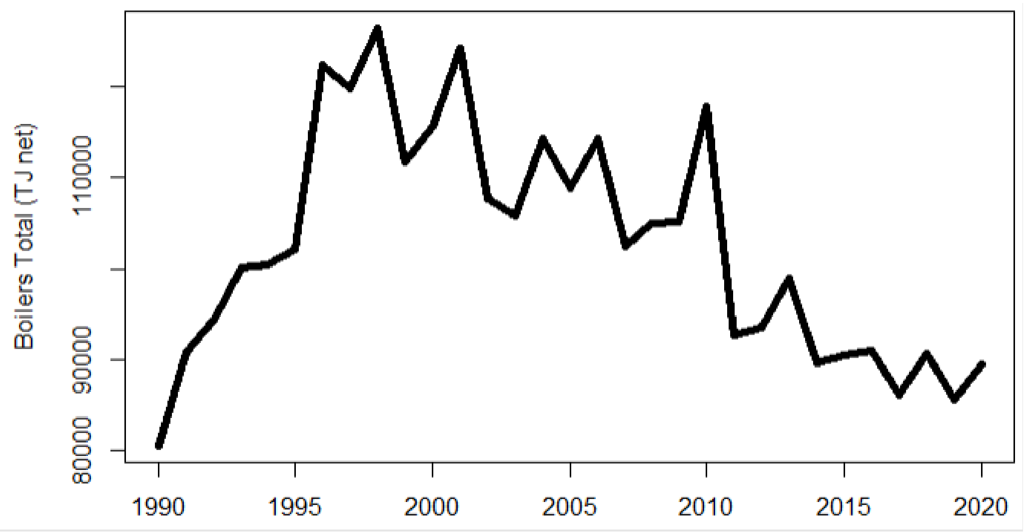
Figure 8-1 Consumption data for burning oil, fuel oil, gas oil and total for domestic combustion (1A4bi).



The DUKES dataset does not distinguish between the amount of oil that is consumed in boilers or other liquid fuel appliances such as room heaters. Relevant stakeholders were identified and contacted to try and establish a technology split however, at the time of preparing this report no response had been provided by stakeholders. The Energy Consumption in the UK (ECUK) dataset[10] provides an estimate of the breakdown of oil consumption for space, water, cooking and other appliances in the UK from 1990 onwards. It has been assumed that the former two categories are applicable to consumption levels in boilers, whilst the consumption figures for cooking (other categories in the ECUK dataset were zero for oil) could be used for other applications. The calculated ratio between the two categories of the ECUK data were then applied to the DUKES dataset. This ratio of the split between space and water heating and cooking was shown to vary from 99% in 1990 to 100% in 2009 onwards. The estimated total oil consumption (i.e. burning oil, fuel oil and gas oil) in boilers is provided in Figure 8-2.

[10] https://www.gov.uk/government/collections/energy-consumption-in-the-uk

Figure 8-2. Total oil consumption in boilers.



A literature review was conducted as part of the model development exercise in order to establish the relevant boiler technologies and their corresponding emission factors for liquid fuels. Limited information on such boiler technologies in the UK were however obtained from such investigations. It was therefore concluded to use a hybrid approach for estimating the emissions.

The approach adopted assumes a consistent generic emission factor for NO_x for the period of 1990 until the enforcement of the Ecodesign Regulations in 2018. A summary of the relevant emission factors to this study are provided in Table 8-1 and Table 8-2.

Table 8-1. Emission factors for NO_x for boilers and other technology in g/GJ net of input fuel.

Technology	Year	NO_x Emission Factors
Boilers	1990-2018	69(1)
	2019-onwards	35(2)
Other technology	All years	34(1)
Roomheater	2018-onwards	34(3)

(1) Tier 2 emission factors from EMEP/EEA 2019 air pollutant emission inventory guidebook for residential plants burning gas oil in boilers (<50 kW_{th}) and other equipment (stoves, etc.)

(2) Ecodesign directive for water heaters and hot water storage tanks (Commission Regulation (EU) No 814/2013)

(3) Ecodesign directive for local space heaters (Commission Regulation (EU) 2015/1188) (not used in model as unable to disaggregate)

Table 8-2. Emission factors for pollutants for boilers and other technology in g/GJ net of input fuel(1).

Pollutant	Boilers	Other technology
CO	3.7	111
As	0.000002	0.000002
B[a]p	0.00008	0.00008
B[b]f	0.00004	0.00004
B[k]f	0.00007	0.00007
BC	0.0585	0.286
Cd	0.000001	0.000001

Pollutant	Boilers	Other technology
Cr	0.0002	0.0002
Cu	0.00013	0.00013
PCDD-F	1.8E-09	0.00000001
Hg	0.00012	0.00012
Indeno[1,2,3-cd]pyrene	0.00016	0.00016
Ni	0.000005	0.000005
Se	0.000002	0.000002
Zn	0.00042	0.00042
Pb	0.000012	0.000012
PM_{10}	1.5	2.2
$PM_{2.5}$	1.5	2.2
TSP	1.5	2.2
NMVOC	0.17	1.2

(1) Tier 2 emission factors from EMEP/EEA 2019 air pollutant emission inventory guidebook for residential plants burning gas oil in boilers (<50 kW_{th}) and other equipment (stoves, etc.)

An age-profile is needed to account for the replacement of one set of technology and rise of another. Due to the absence of stakeholder input, the same age-profile as applied to gas boilers has been applied to oil fuel appliances.

As discussed earlier in the section, the consultation with the relevant stakeholders in this area, for instance OFTEC (Oil Firing Technical Association), is still ongoing and depending on the outcome of these consultations, the assumptions on the ratio of fuel consumed in boilers and space heaters and other technologies and their representative emission factors and age profiles may be modified at a future date to be more representative of the activity patterns in the UK.

8.3 RESULTS

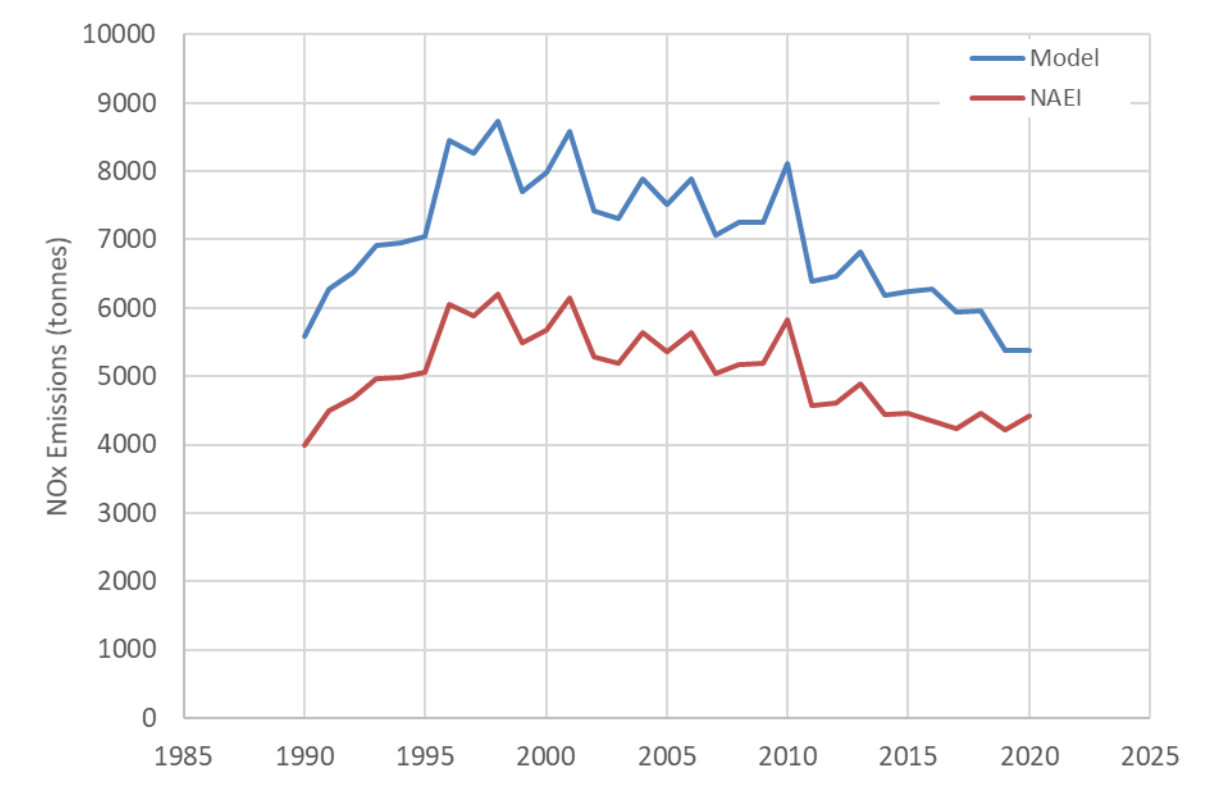
The results from the model for combustion of liquid fuels for space heating and in boilers are presented in this section. The emissions from such applications are obtained from the methodology discussed in section 8.2.

The NO_x emissions from the combustion of liquid fuels in boilers and heaters are provided in Figure 8-3. The emission trend from the NAEI 2022 submission is also provided for comparison purposes. It should be noted that a range of liquid fuels, such as burning fuel, fuel oil and gas oil are provided in the NAEI for domestic combustion, and therefore the total figure across these fuels is provided here.

The NO_x emissions from the proposed model are higher than those of the current estimates in the NAEI. The difference between the two estimations is attributed to the higher NO_x emission factor for boilers that are utilised in the updated model. The overall reduction of the emissions is attributed to the reduction of fuel consumption as well as the implementation of the Ecodesign regulations in recent years.

The CO emissions from the proposed liquid fuel model, presented in the Appendix, are lower than those of the current estimates in the NAEI. The difference between the two is mainly attributed to the large difference between the current Tier 2 emission factor of 3.7 g/GJ compared to the current NAEI emission factor (57 g/GJ).

Figure 8-3 Emission estimates from residential liquid fuel appliances for NO_x.



A comparison between a number of pollutants as estimated from the new model with those of the NAEI submitted in 2022 is provided in Table 8-3. The main reason for the difference between the two models is attributed to the change from Tier 1 to Tier 2 emission factors.

Table 8-3 Comparison of emissions from liquid fuel combustion estimated from the new model vs 2022 submission outputs

ShortPollName	Units	EmissionYear	New model	NAEI20	Raw Difference	% Change
As	kt	1990	1.6E-07	1.1E-05	-1.1E-05	-99%
As	kt	2005	2.2E-07	3.7E-06	-3.4E-06	-94%
As	kt	2020	1.8E-07	3.6E-06	-3.4E-06	-95%
B[a]p	kg	1990	6.5E+00	6.3E+00	2.1E-01	3%
B[a]p	kg	2005	8.7E+00	8.4E+00	3.1E-01	4%
B[a]p	kg	2020	7.2E+00	6.9E+00	2.3E-01	3%
Benzo[b]fluoranthene	kg	1990	3.2E+00	3.1E+00	1.0E-01	3%
Benzo[b]fluoranthene	kg	2005	4.4E+00	4.2E+00	1.5E-01	4%
Benzo[b]fluoranthene	kg	2020	3.6E+00	3.5E+00	1.2E-01	3%
Benzo[k]fluoranthene	kg	1990	5.7E+00	5.5E+00	1.8E-01	3%
Benzo[k]fluoranthene	kg	2005	7.6E+00	7.4E+00	2.7E-01	4%
Benzo[k]fluoranthene	kg	2020	6.3E+00	6.1E+00	2.1E-01	3%
Black Carbon	kt	1990	4.8E-03	1.3E-02	-7.8E-03	-62%
Black Carbon	kt	2005	6.4E-03	1.7E-02	-1.1E-02	-62%
Black Carbon	kt	2020	5.2E-03	1.4E-02	-8.8E-03	-63%
Cd	kt	1990	8.1E-08	2.7E-05	-2.7E-05	-100%
Cd	kt	2005	1.1E-07	2.6E-05	-2.6E-05	-100%

ShortPollName	Units	EmissionYear	New model	NAEI20	Raw Difference	% Change
Cd	kt	2020	9.0E-08	2.2E-05	-2.1E-05	-100%
CO	kt	1990	1.6E-05	3.0E-05	-1.3E-05	-45%
CO	kt	2005	2.2E-05	2.6E-05	-4.5E-06	-17%
CO	kt	2020	1.8E-05	2.2E-05	-4.1E-06	-19%
Cr	kt	1990	3.4E-01	4.5E+00	-4.1E+00	-92%
Cr	kt	2005	4.2E-01	6.0E+00	-5.6E+00	-93%
Cr	kt	2020	3.3E-01	4.9E+00	-4.6E+00	-93%
Cu	kt	1990	1.1E-05	1.3E-04	-1.2E-04	-92%
Cu	kt	2005	1.4E-05	1.3E-04	-1.1E-04	-89%
Cu	kt	2020	1.2E-05	1.1E-04	-9.5E-05	-89%
Dioxins	g-ITEq	1990	1.5E-01	4.6E-01	-3.1E-01	-68%
Dioxins	g-ITEq	2005	2.0E-01	6.2E-01	-4.2E-01	-68%
Dioxins	g-ITEq	2020	1.6E-01	5.1E-01	-3.5E-01	-68%
Hg	kt	1990	9.7E-06	3.9E-06	5.8E-06	148%
Hg	kt	2005	1.3E-05	1.8E-06	1.1E-05	637%
Hg	kt	2020	1.1E-05	1.7E-06	9.0E-06	531%
Indeno[123-cd]pyrene	kg	1990	1.3E+01	1.3E+01	4.1E-01	3%
Indeno[123-cd]pyrene	kg	2005	1.7E+01	1.7E+01	6.2E-01	4%
Indeno[123-cd]pyrene	kg	2020	1.4E+01	1.4E+01	4.7E-01	3%
Ni	kt	1990	4.0E-07	8.4E-04	-8.4E-04	-100%
Ni	kt	2005	5.4E-07	2.4E-04	-2.3E-04	-100%
Ni	kt	2020	4.5E-07	2.2E-04	-2.2E-04	-100%
NOx	kt	1990	5.6E+00	4.0E+00	1.6E+00	39%
NOx	kt	2005	7.5E+00	5.4E+00	2.2E+00	40%
NOx	kt	2020	5.4E+00	4.4E+00	9.7E-01	22%
Pb	kt	1990	9.7E-07	2.3E-04	-2.3E-04	-100%
Pb	kt	2005	1.3E-06	2.4E-04	-2.4E-04	-99%
Pb	kt	2020	1.1E-06	2.0E-04	-2.0E-04	-99%
PM_{10}	kt	1990	1.2E-01	1.5E-01	-2.7E-02	-18%
PM_{10}	kt	2005	1.6E-01	2.0E-01	-3.6E-02	-18%
PM_{10}	kt	2020	1.3E-01	1.6E-01	-3.0E-02	-18%
$PM_{2.5}$	kt	1990	1.2E-01	1.5E-01	-2.7E-02	-18%
$PM_{2.5}$	kt	2005	1.6E-01	2.0E-01	-3.6E-02	-18%
$PM_{2.5}$	kt	2020	1.3E-01	1.6E-01	-3.0E-02	-18%
Se	kt	1990	1.6E-07	2.6E-04	-2.6E-04	-100%
Se	kt	2005	2.2E-07	3.4E-04	-3.4E-04	-100%
Se	kt	2020	1.8E-07	2.8E-04	-2.8E-04	-100%
TPM	kt	1990	1.2E-01	1.5E-01	-2.7E-02	-18%
TPM	kt	2005	1.6E-01	2.0E-01	-3.6E-02	-18%
TPM	kt	2020	1.3E-01	1.6E-01	-3.0E-02	-18%

ShortPollName	Units	EmissionYear	New model	NAEI20	Raw Difference	% Change
VOC	kt	1990	1.4E-02	9.2E-02	-7.8E-02	-85%
VOC	kt	2005	1.9E-02	1.2E-01	-1.0E-01	-85%
VOC	kt	2020	1.5E-02	1.0E-01	-8.5E-02	-85%
Zn	kt	1990	3.4E-05	8.8E-05	-5.4E-05	-61%
Zn	kt	2005	4.6E-05	4.7E-05	-1.2E-06	-3%
Zn	kt	2020	3.8E-05	4.2E-05	-4.7E-06	-11%

8.4 LIMITATIONS AND UNCERTAINTIES

Consultation with the relevant stakeholders in this area, for instance OFTEC, is still ongoing and may provide refinement of assumptions on the technology mix, technologies and their representative emission factors and age profiles.

8.5 FUTURE IMPROVEMENTS

There are a number of improvements that could be included in the liquid fuel module in future inventory cycles, for example:

i) Establish technology split for liquid fuels– assumptions have been used for the proposed model to allow adoption of a higher Tier methodology. It is recommended that work is undertaken to better characterise the current and historic appliance population and emission factors.

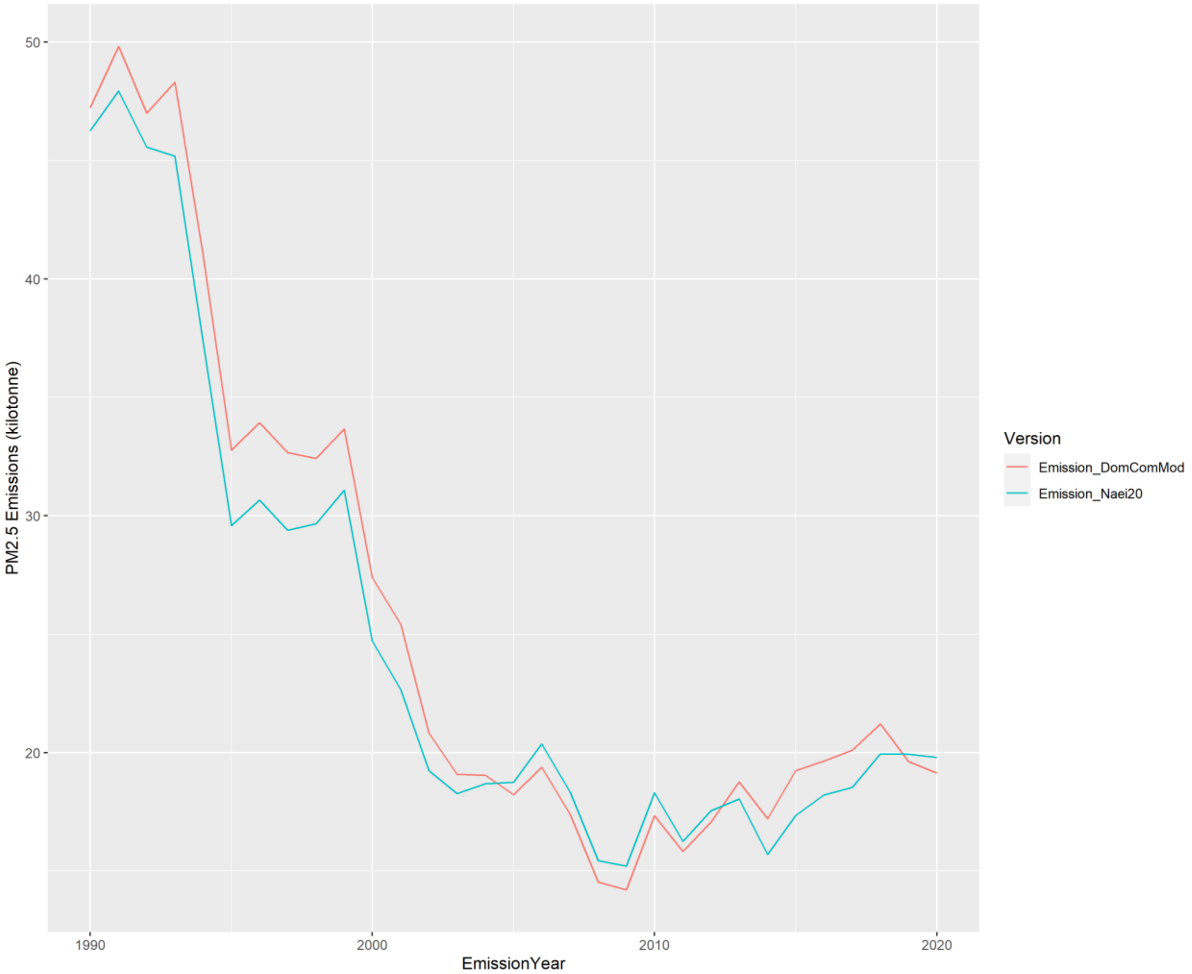
ii) Domestic Biofuels – The domestic use of fuels such as biodiesel have been growing in recent years, and the expectation is that these will be accounted for within DUKES in the coming years. In order to account for this new fuel use within the domestic model it is recommended to establish closer links with stakeholders and investigate biofuel emission factors.

9. RESULTS

9.1 NECR POLLUTANTS

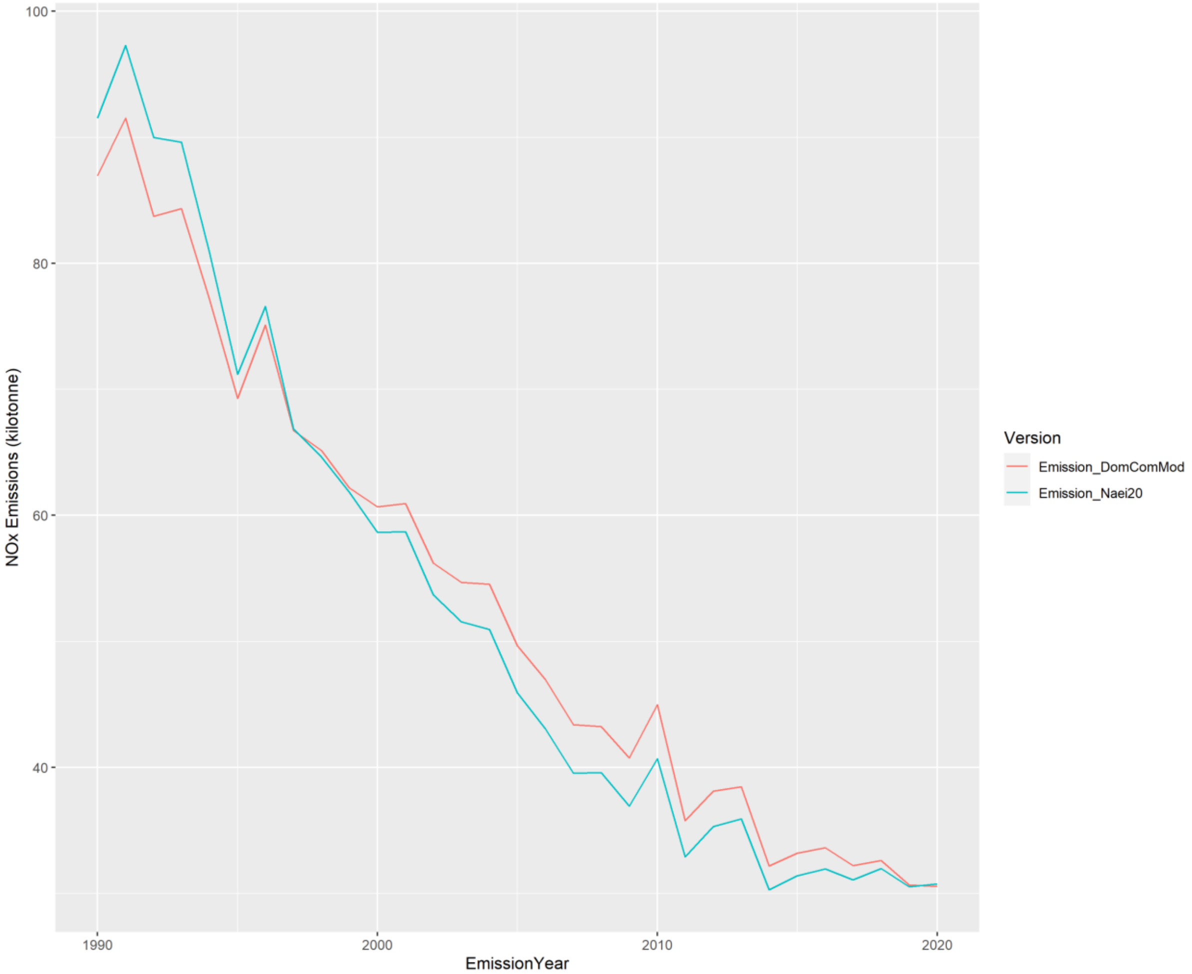
Results for each fuel group are contained within the relevant chapter, this section provides a high level overview for the major pollutants at the NFR level, i.e. 1A4bi. Presented here are graphs and data for NECR pollutants $PM_{2.5}$, NO_X, NH_3, NMVOC. Emissions of SOx are not included because country-specific emission factors are used for main fuels and there is no difference in approach from the current NAEI, with the exception of the improved Sulphur Coal model, which is expected to be implemented in the 2023 submission. For the remaining pollutants, please refer to Section 9.2 and the graphs in Appendix 4.

Figure 9-1 Comparison of 1A4bi estimates for $PM_{2.5}$ from the new model versus the 2022 submission



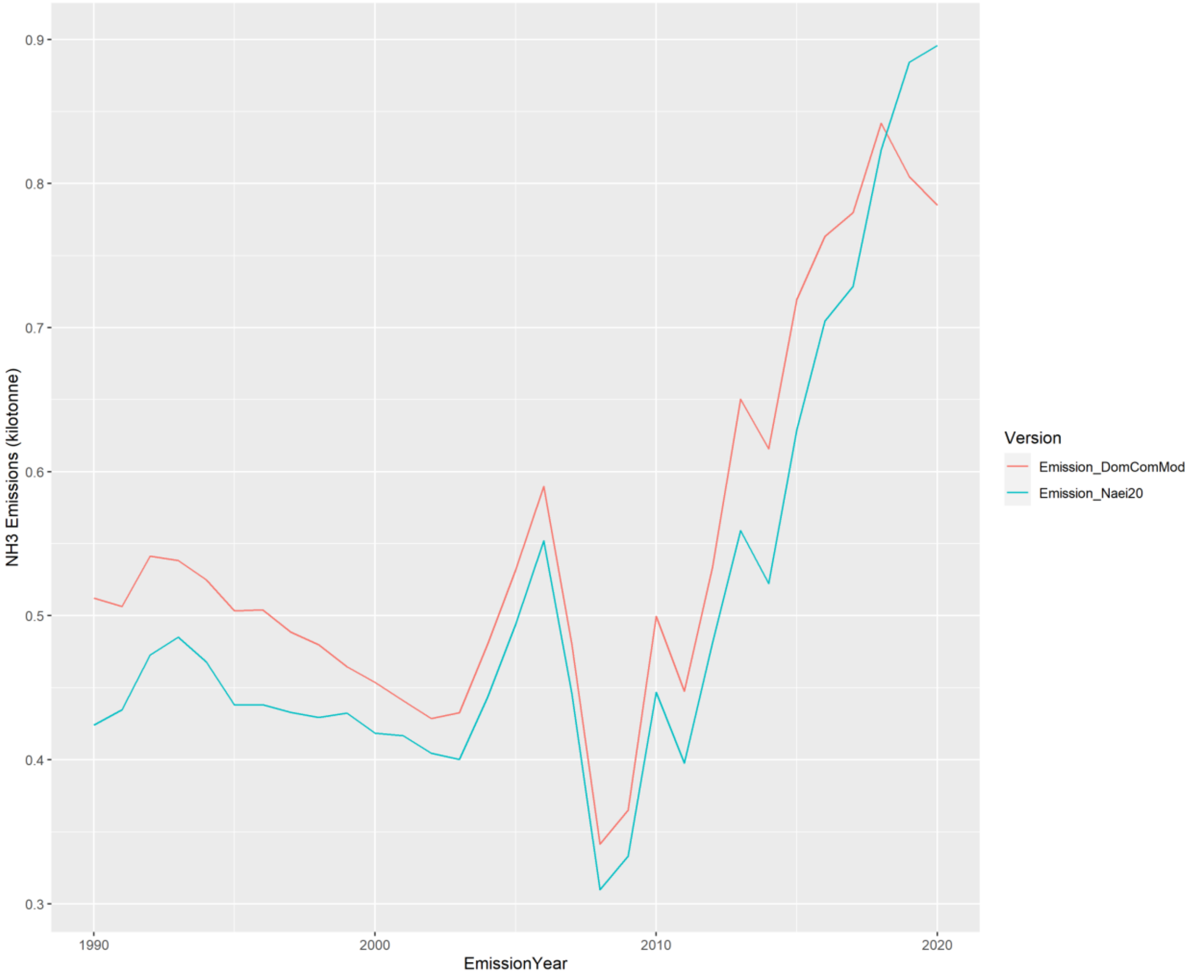
The change in emissions over time is driven by the changes made to the solid fuel estimates, including but not limited to appliance age profiles/types, and reviewing the splits of the proportions of where different fuels are burnt.

Figure 9-2 Comparison of 1A4bi estimates for NOx from the new model versus the 2022 submission



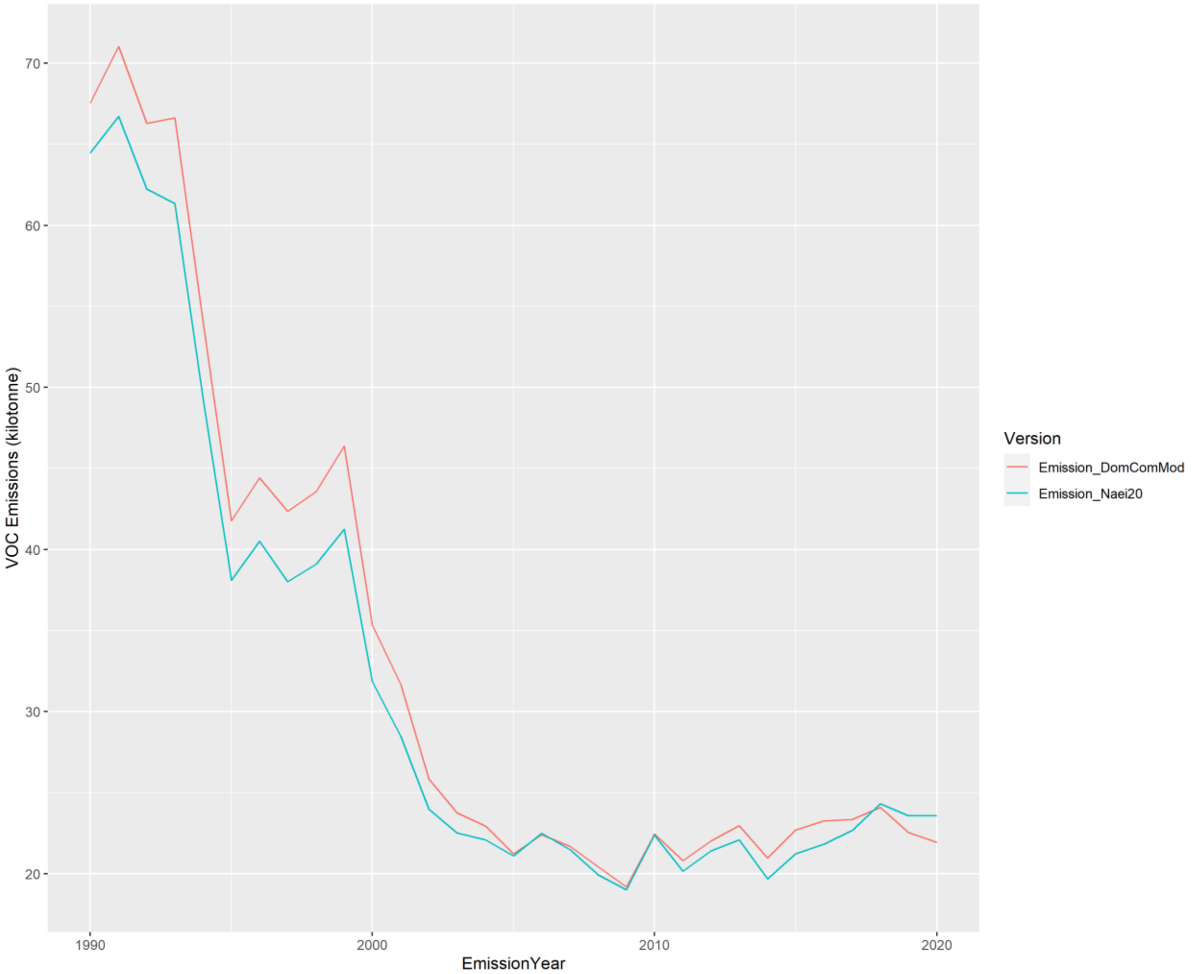
The emissions increase in more recent years is driven by the re-evaluation of the activity split provided by ECUK, meaning that more activity is attributed to non-boiler units, which have an increased EF.

Figure 9-3 Comparison of 1A4bi estimates for NH_3 from the new model versus the 2022 submission



The large drop in emissions in the later years (red line) is as a result of taking into account partial Ecodesign stoves from 2017, as opposed from the old model which suggested the start year would be 2021.

Figure 9-4 Comparison of 1A4bi estimates for NMVOC from the new model versus the 2022 submission



NMVOC emissions are generally increased in the new model with respect to those presented in NAEI20 as a result of increased emission factors through using the EMEP/EEA guidebook factors for solid fuels where appropriate.

9.2 ALL POLLUTANTS

Table 9-1 contains a summary by pollutant for each of the year 1990, 2005, and 2020, comparing the model outputs to that of the 2022 submission. A comparison of SO_2 is not made, as country specific factors are derived via other means on a fuel specific basis.

Table 9-1 Comparison of results at the NFR level (1A4bi) for domestic combustion

ShortPollName	Units	EmissionYear	New model	NAEI20	Raw Difference	% Change
As	kt	1990	6.10E-04	2.95E-03	-2.35E-03	-79%
As	kt	2005	2.53E-04	6.47E-04	-3.94E-04	-61%
As	kt	2020	1.79E-04	5.49E-04	-3.69E-04	-67%
B[a]p	kg	1990	3.29E+04	6.97E+03	2.59E+04	372%
B[a]p	kg	2005	8.81E+03	2.60E+03	6.21E+03	238%
B[a]p	kg	2020	7.49E+03	2.84E+03	4.65E+03	164%
Benzo[b]fluoranthene	kg	1990	4.02E+04	2.05E+03	3.81E+04	1864%
Benzo[b]fluoranthene	kg	2005	1.04E+04	1.92E+03	8.49E+03	443%
Benzo[b]fluoranthene	kg	2020	8.95E+03	2.26E+03	6.69E+03	296%
Benzo[k]fluoranthene	kg	1990	1.86E+04	7.30E+02	1.79E+04	2451%
Benzo[k]fluoranthene	kg	2005	4.60E+03	7.25E+02	3.87E+03	534%
Benzo[k]fluoranthene	kg	2020	3.87E+03	8.38E+02	3.03E+03	361%
Black Carbon	kt	1990	4.01E+00	4.31E+00	-2.98E-01	-7%
Black Carbon	kt	2005	1.54E+00	1.57E+00	-2.79E-02	-2%
Black Carbon	kt	2020	1.94E+00	1.81E+00	1.23E-01	7%
Cd	kt	1990	4.65E-04	3.85E-04	8.07E-05	21%
Cd	kt	2005	2.86E-04	2.72E-04	1.34E-05	5%
Cd	kt	2020	3.91E-04	4.45E-04	-5.43E-05	-12%
CO	kt	1990	9.25E+02	9.43E+02	-1.85E+01	-2%
CO	kt	2005	2.74E+02	2.87E+02	-1.23E+01	-4%
CO	kt	2020	2.48E+02	2.74E+02	-2.68E+01	-10%
Cr	kt	1990	2.42E-03	6.31E-03	-3.89E-03	-62%
Cr	kt	2005	8.54E-04	1.99E-03	-1.14E-03	-57%
Cr	kt	2020	9.31E-04	2.20E-03	-1.27E-03	-58%
Cu	kt	1990	4.18E-03	1.57E-03	2.61E-03	167%
Cu	kt	2005	9.62E-04	6.76E-04	2.86E-04	42%
Cu	kt	2020	7.20E-04	7.21E-04	-9.26E-07	0%
Dioxins	g-ITEq	1990	1.09E+02	1.51E+02	-4.26E+01	-28%
Dioxins	g-ITEq	2005	3.52E+01	4.45E+01	-9.28E+00	-21%

ShortPollName	Units	EmissionYear	New model	NAEI20	Raw Difference	% Change
Dioxins	g-ITEq	2020	3.02E+01	3.95E+01	-9.23E+00	-23%
HCB	kg	1990	1.85E-01	1.10E-01	7.43E-02	67%
HCB	kg	2005	1.11E-01	8.74E-02	2.39E-02	27%
HCB	kg	2020	1.54E-01	1.57E-01	-2.78E-03	-2%
Hg	kt	1990	8.64E-04	7.13E-04	1.51E-04	21%
Hg	kt	2005	3.06E-04	1.96E-04	1.10E-04	56%
Hg	kt	2020	2.29E-04	1.86E-04	4.37E-05	24%
Indeno[123-cd]pyrene	kg	1990	1.62E+04	4.74E+03	1.14E+04	241%
Indeno[123-cd]pyrene	kg	2005	4.49E+03	1.60E+03	2.89E+03	180%
Indeno[123-cd]pyrene	kg	2020	4.11E+03	1.68E+03	2.43E+03	145%
NH_3	kt	1990	5.12E-01	4.24E-01	8.81E-02	21%
NH_3	kt	2005	5.32E-01	4.94E-01	3.78E-02	8%
NH_3	kt	2020	7.85E-01	8.96E-01	-1.11E-01	-12%
Ni	kt	1990	2.40E-03	1.31E-02	-1.07E-02	-82%
Ni	kt	2005	5.23E-04	6.02E-02	-5.97E-02	-99%
Ni	kt	2020	3.57E-04	6.79E-02	-6.75E-02	-99%
NOx	kt	1990	8.70E+01	9.15E+01	-4.58E+00	-5%
NOx	kt	2005	4.97E+01	4.59E+01	3.72E+00	8%
NOx	kt	2020	3.06E+01	3.08E+01	-2.01E-01	-1%
Pb	kt	1990	2.41E-02	1.85E-02	5.62E-03	30%
Pb	kt	2005	5.34E-03	3.51E-03	1.84E-03	52%
Pb	kt	2020	3.76E-03	3.13E-03	6.29E-04	20%
PCB	kg	1990	2.90E+01	2.15E+01	7.46E+00	35%
PCB	kg	2005	6.04E+00	3.35E+00	2.68E+00	80%
PCB	kg	2020	4.19E+00	2.61E+00	1.58E+00	61%
PM_{10}	kt	1990	4.82E+01	4.71E+01	1.09E+00	2%
PM_{10}	kt	2005	1.86E+01	1.91E+01	-5.16E-01	-3%
PM_{10}	kt	2020	1.96E+01	2.02E+01	-6.47E-01	-3%
$PM_{2.5}$	kt	1990	4.72E+01	4.63E+01	9.69E-01	2%
$PM_{2.5}$	kt	2005	1.82E+01	1.87E+01	-5.29E-01	-3%
$PM_{2.5}$	kt	2020	1.91E+01	1.98E+01	-6.57E-01	-3%
Se	kt	1990	2.74E-04	2.95E-03	-2.67E-03	-91%
Se	kt	2005	7.73E-05	1.13E-03	-1.05E-03	-93%
Se	kt	2020	6.22E-05	1.02E-03	-9.54E-04	-94%
TPM	kt	1990	5.17E+01	5.10E+01	7.00E-01	1%
TPM	kt	2005	1.97E+01	2.03E+01	-5.50E-01	-3%
TPM	kt	2020	2.06E+01	2.14E+01	-7.41E-01	-3%

ShortPollName	Units	EmissionYear	New model	NAEI20	Raw Difference	% Change
VOC	kt	1990	6.76E+01	6.45E+01	3.09E+00	5%
VOC	kt	2005	2.12E+01	2.11E+01	1.32E-01	1%
VOC	kt	2020	2.19E+01	2.36E+01	-1.66E+00	-7%
Zn	kt	1990	4.89E-02	2.16E-02	2.72E-02	126%
Zn	kt	2005	1.76E-02	1.20E-02	5.60E-03	47%
Zn	kt	2020	1.97E-02	1.87E-02	1.07E-03	6%

10. LIMITATIONS AND UNCERTAINTIES

Limitations and uncertainties of each module are laid out in the relevant section. This section summarises the key limitations within the model suite for emissions and uncertainty.

i) Moisture content of wood – At present, it is assumed that the split in wood by moisture content presented in the Defra Burning Survey can be applied to all years. With the ban on the sale of wet wood in England coming into effect in 2021, it is unlikely that this assumption will remain true in the coming years. If the Defra Burning Survey is re-run as is planned, it potentially will provide more data and allow understanding of (initial) implementation of legislation controlling wood and other solid fuels in England.

ii) Age Profiles of technologies – This is a limitation across all fuel groups. There are survey data for solid fuel appliance age and, to a limited extent, natural gas boilers. The gaseous fuel age profile model is based on a single point in time survey carried out in 2012 in London, it would be beneficial to carry out a wider, more recent survey of boiler ages in use across the UK. The age profile for liquid fuels utilises the same age profile as that of the gaseous fuels, as a result of no such data being able to be located.

iii) Gaseous and liquid Fuel Emission Factors – Currently, the same Tier 2 factors from the EMEP/EEA are used for all liquid fuels, such as burning oil and gas oil and, in future, liquid biofuels. Similarly, for gaseous fuels there is a gap in emission factors for future fuels such as hydrogen.

iv) Gaseous and liquid fuel technology mix – the ECUK provides a limited disaggregation of national fuel use but further understanding of the use and technologies of such fuels would allow improved understanding and application of more appropriate emission factors.

11. RECOMMENDATIONS AND FUTURE WORK

On the basis of this report, taking into consideration the following:

i) The comparability of the emission estimates of major pollutants to those currently estimated in the NAEI as part of the 2022 submission;

ii) The scalability of the model to easily incorporate new evidence and data from a wide range of sources, notably, EF for wet wood and solid fuels from the Emission Factors for Domestic Solid Fuels Project, potentially new fuels;

iii) Inclusion of emission estimates for pollutants which are not estimated in the current NAEI and proposed adjustments to include emission factors of minor (non-LRTAP) pollutants using more relevant methods as presented in the report, notably in Section 6.5, which are intended to be addressed prior to the start of compilation;

iv) Expected input from, and future stakeholder consultation, with key groups, such as the Stove Industry Alliance, HETAS etc.

v) The improved flexibility to incorporate updates to solid fuel emission factors, new DUKES statistics, feedback from continued engagement with the domestic heating community, and adjustments required to the Overseas Territories and Crown Dependencies.

The following recommendation is presented to Defra and the AQISG (Air Quality Inventory Steering Group):

- To approve the implementation of the new domestic combustion model into the NAEI, such that it is able to be implemented for the 2022/23 inventory cycle;

In addition, the project has identified a number of recommendations for future work to improve the uncertainty of emission estimates for residential burning:

1. Solid fuels (wood & solid mineral fuels)
    a. Include improved wood emission factors – The Emission Factors for Domestic Solid Fuel project will produce emission factors for wood of differing moisture contents burnt in a

range of appliances and technologies. These data are expected to be available in time for the **2023 submission**.

b. Include improved mineral fuel emission factors - The Defra Emission Factors for Domestic Solid Fuel project will produce emission factors several mineral fuels burnt in a range of appliances and technologies. These data are expected to be available in time for the **2024 submission**.
c. Additional point in time data for appliance age, usage, and fuel mix – The Defra burning survey, from which the results were reported in 2020 is anticipated to be repeated. The current timeline for this to be completed is **yet to be determined**.
d. Inclusion of novel fuels – There is a project being carried out presently to investigate the extent to which novel fuels e.g. coffee logs are burnt domestically. This is expected to feed into the **2024 submission at the earliest**.
e. Expansion to non-LRTAP pollutants – The NAEI calculates emissions for a range of other minor pollutants that are not reported under NECR or LRTAP, e.g. beryllium, naphthalene. Presently, these are estimated via a simple T1 method, however it would be possible to estimate T2 EFs by scaling and EF for a similar pollutant based on the old ratio and including these within the model. This is possible to include in the solid fuel module in time for the **2023 submission**.
f. Stakeholder consultation – To further improve the accuracy of the solid fuel module, the Inventory Agency intend to continue to have regular contact with key stakeholders such as the Stove Industry Alliance. This will be **ongoing amongst all future submissions**.
g. Outdoor wood use – The Defra burning survey reported indoor and outdoor solid fuel use. The proposed model includes some outdoor fuel use (and outdoor waste-burning is covered elsewhere in the NAEI) but it is recommended that the Defra burning survey outdoor data are further reviewed to assure that activity and emissions are not double-counted or omitted from the NAEI.

2. Gaseous fuels
    a. Differentiation of natural gas and LPG emission factors – Current LPG emission factors are not LPG specific but rather based on combustion of 'gas fuels' in general. It is recommended that further work is undertaken to obtain more applicable emission factors through continued literature review.
    b. Inclusion of new gaseous fuels – use of biomethane and bio-LPG should not impact emission estimates as the fuels are chemically the same as the fossil equivalent. Use of pure or blended hydrogen is anticipated to be important in future years but no EFs for air quality pollutants were identified in this study – it is recommended that further work is undertaken to identify and implement appropriate EFs.
    c. Stakeholder consultation – To further improve the accuracy of the gaseous fuel module, the Inventory Agency intend to continue seeking regular contact with key stakeholders.
    d. Disaggregation of non-combustion fuel use – In the NAEI methodology to estimate emissions of methane from gas boilers, an amount of gas leakage prior to combustion is calculated. It was chosen not to use this method in the new model, as assumptions are highly dependent on historical expert judgement. It is recommended that future engagement with stakeholders be used allow a more robust estimation of the quantity of gas which is not combusted and apply this to the new model.
3. Liquid fuels
    a. Establish technology split for liquid fuels– assumptions have been used for the proposed model to allow adoption of a higher Tier methodology. It is recommended that work is undertaken to better characterise the current and historic appliance population and emission factors.
    b. Emission factors for domestic Biofuels – The domestic use of fuels such as biodiesel have been growing in recent years, and the expectation is that these will be accounted for within DUKES in the coming years. In order to account for this new fuel use within the domestic model it is recommended to establish closer links with stakeholders and investigate biofuel emission factors.

12. IMPROVEMENTS FOLLOWING COMPLETION OF WORK

The work for this project was completed in March 2022 and results fed into the 2023 submission of the NAEI. Since then, there have been a number of improvements made to the methodologies. For the latest information, the Informative Inventory Report should be referred to.

Improvements made have included:

- Alignment of the inventory methodology with the approach used in national energy data to estimate residential wood use in years since the domestic burning survey.
- Changes in wet wood use in England following the implementation of the Air Quality Domestic Solid Fuel Standards (England) Regulations 2018 have been estimated.
- Adjustment of the methodology for domestic gas use – to reflect better understanding of apportioning of gaseous fuels to appliance types.
- More accurate allocation of petroleum coke to solid fuel manufacture (impacts nickel emissions).
- Incorporation of assumptions derived from the second Domestic Burning Survey, published in February 2025.
- Incorporation of emission factors for solid fuels that have been developed as part of the Emission Factors for Domestic Solid Fuels project, results from this are presented in the Work Package 3 report, published in February 2025.

13. REFERENCES

APARG, Report on the Abatement of Toxic Organic Micropollutants (TOMPs) from Stationary Sources, 1995

BEIS, Digest of United Kingdom Energy Statistics, 2021

BEIS, Energy Consumption in the United Kingdom, 2021

Brain, S.A. etc, 'Emissions of Volatile Organic Compounds from Coal Fired Appliances', CRE Report No COAL R033, 1994

Defra, Burning in UK Homes and Gardens, 2020 https://uk-air.defra.gov.uk/library/reports?report_id=1014

EMEP/EEA 2019 Guidebook https://www.eea.europa.eu/publications/emep-eea-guidebook-2019/part-b-sectoral-guidance-chapters/1-energy/1-a-combustion/1-a-4-small-combustion/view

Greater London Authority (2012), https://www.london.gov.uk/sites/default/files/domestic_boiler_emission_testing_report.pdf

Perry, R.E., Report on a project to measure emissions and calculate emission factors for a range of pollutants released to air during the combustion of solid fuels on an open fire, CPL Ltd, Report Reference 02/aeat/1, January 2002

Smith, I. M., PAH from Coal Utilisation - Emissions and Effects, IEA Coal Research, 1984; Radian Corporation, Locating and Estimating Air Emissions from Sources of Polycyclic Organic Matter, Radian No 298-130-43, 1995

APPENDICES

APPENDIX 1 – SOLID FUEL EMISSION COMPARISONS

Figure 13-1 Comparison of emissions of arsenic from solid fuel combustion in the residential sector by fuel as calculated by the domestic combustion model versus NAEI20.

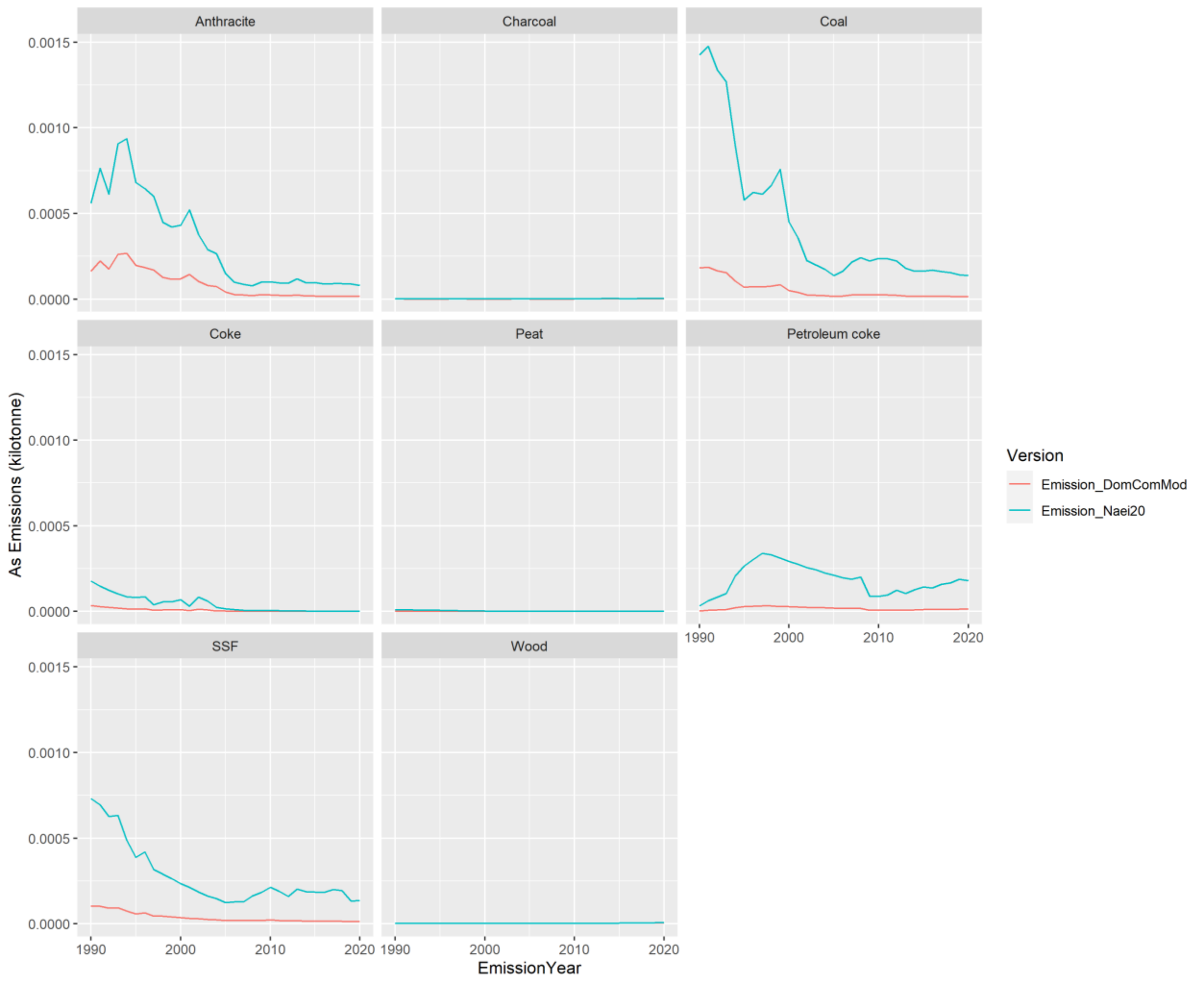


Figure 13-2 Comparison of emissions of benzo[a]pyrene from solid fuel combustion in the residential sector by fuel as calculated by the domestic combustion model versus NAEI20.

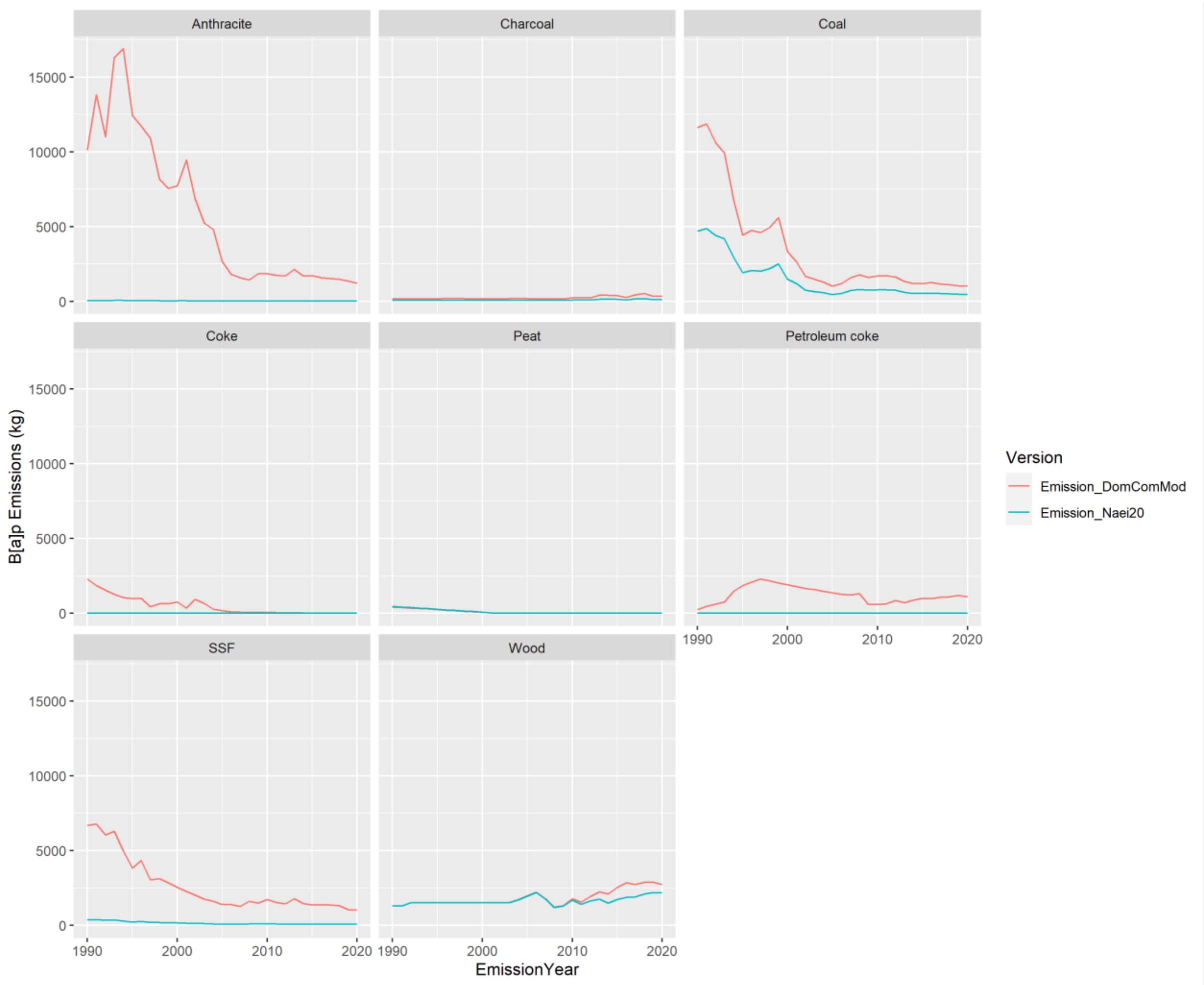


Figure 13-3 Comparison of emissions of benzo[b]fluoranthene from solid fuel combustion in the residential sector by fuel as calculated by the domestic combustion model versus NAEI20.

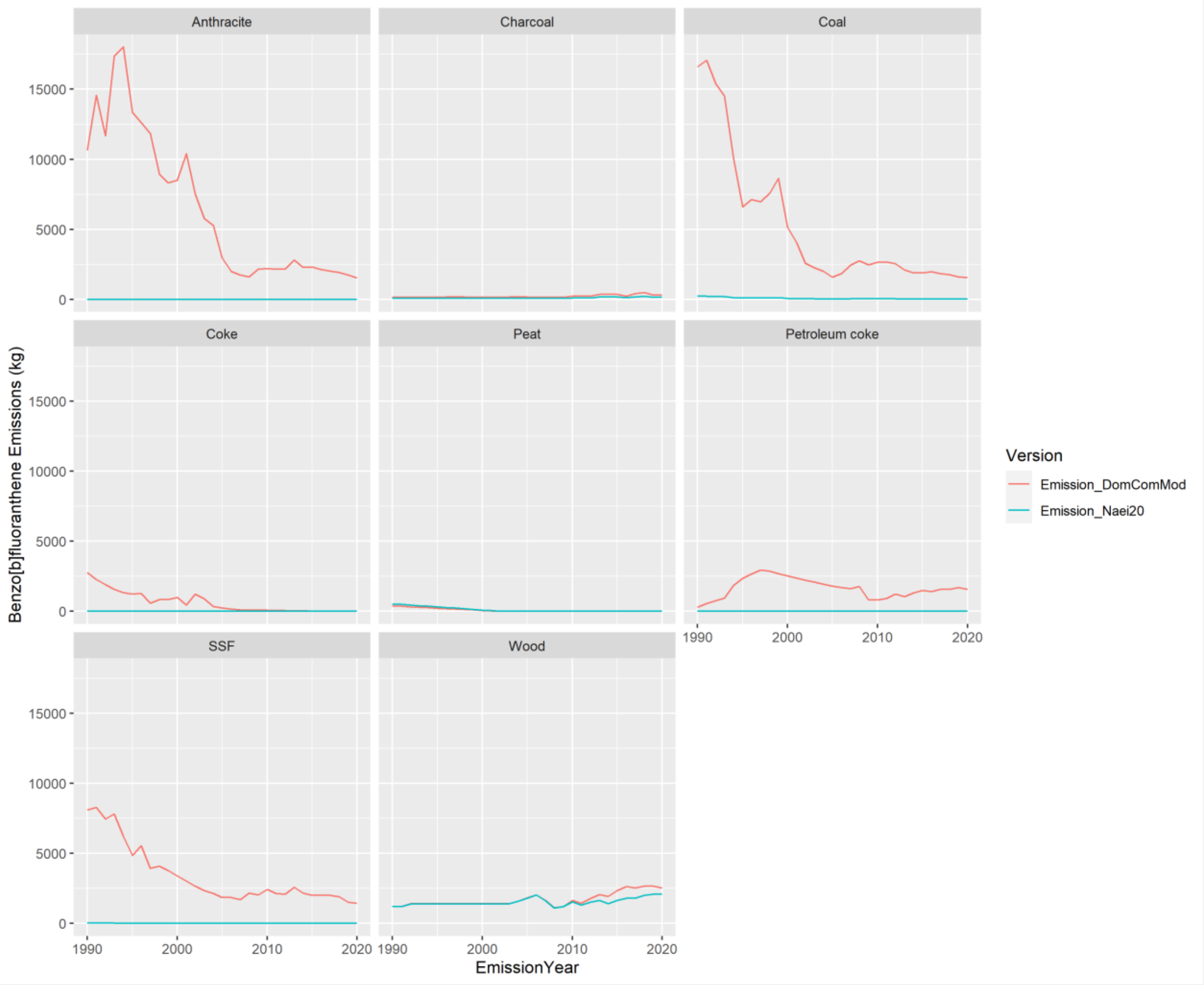


Figure 13-4 Comparison of emissions of benzo[k]fluoranthene from solid fuel combustion in the residential sector by fuel as calculated by the domestic combustion model versus NAEI20.

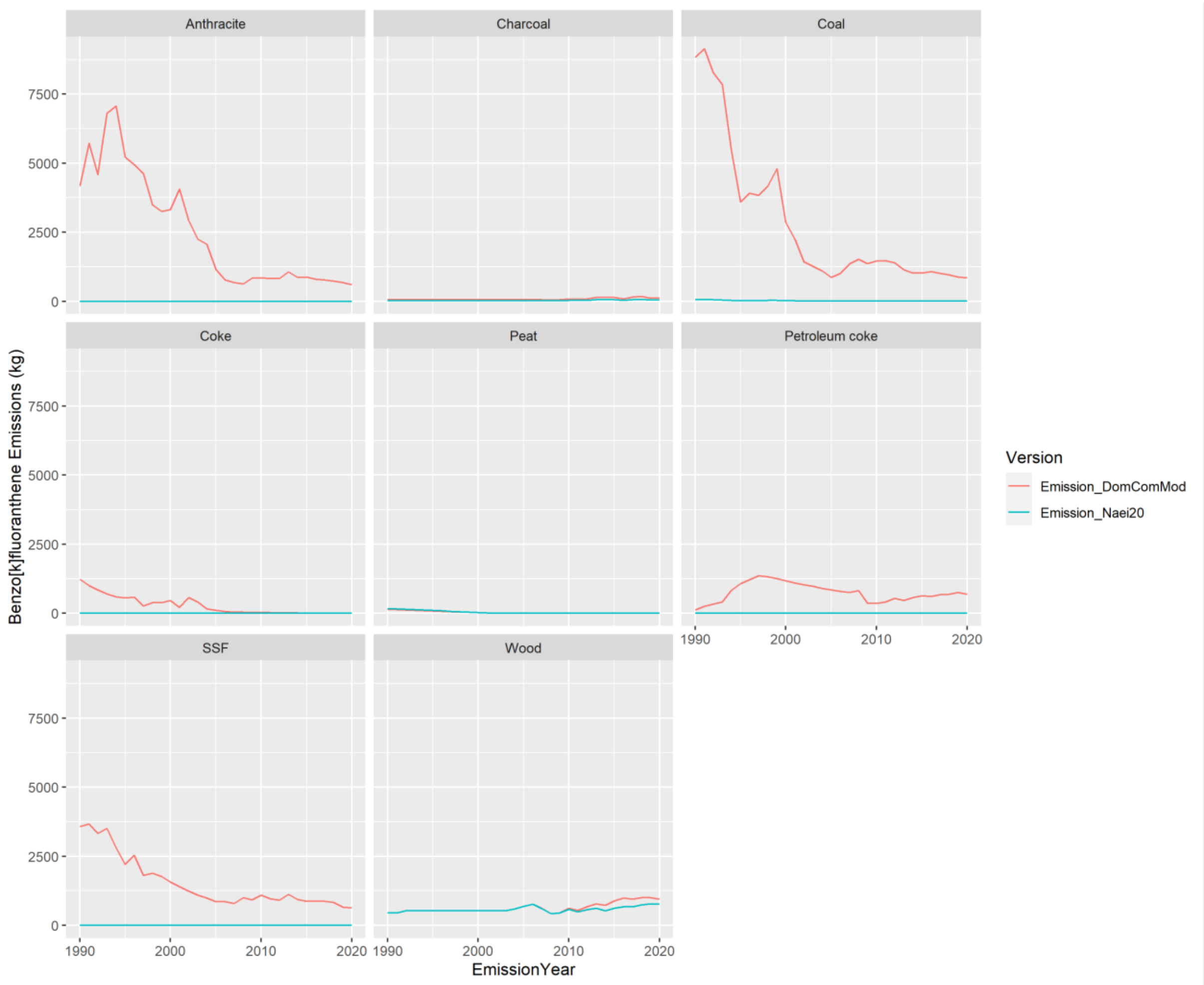


Figure 13-5 Comparison of emissions of black carbon from solid fuel combustion in the residential sector by fuel as calculated by the domestic combustion model versus NAEI20.

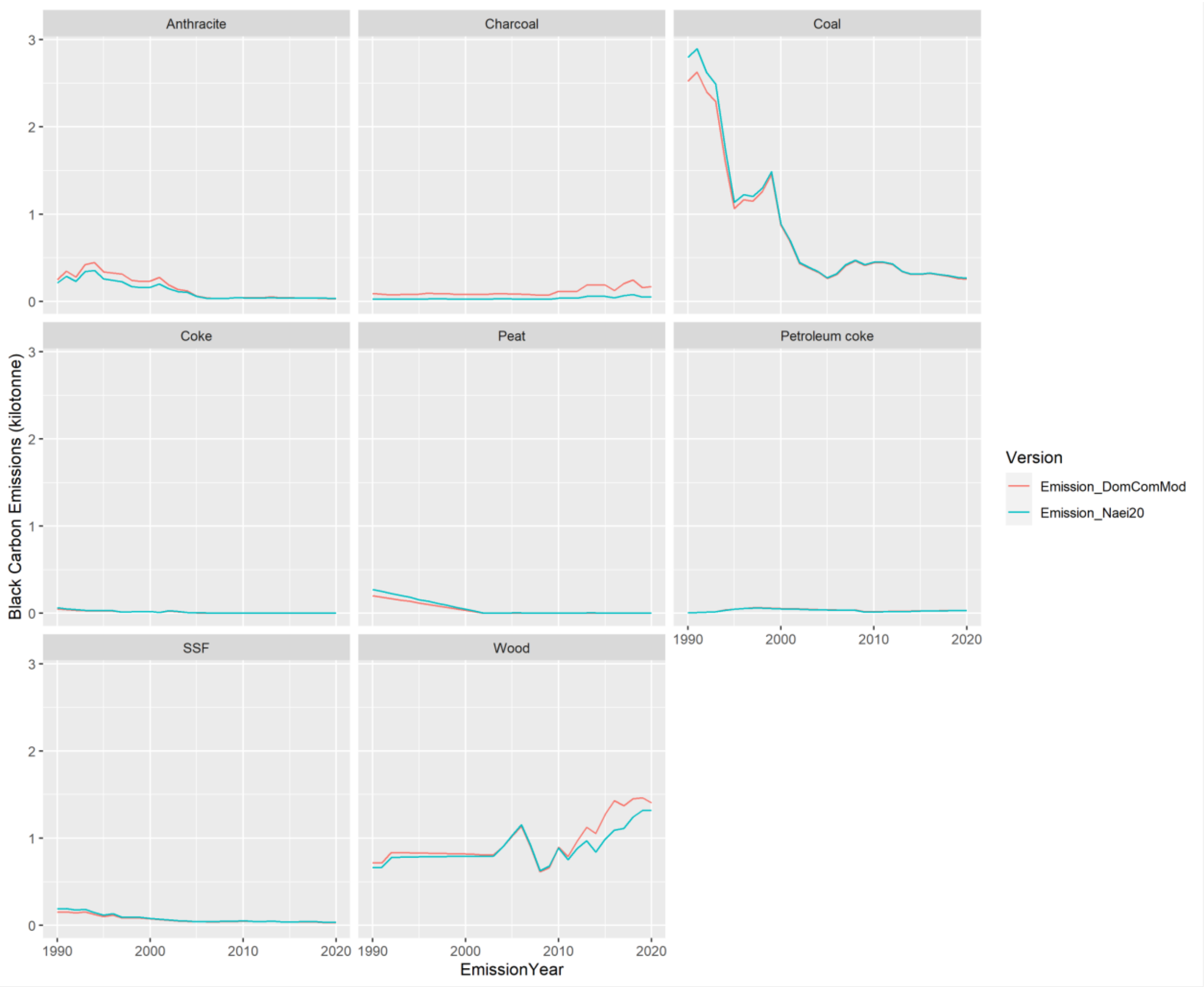


Figure 13-6 Comparison of emissions of cadmium from solid fuel combustion in the residential sector by fuel as calculated by the domestic combustion model versus NAEI20.

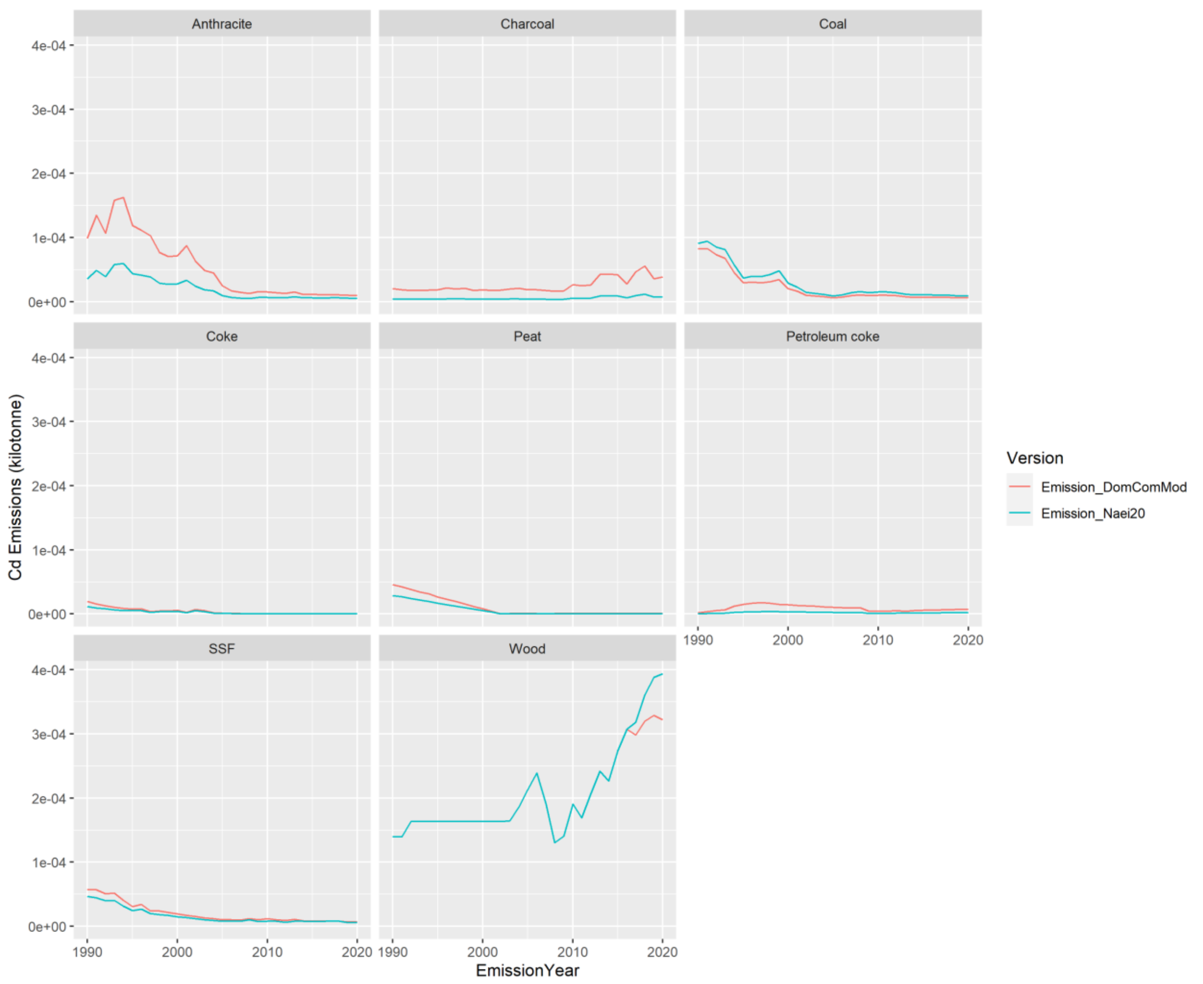


Figure 13-7 Comparison of emissions of carbon monoxide from solid fuel combustion in the residential sector by fuel as calculated by the domestic combustion model versus NAEI20.

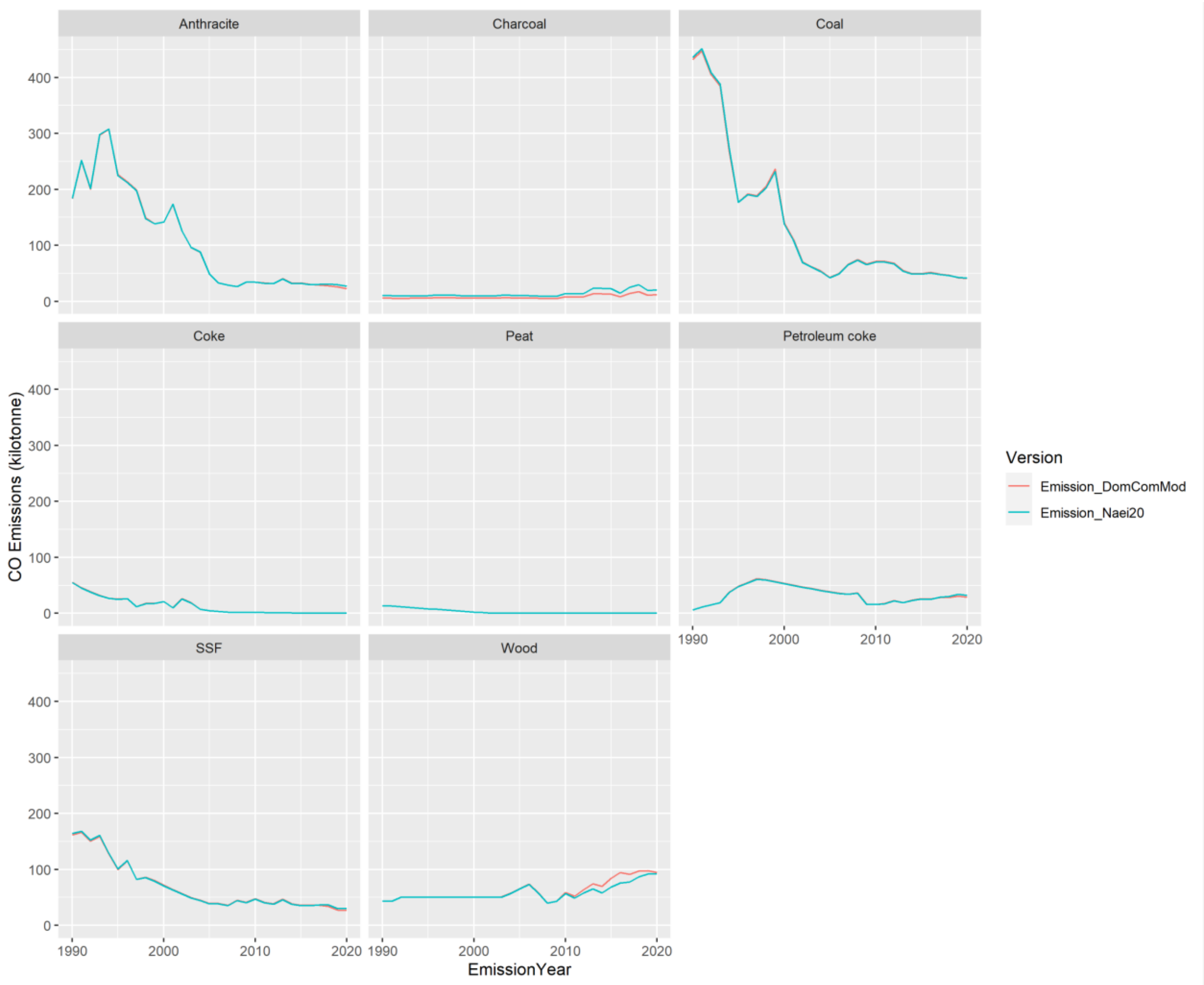


Figure 13-8 Comparison of emissions of chromium from solid fuel combustion in the residential sector by fuel as calculated by the domestic combustion model versus NAEI20.

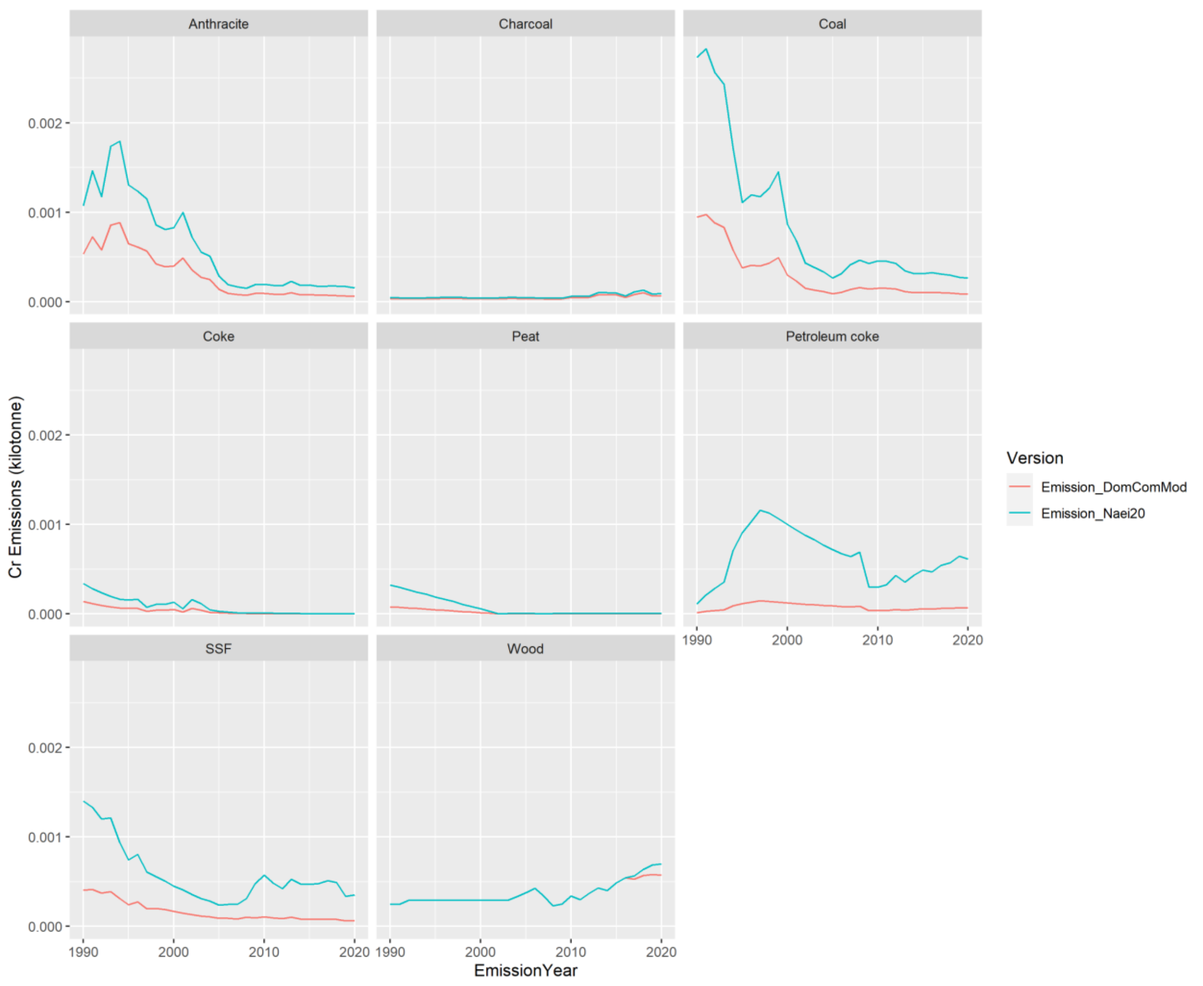


Figure 13-9 Comparison of emissions of copper from solid fuel combustion in the residential sector by fuel as calculated by the domestic combustion model versus NAEI20.

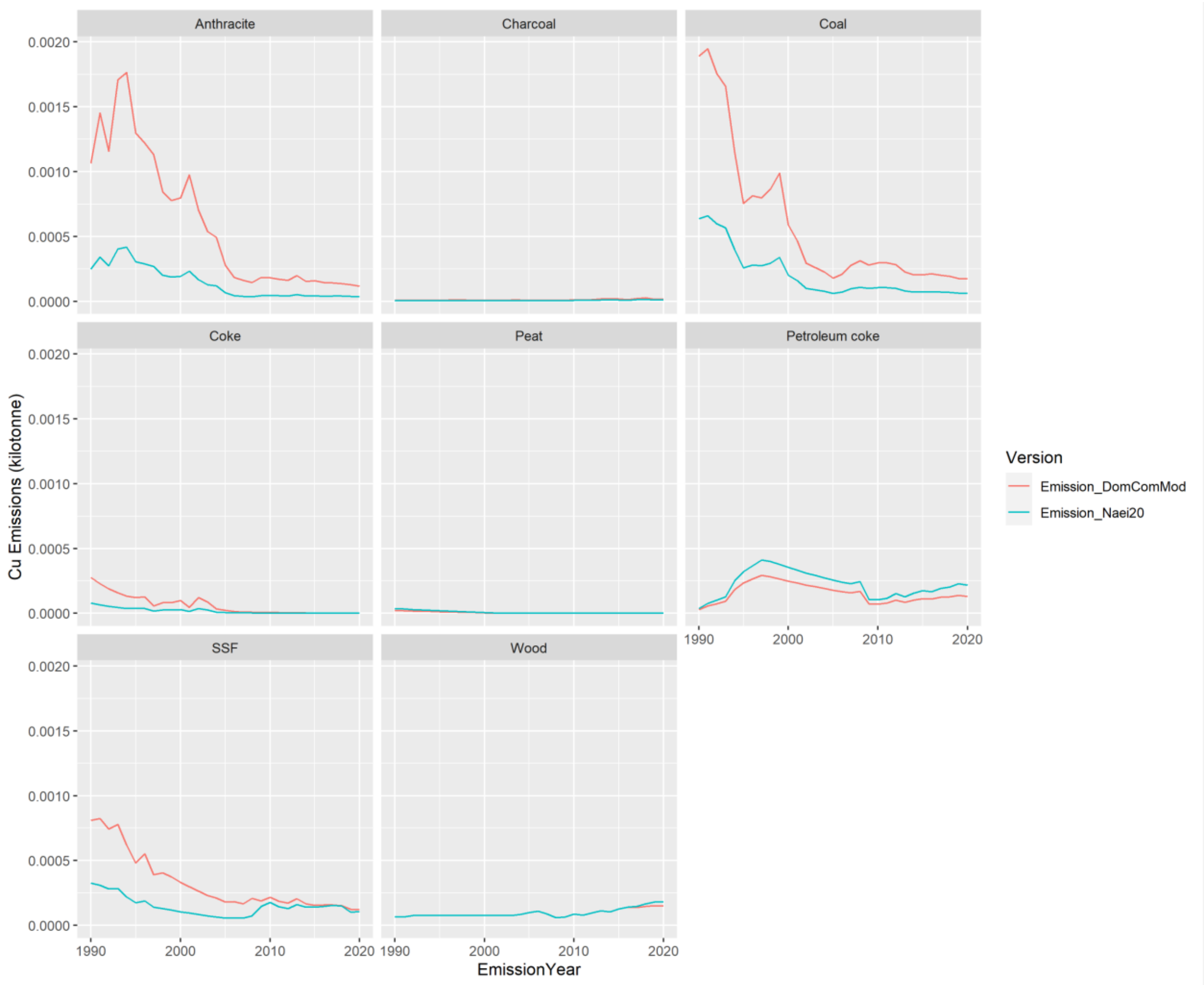


Figure 13-10 Comparison of emissions of dioxins from solid fuel combustion in the residential sector by fuel as calculated by the domestic combustion model versus NAEI20.

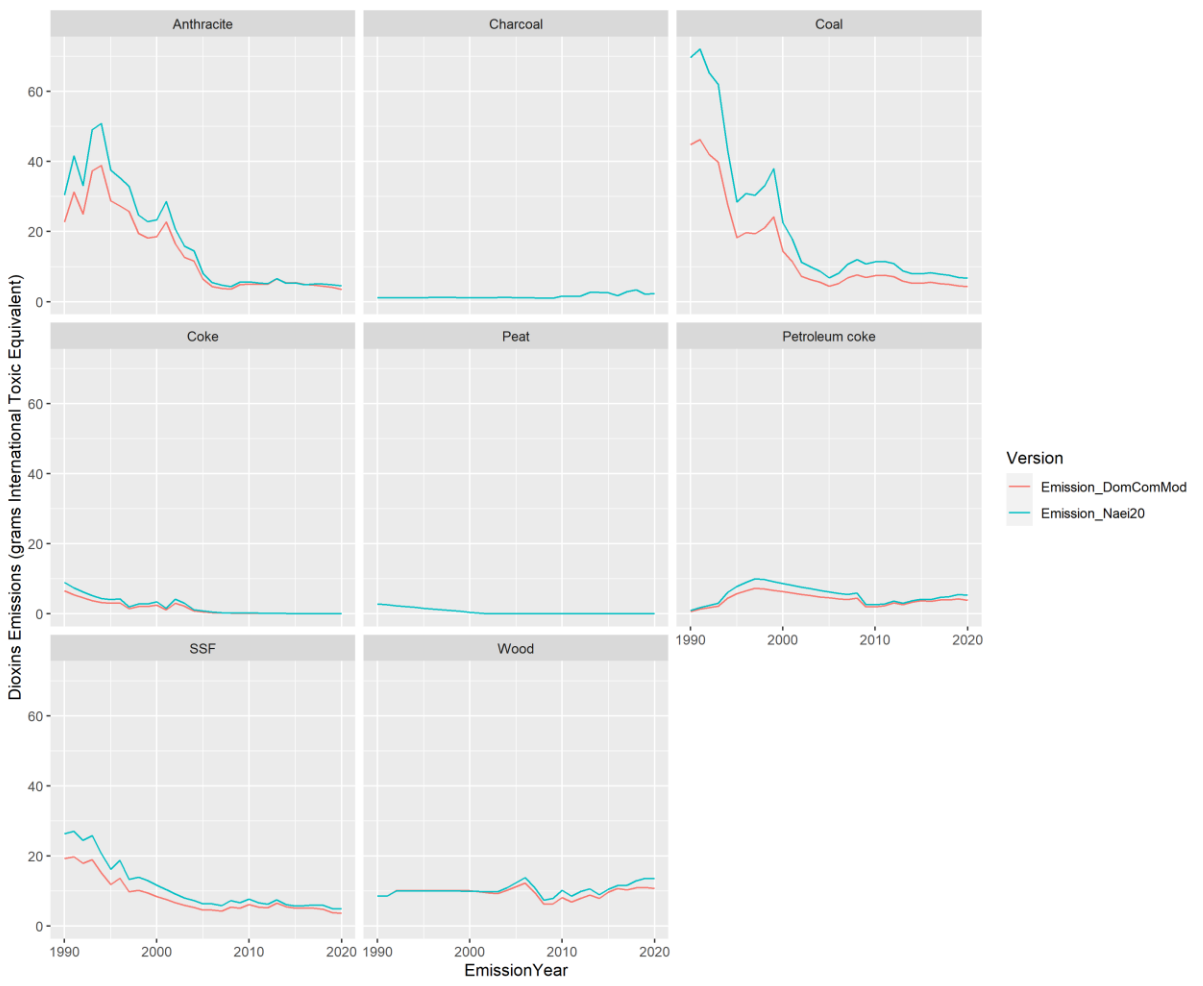


Figure 13-11 Comparison of emissions of hexachlorobenzene from solid fuel combustion in the residential sector by fuel as calculated by the domestic combustion model versus NAEI20.

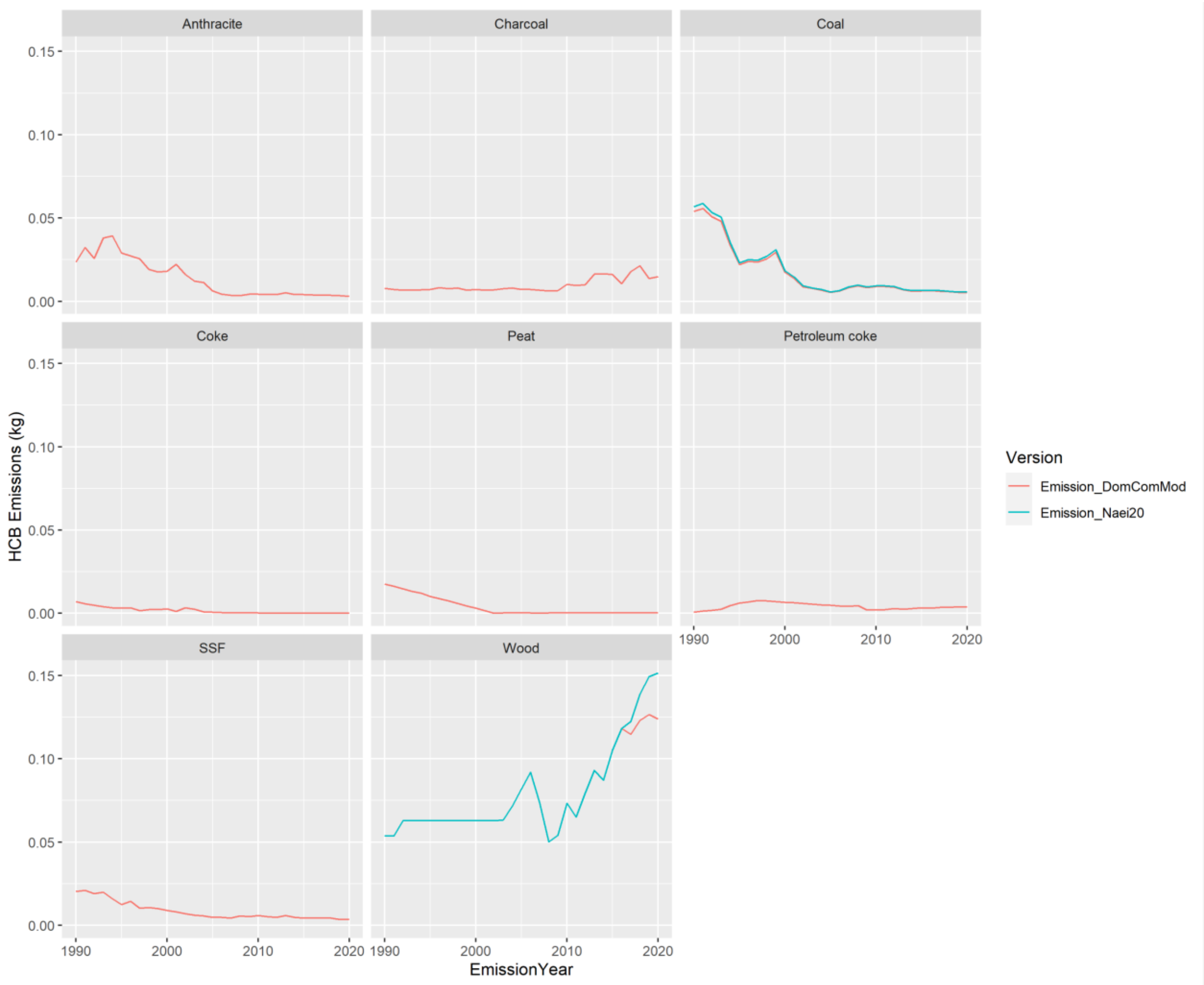


Figure 13-12 Comparison of emissions of mercury from solid fuel combustion in the residential sector by fuel as calculated by the domestic combustion model versus NAEI20.

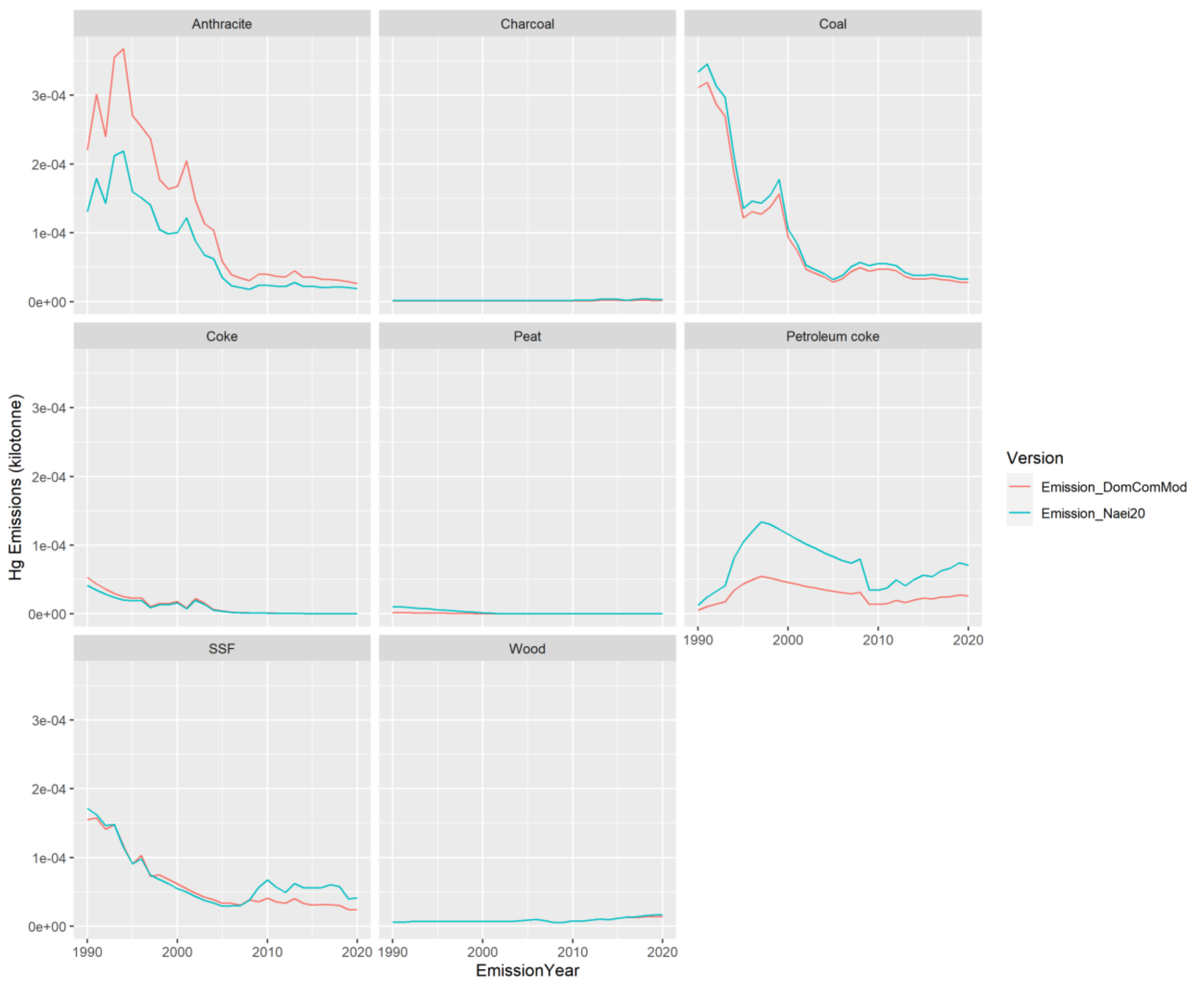


Figure 13-13 Comparison of emissions of indeno(123-cd)pyrene from solid fuel combustion in the residential sector by fuel as calculated by the domestic combustion model versus NAEI20.

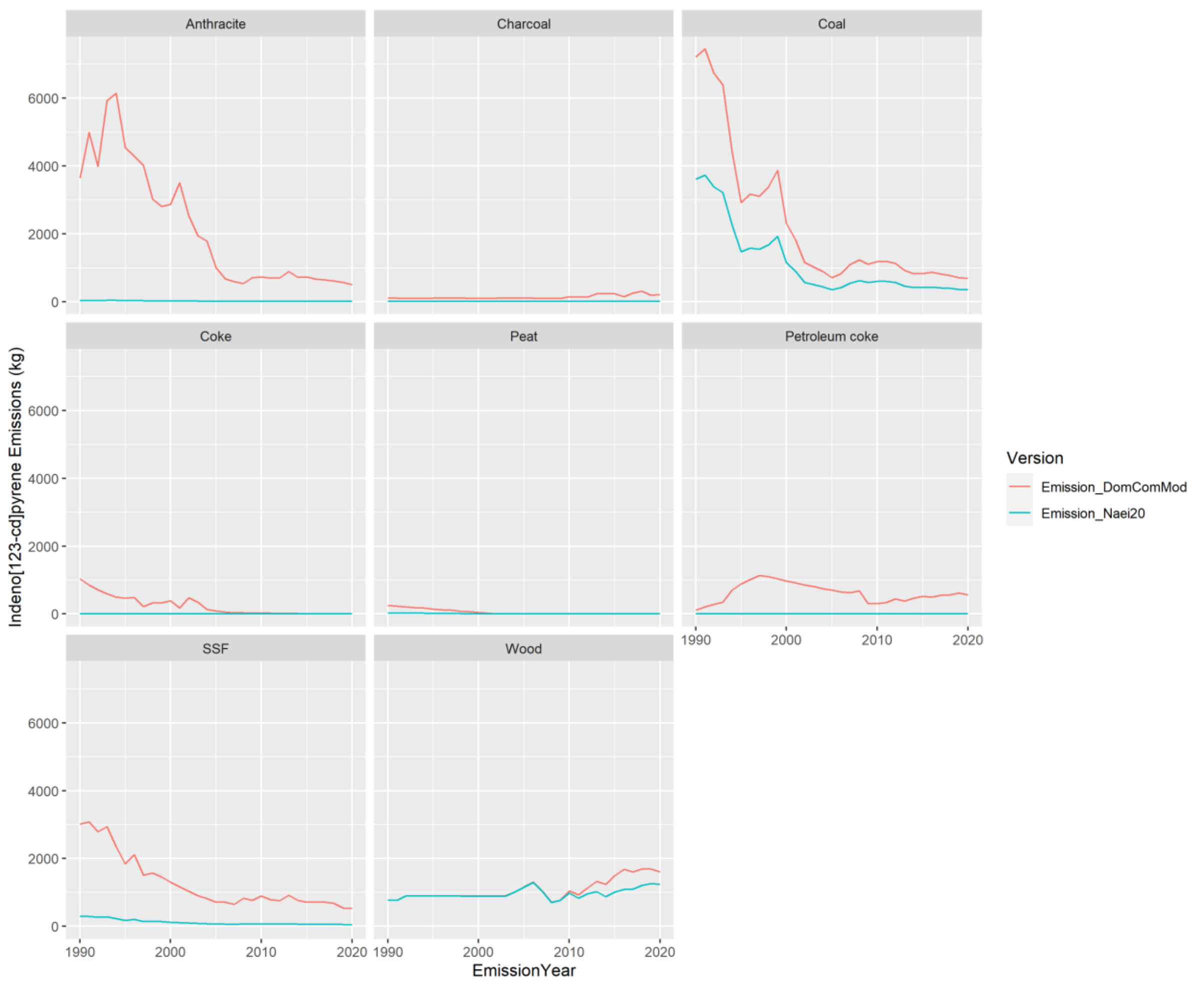


Figure 13-14 Comparison of emissions of ammonia from solid fuel combustion in the residential sector by fuel as calculated by the domestic combustion model versus NAEI20.

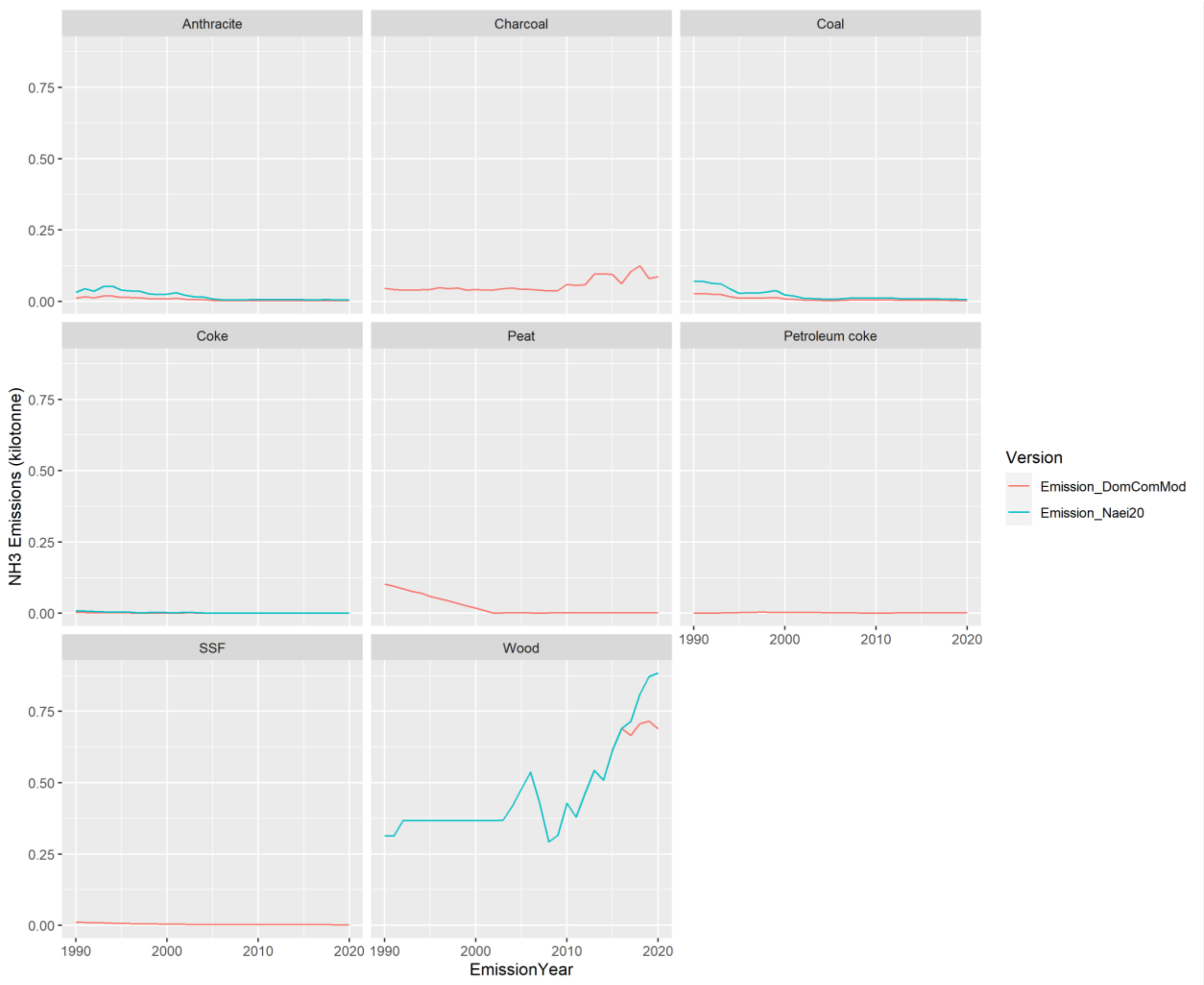


Figure 13-15 Comparison of emissions of nickel from solid fuel combustion in the residential sector by fuel as calculated by the domestic combustion model versus NAEI20.

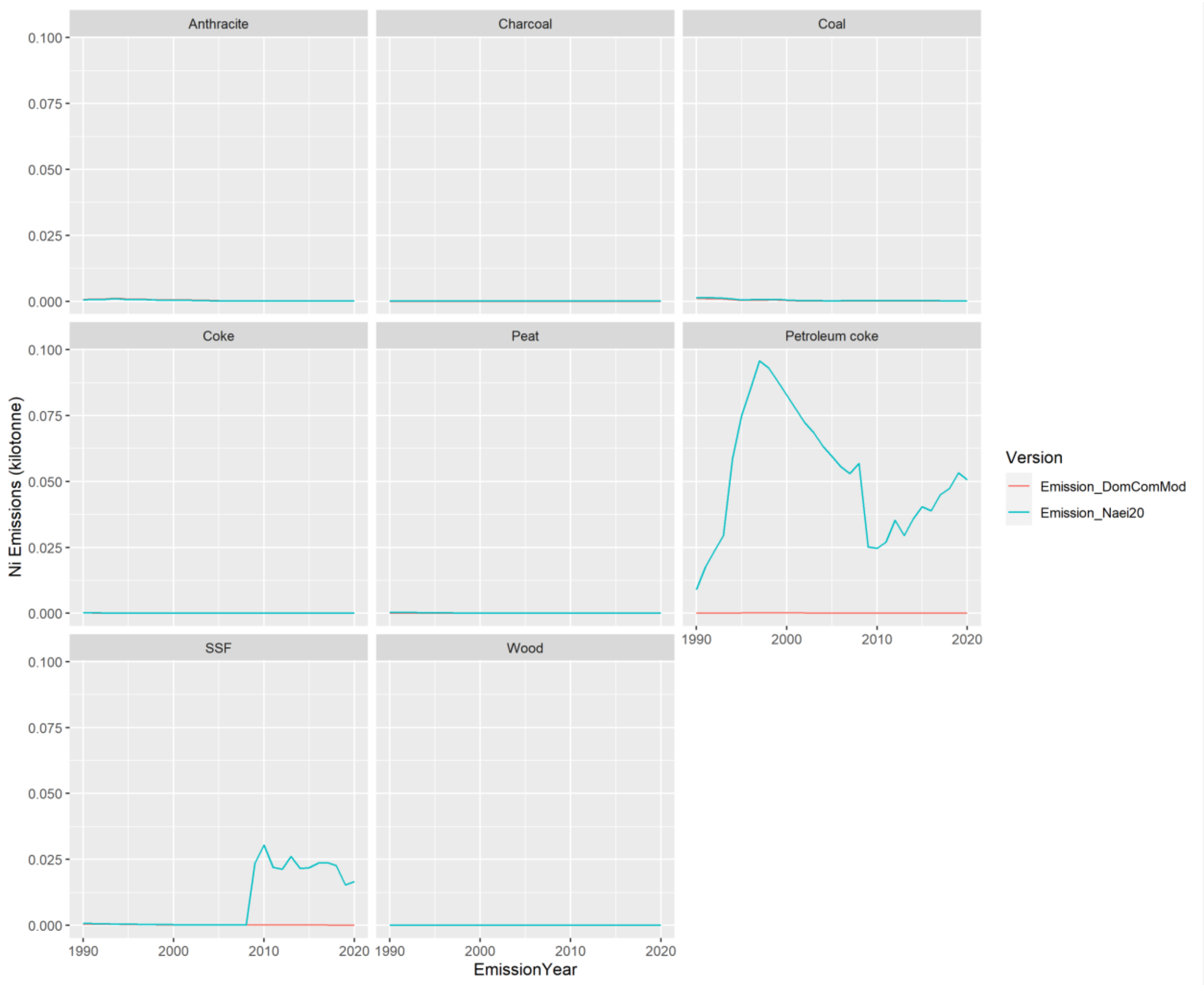


Figure 13-16 Comparison of emissions of nitrogen oxides from solid fuel combustion in the residential sector by fuel as calculated by the domestic combustion model versus NAEI20.

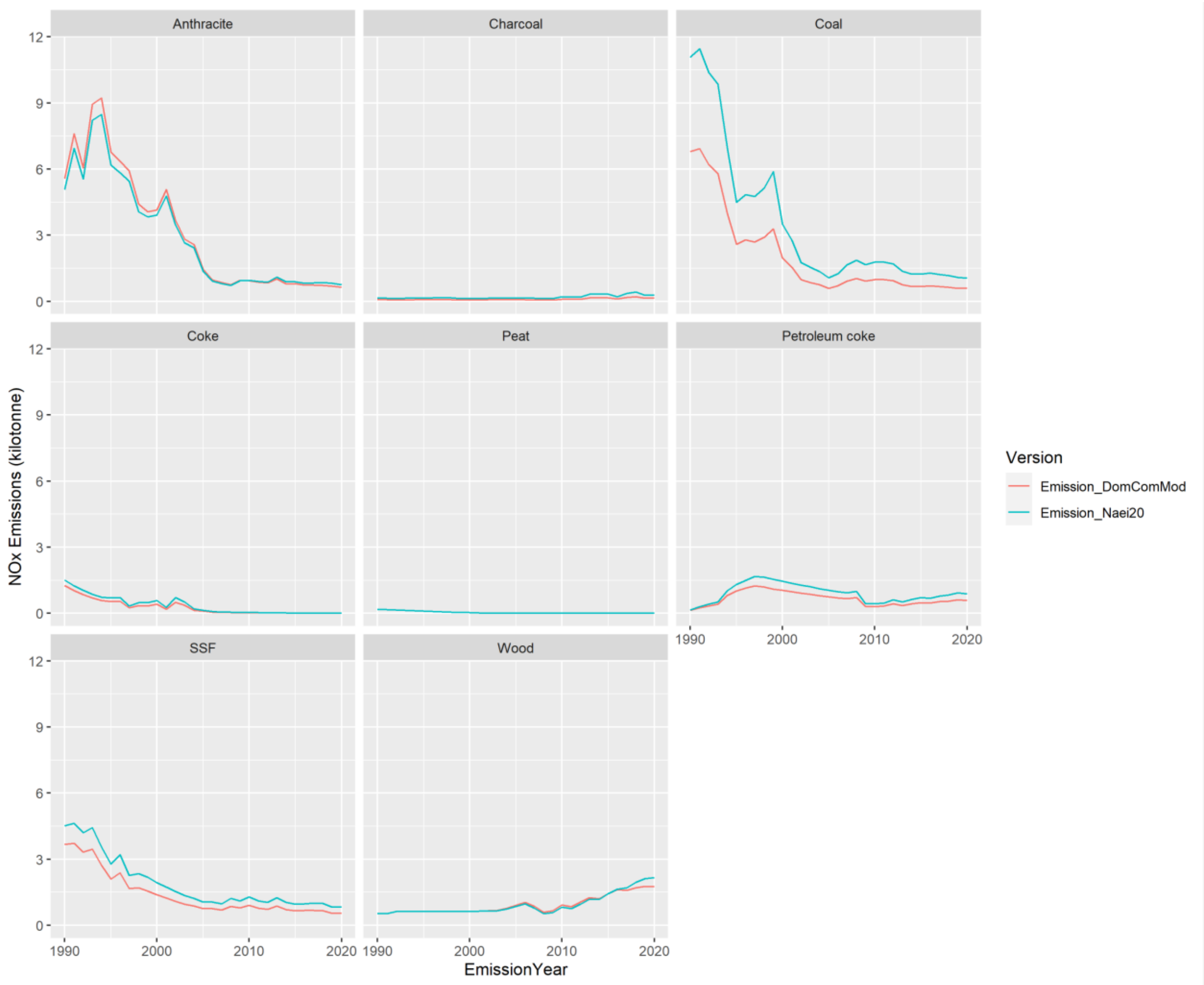


Figure 13-17 Comparison of emissions of lead from solid fuel combustion in the residential sector by fuel as calculated by the domestic combustion model versus NAEI20.

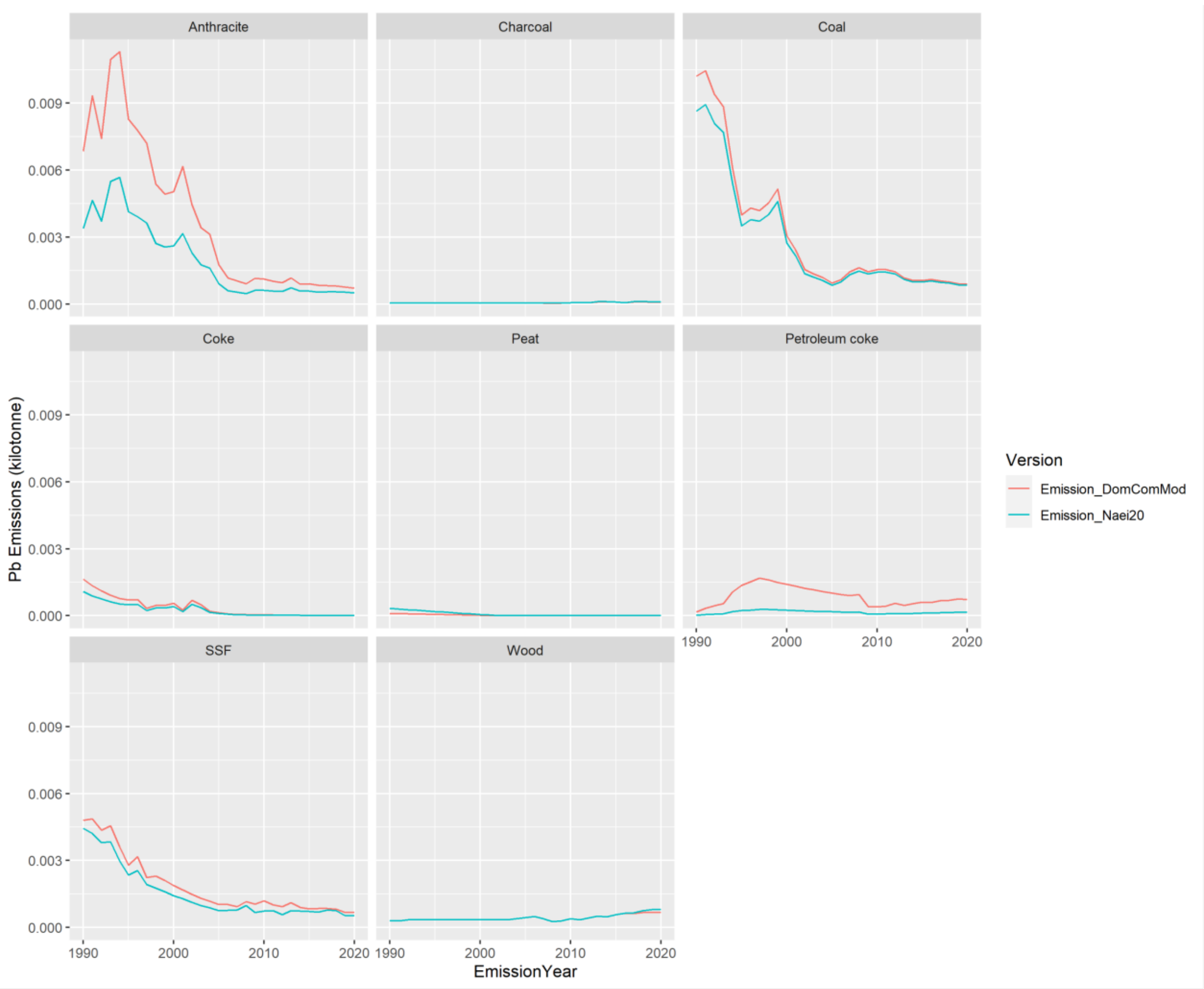


Figure 13-18 Comparison of emissions of polychlorinated biphenyls from solid fuel combustion in the residential sector by fuel as calculated by the domestic combustion model versus NAEI20.

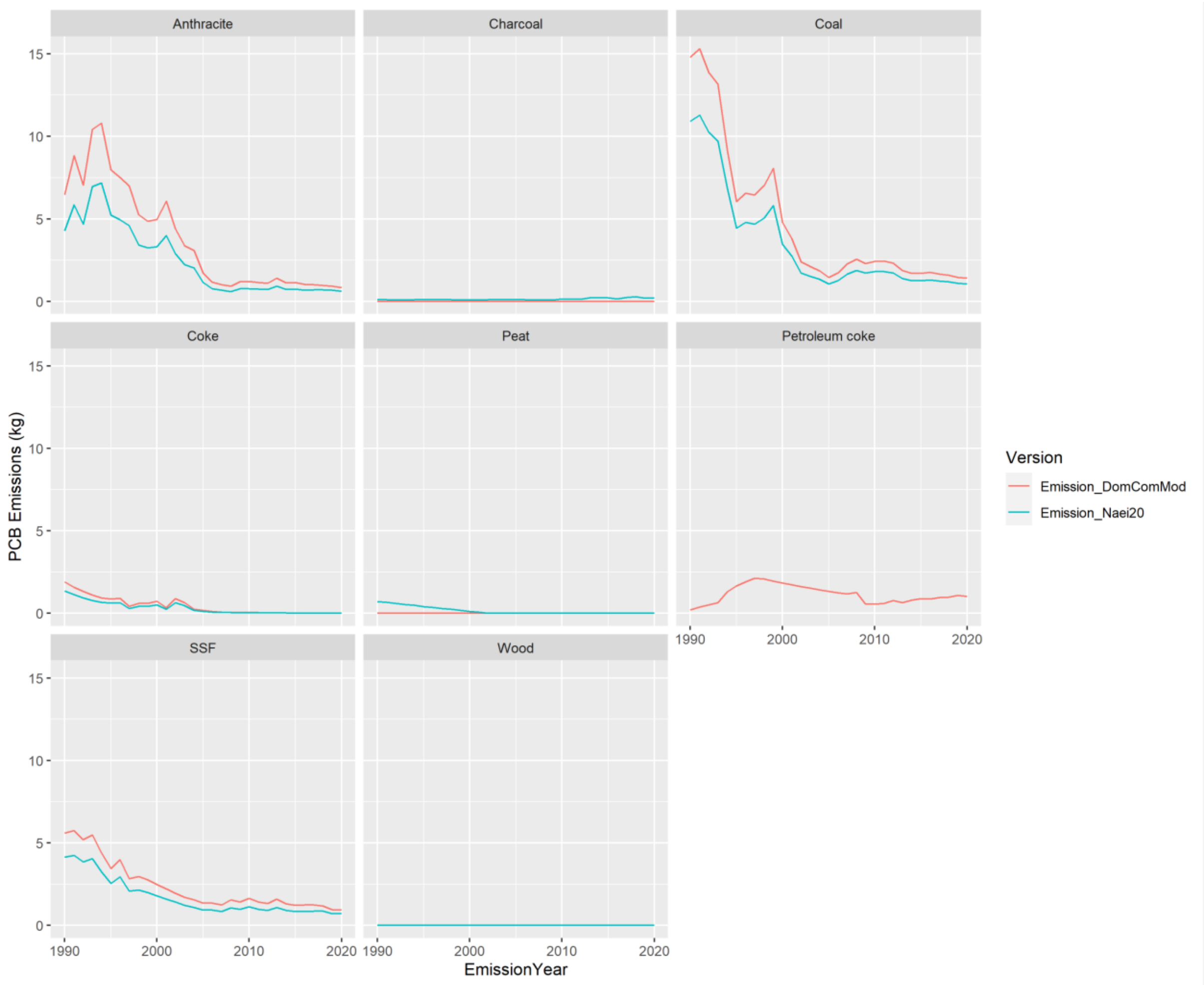


Figure 13-19 Comparison of emissions of particulate matter < 2.5 µm from solid fuel combustion in the residential sector by fuel as calculated by the domestic combustion model versus NAEI20.

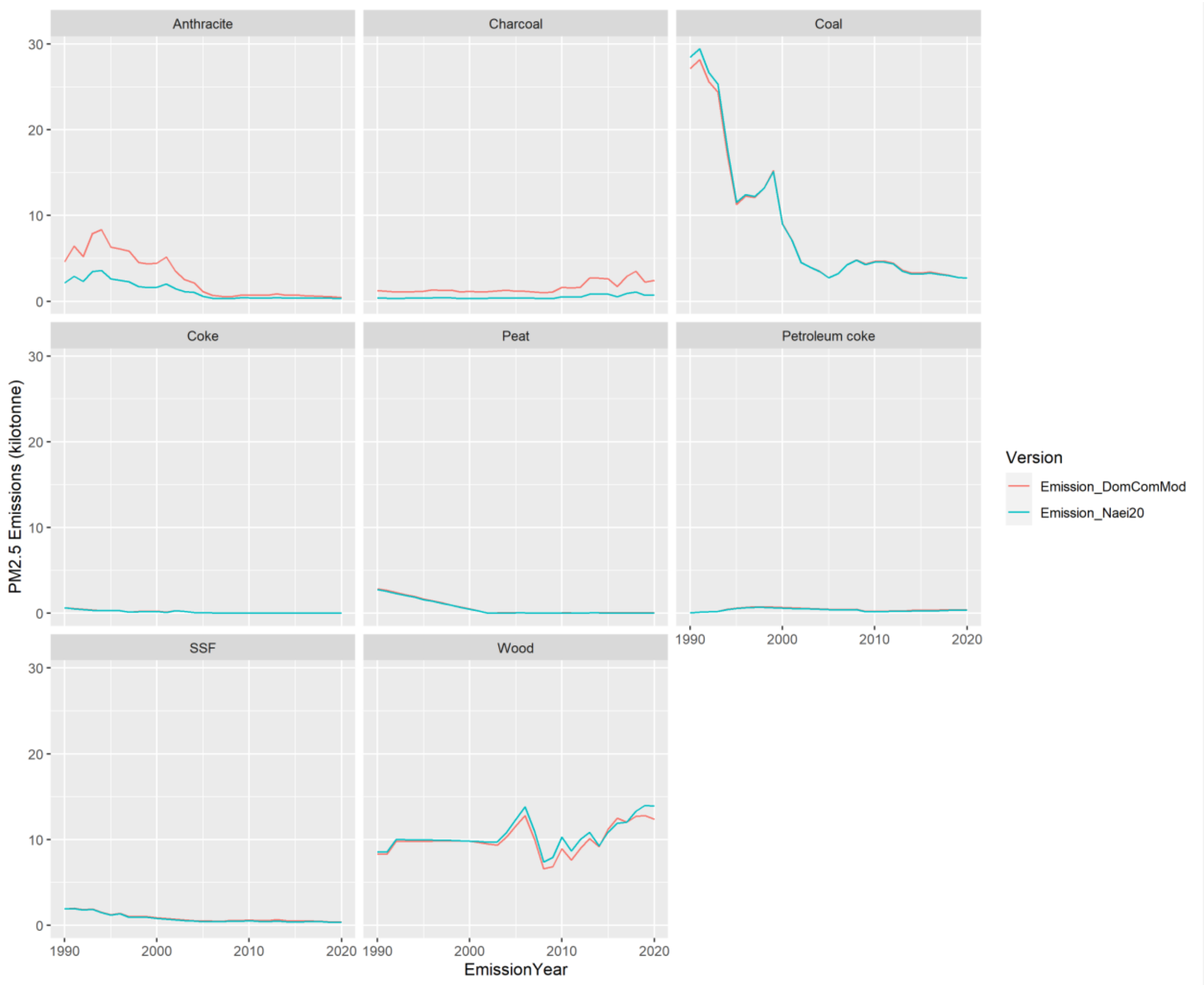


Figure 13-20 Comparison of emissions of particulate matter < 10 µm from solid fuel combustion in the residential sector by fuel as calculated by the domestic combustion model versus NAEI20.

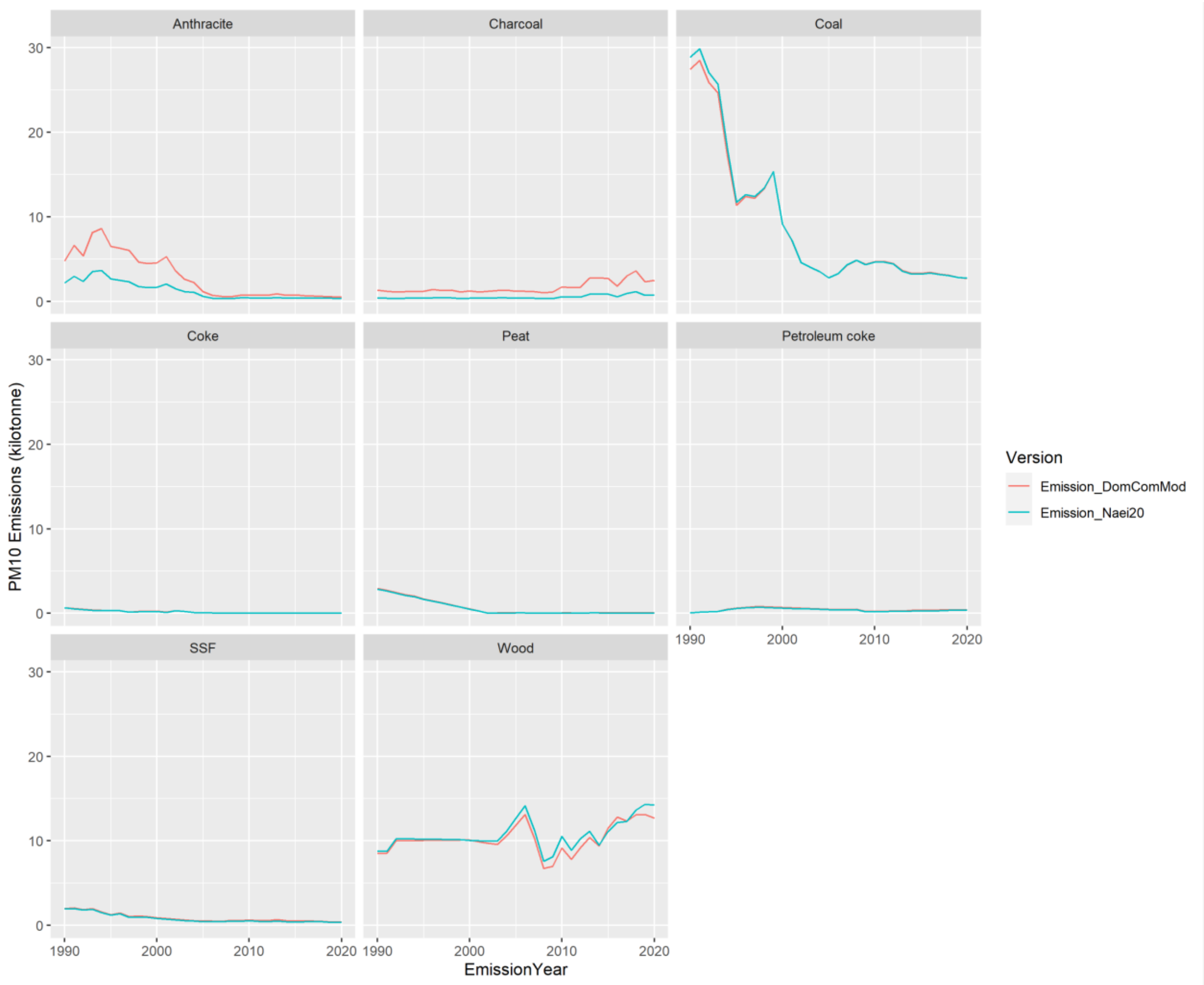


Figure 13-21 Comparison of emissions of selenium from solid fuel combustion in the residential sector by fuel as calculated by the domestic combustion model versus NAEI20.

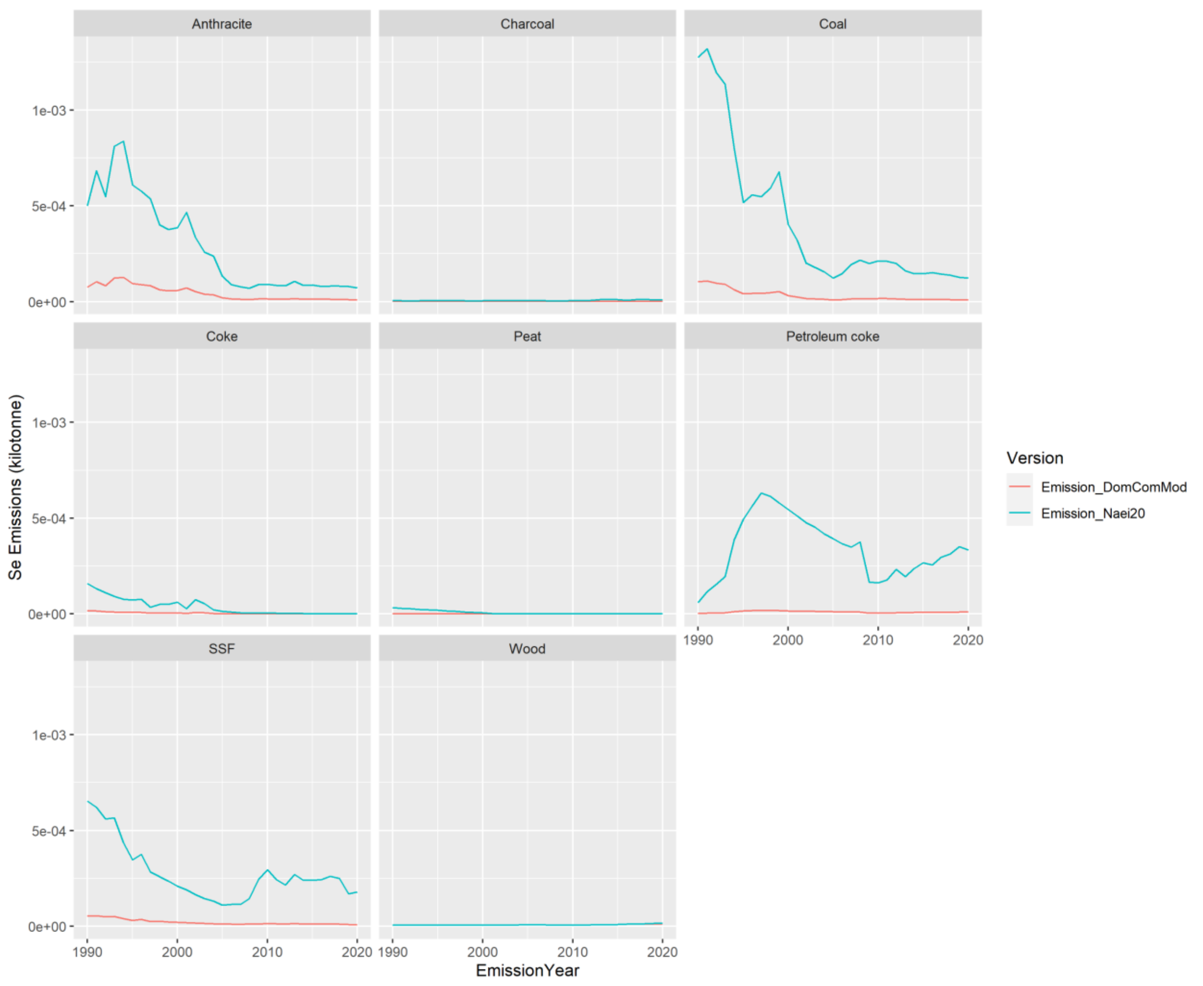


Figure 13-22 Comparison of emissions of total particulate matter from solid fuel combustion in the residential sector by fuel as calculated by the domestic combustion model versus NAEI20.

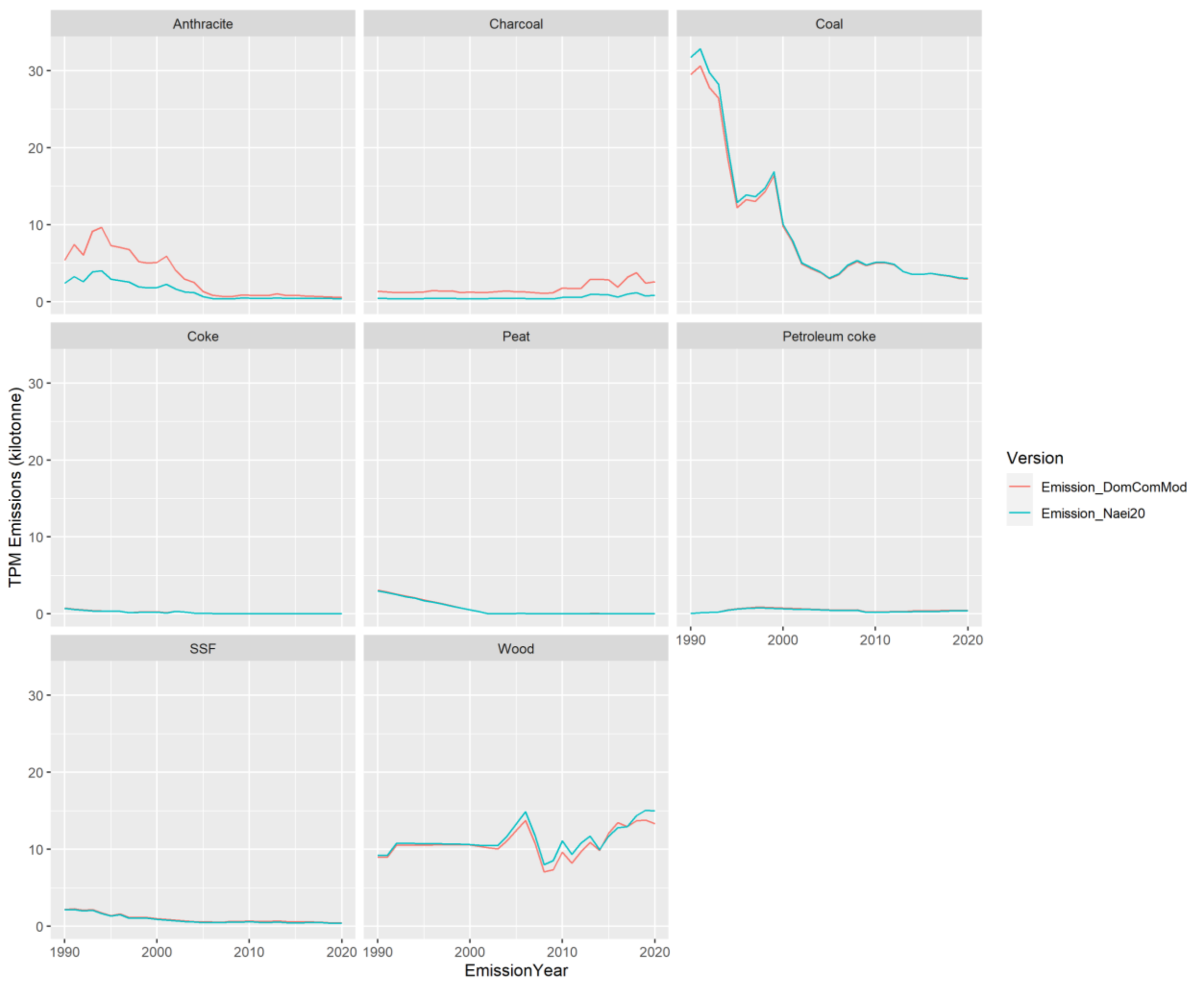


Figure 13-23 Comparison of emissions of non-methane volatile organic compounds from solid fuel combustion in the residential sector by fuel as calculated by the domestic combustion model versus NAEI20.

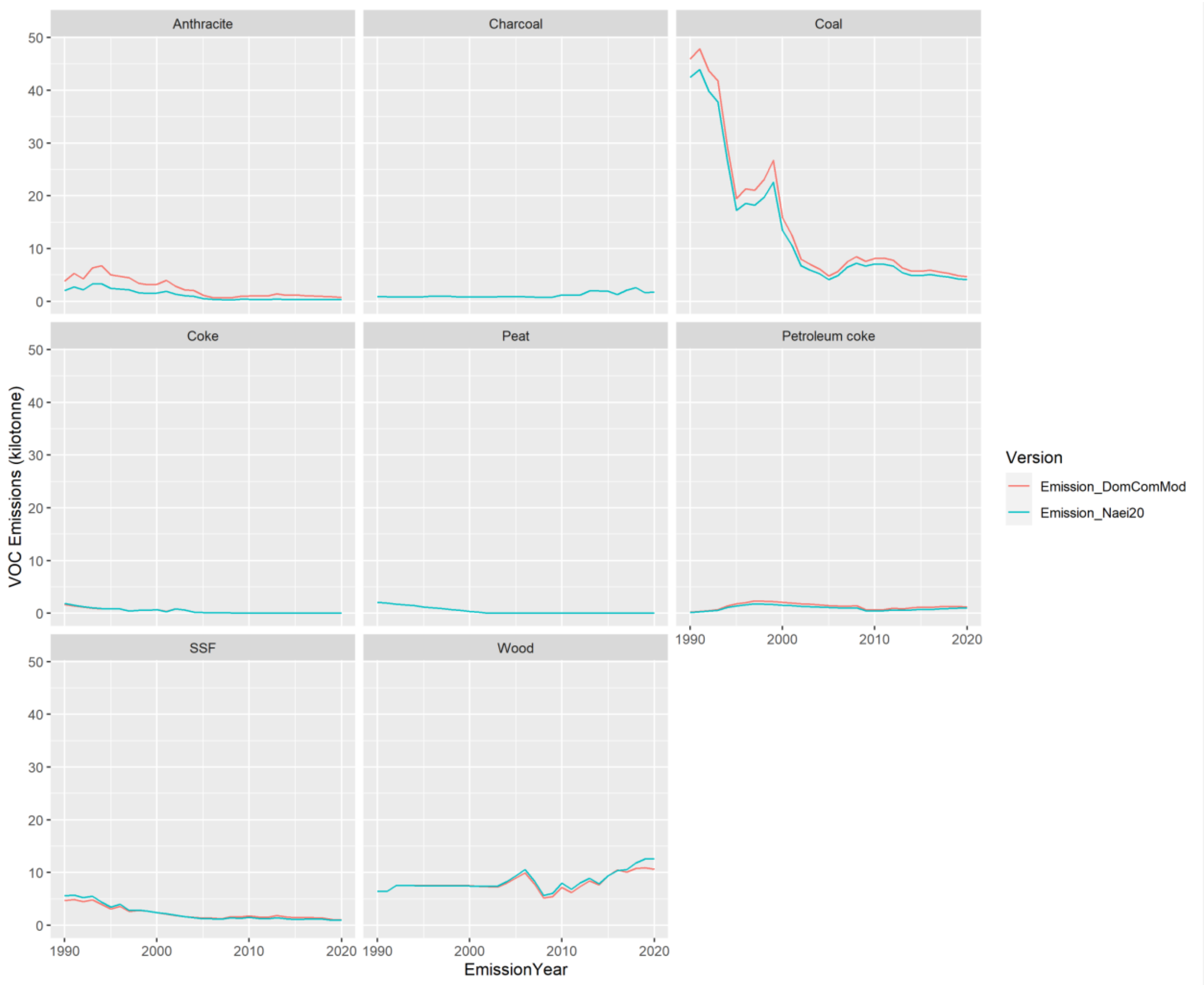
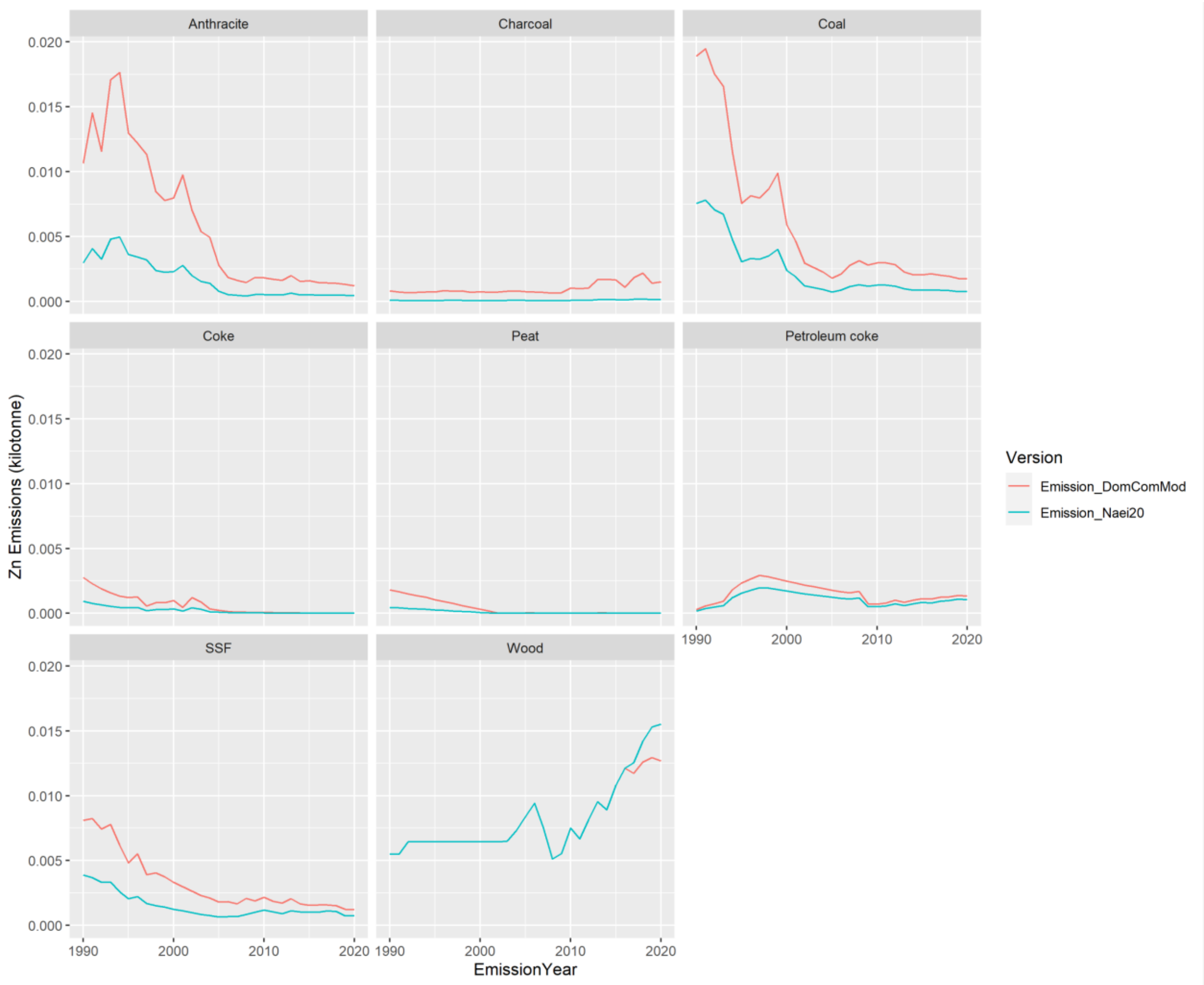


Figure 13-24 Comparison of emissions of zinc from solid fuel combustion in the residential sector by fuel as calculated by the domestic combustion model versus NAEI20.



APPENDIX 2 – GASEOUS FUEL EMISSION COMPARISONS

Figure 13-25 Comparison of emissions of arsenic from gaseous fuel combustion in the residential sector by fuel as calculated by the domestic combustion model versus NAEI20.

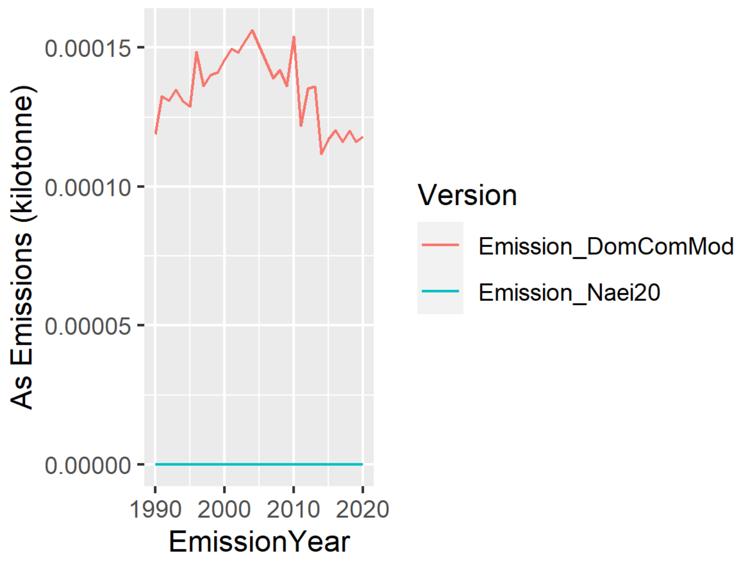
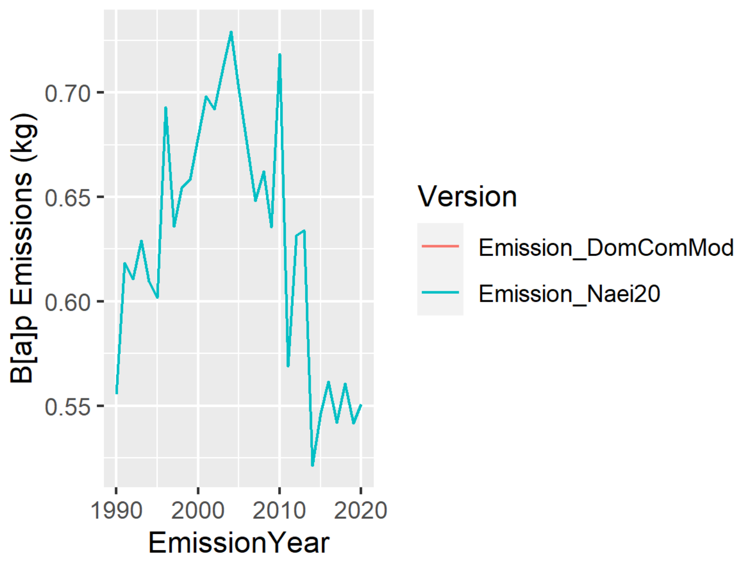
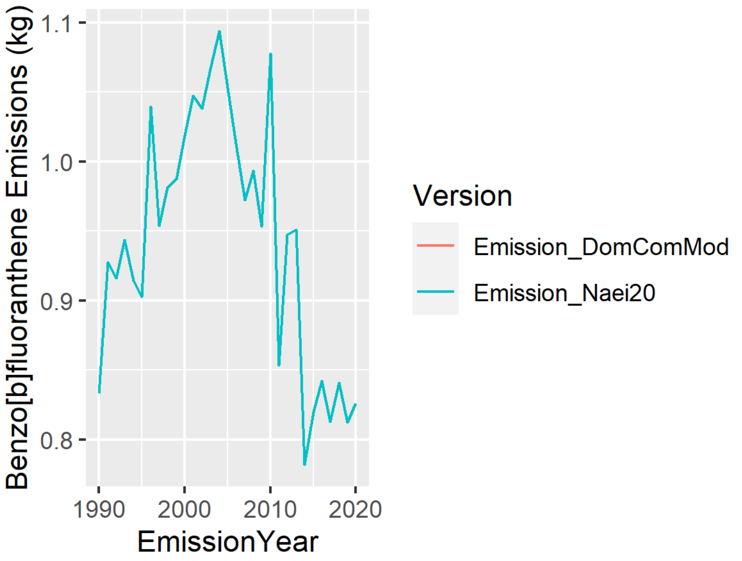


Figure 13-26 Comparison of emissions of benzo[a]pyrene from gaseous fuel combustion in the residential sector by fuel as calculated by the domestic combustion model versus NAEI20.



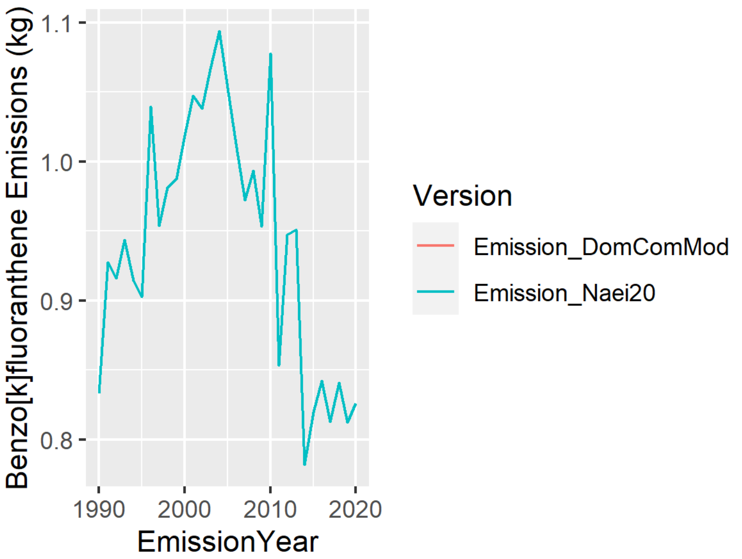
Only the blue line representing emissions from NAEI20 for benzo[a]pyrene from the combustion of gaseous fuels is visible due to extremely small variations in the two model outputs (1 x 10^{-5}).

Figure 13-27 Comparison of emissions of benzo[b]fluoranthene from gaseous fuel combustion in the residential sector by fuel as calculated by the domestic combustion model versus NAEI20.



Only the blue line representing emissions from NAEI20 for benzo[b]fluoranthene from the combustion of gaseous fuels is visible due to extremely small variations in the two model outputs (1×10^{-5}).

Figure 13-28 Comparison of emissions of benzo[k]fluoranthene from gaseous fuel combustion in the residential sector by fuel as calculated by the domestic combustion model versus NAEI20.



Only the blue line representing emissions from NAEI20 for benzo[k]flouranthene from the combustion of gaseous fuels is visible due to extremely small variations in the two model outputs (1×10^{-5}).

Figure 13-29 Comparison of emissions of black carbon from gaseous fuel combustion in the residential sector by fuel as calculated by the domestic combustion model versus NAEI20.

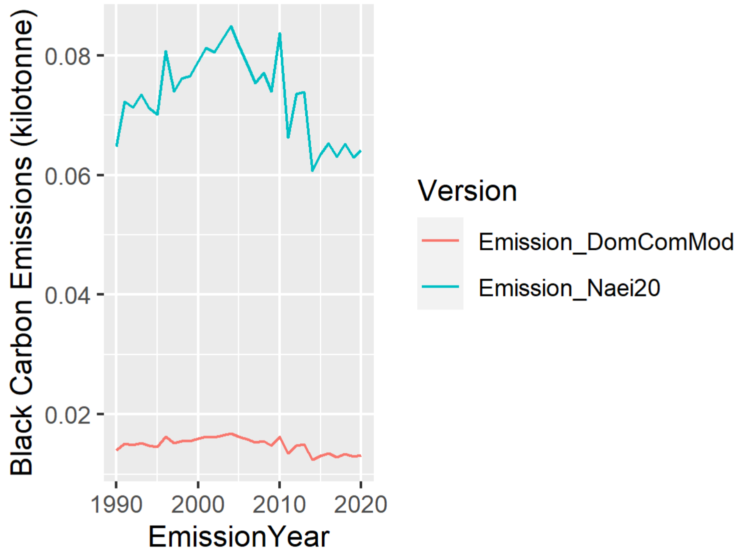


Figure 13-30 Comparison of emissions of cadmium from gaseous fuel combustion in the residential sector by fuel as calculated by the domestic combustion model versus NAEI20.

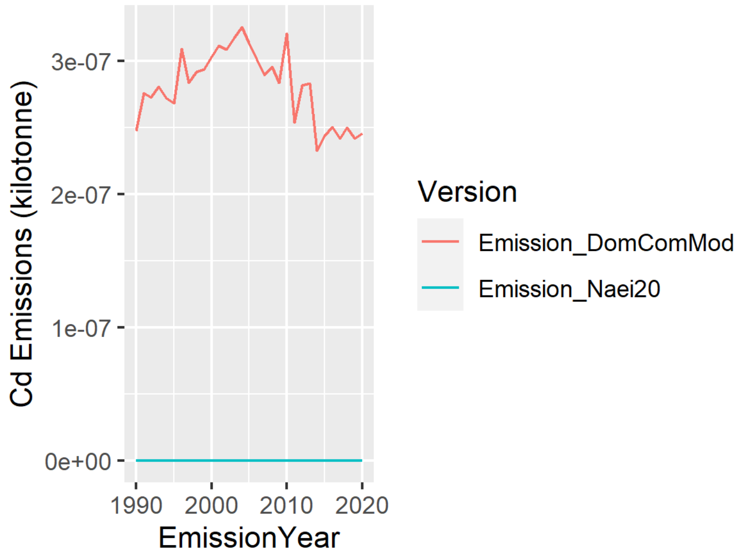


Figure 13-31 Comparison of emissions of carbon monoxide from gaseous fuel combustion in the residential sector by fuel as calculated by the domestic combustion model versus NAEI20.

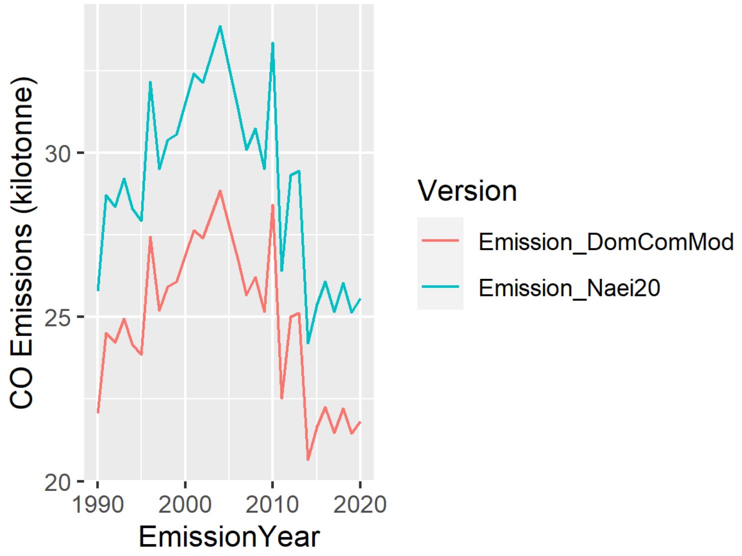


Figure 13-32 Comparison of emissions of chromium from gaseous fuel combustion in the residential sector by fuel as calculated by the domestic combustion model versus NAEI20.

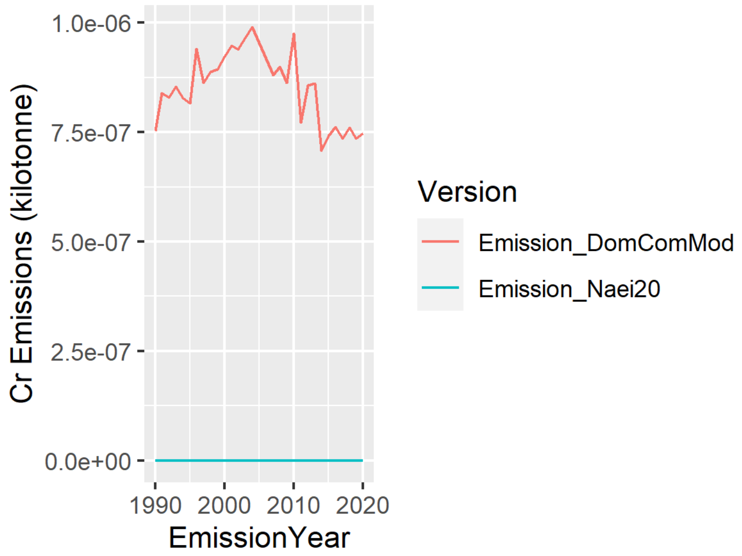


Figure 13-33 Comparison of emissions of copper from gaseous fuel combustion in the residential sector by fuel as calculated by the domestic combustion model versus NAEI20.

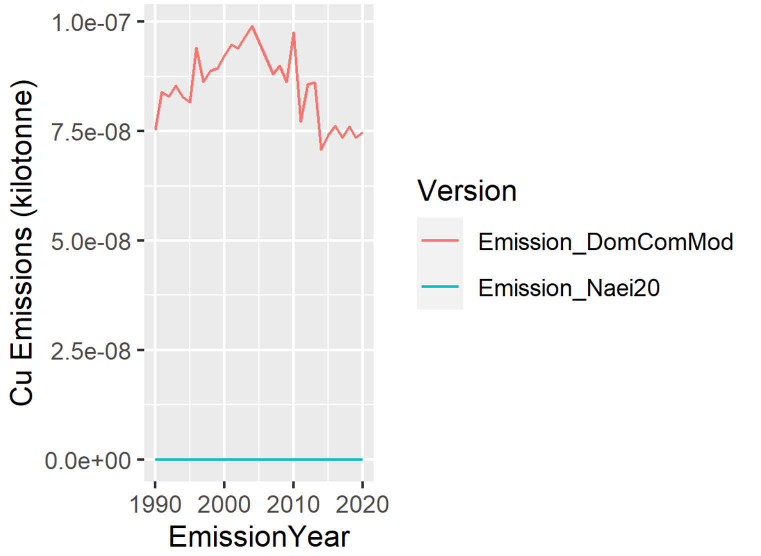
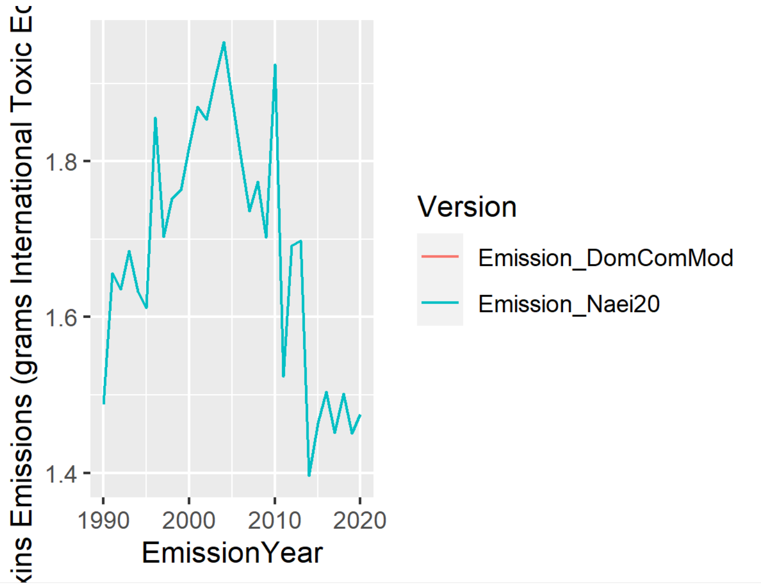


Figure 13-34 Comparison of emissions of dioxins from gaseous fuel combustion in the residential sector by fuel as calculated by the domestic combustion model versus NAEI20.



Only the blue line representing emissions from NAEI20 for dioxins from the combustion of gaseous fuels is visible due to extremely small variations in the two model outputs (1×10^{-5}).

Figure 13-35 Comparison of emissions of mercury from gaseous fuel combustion in the residential sector by fuel as calculated by the domestic combustion model versus NAEI20.

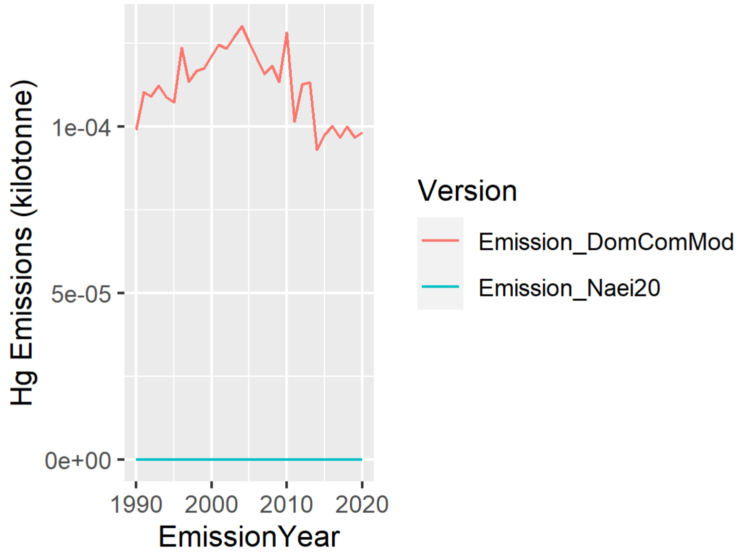
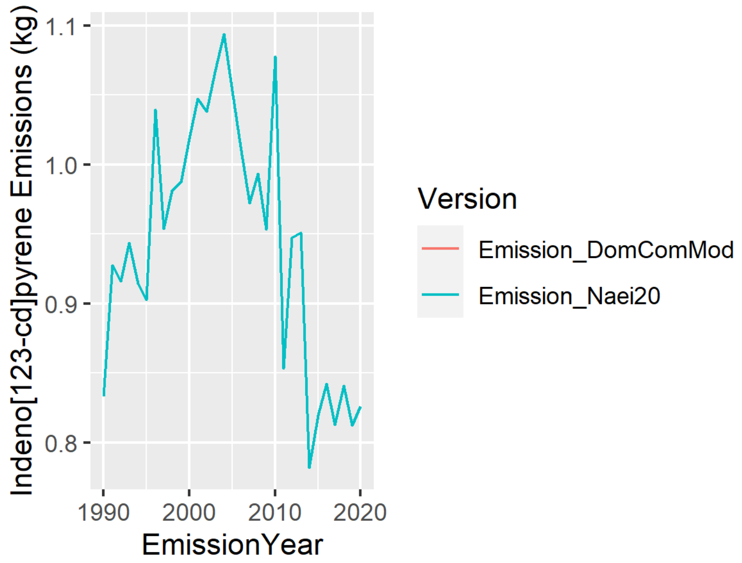


Figure 13-36 Comparison of emissions of indeno(123-cd)pyrene from gaseous fuel combustion in the residential sector by fuel as calculated by the domestic combustion model versus NAEI20.



Only the blue line representing emissions from NAEI20 for indeno(123-cd)pyrene from the combustion of gaseous fuels is visible due to extremely small variations in the two model outputs (1×10^{-5}).

Figure 13-37 Comparison of emissions of nickel from gaseous fuel combustion in the residential sector by fuel as calculated by the domestic combustion model versus NAEI20.

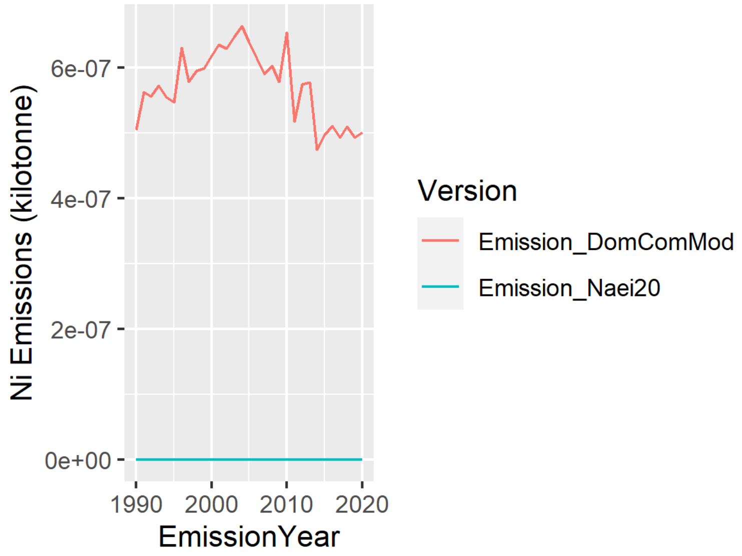


Figure 13-38 Comparison of emissions of nitrogen oxides from gaseous fuel combustion in the residential sector by fuel as calculated by the domestic combustion model versus NAEI20.

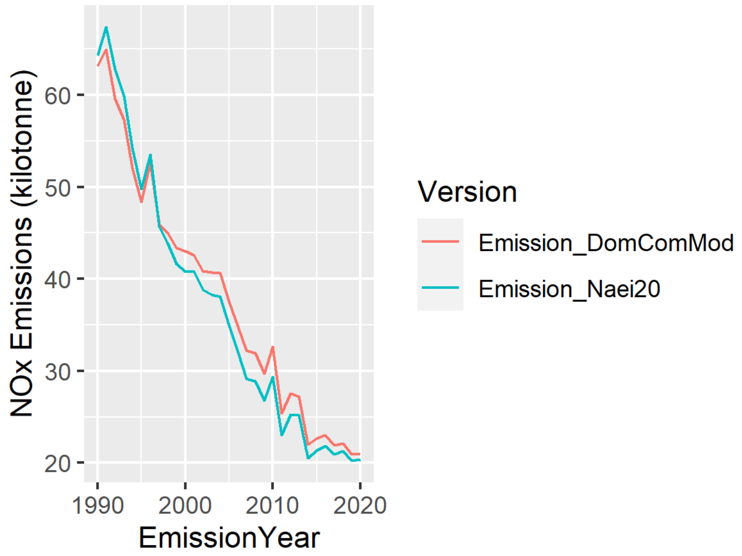


Figure 13-39 Comparison of emissions of lead from gaseous fuel combustion in the residential sector by fuel as calculated by the domestic combustion model versus NAEI20.

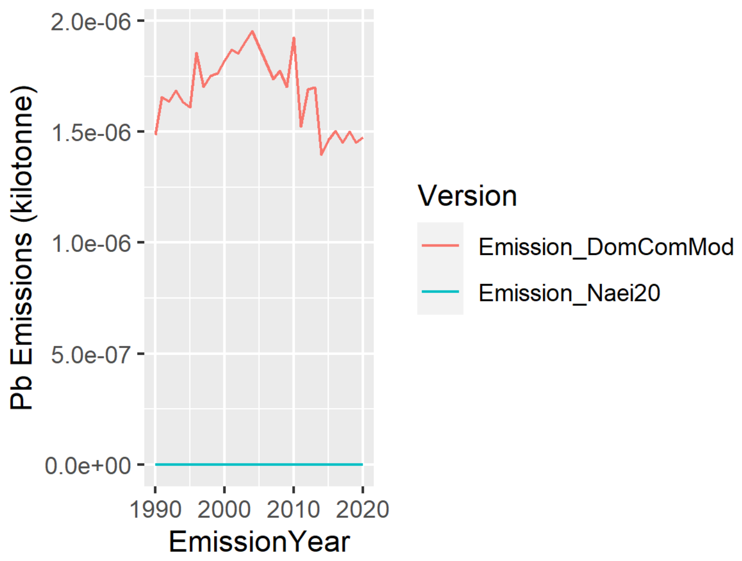


Figure 13-40 Comparison of emissions of particulate matter < 2.5 µm from gaseous fuel combustion in the residential sector by fuel as calculated by the domestic combustion model versus NAEI20.

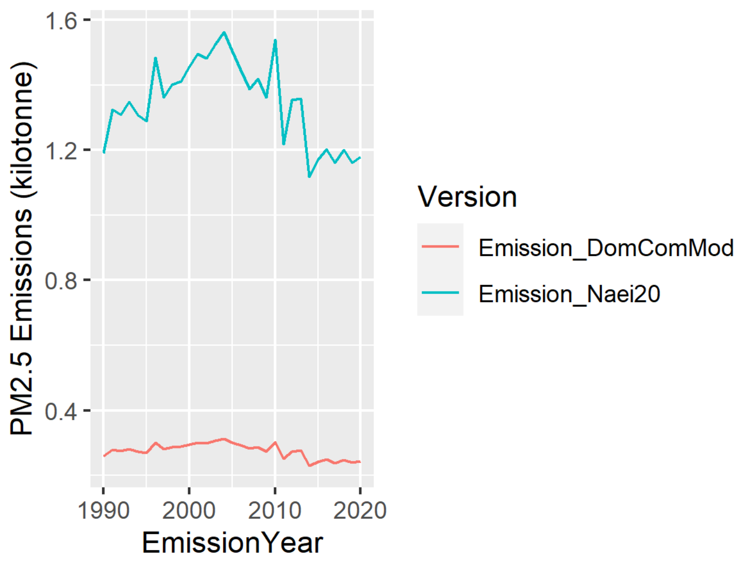


Figure 13-41 Comparison of emissions of particulate matter < 10 µm from gaseous fuel combustion in the residential sector by fuel as calculated by the domestic combustion model versus NAEI20.

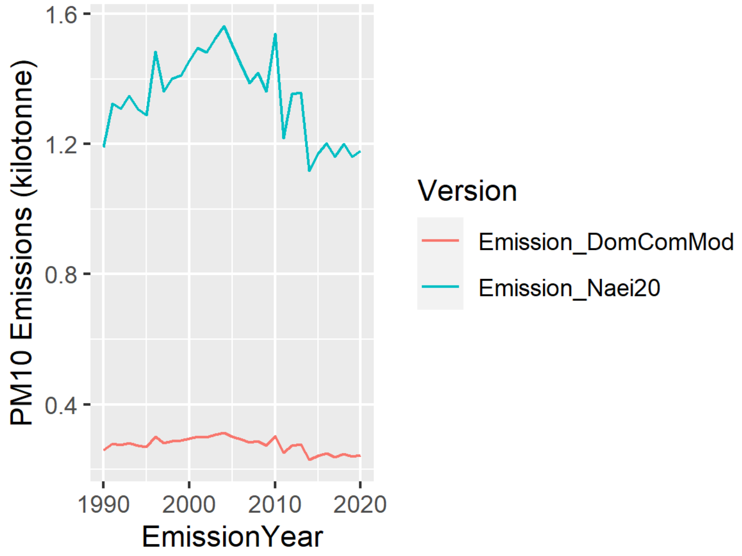


Figure 13-42 Comparison of emissions of selenium from gaseous fuel combustion in the residential sector by fuel as calculated by the domestic combustion model versus NAEI20.

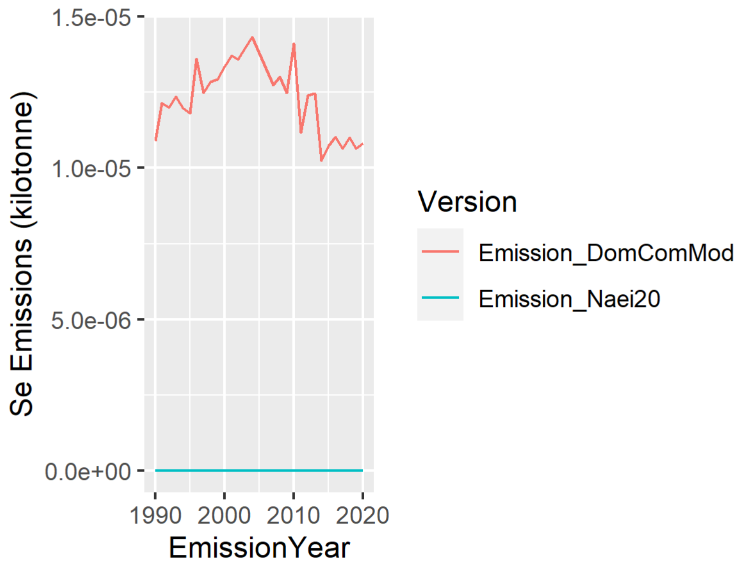


Figure 13-43 Comparison of emissions of sulphur dioxide from gaseous fuel combustion in the residential sector by fuel as calculated by the domestic combustion model versus NAEI20.

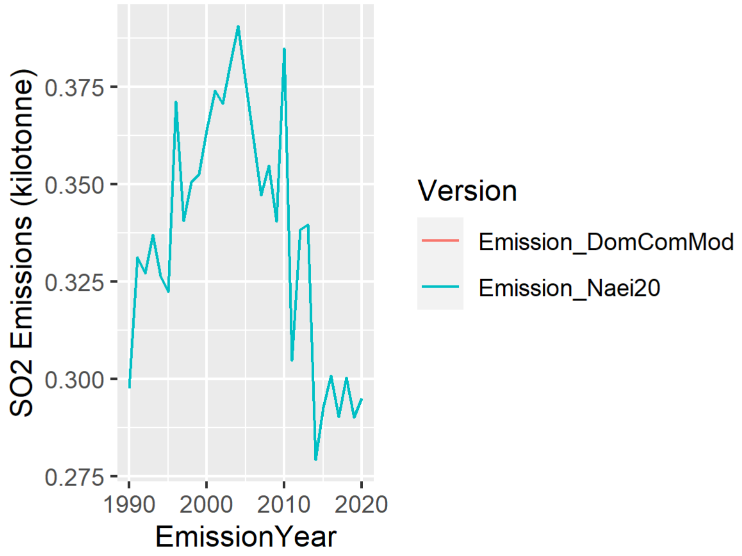


Figure 13-44 Comparison of emissions of total particulate matter from gaseous fuel combustion in the residential sector by fuel as calculated by the domestic combustion model versus NAEI20.

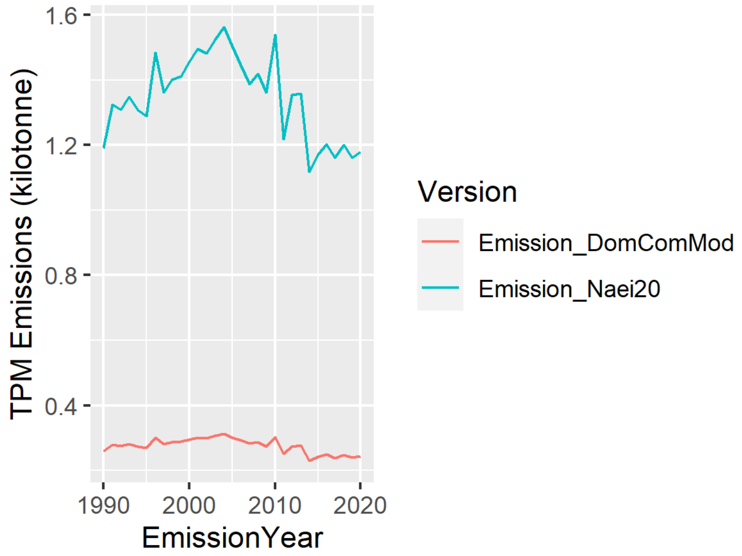


Figure 13-45 Comparison of emissions of non-methane volatile organic compounds from gaseous fuel combustion in the residential sector by fuel as calculated by the domestic combustion model versus NAEI20.

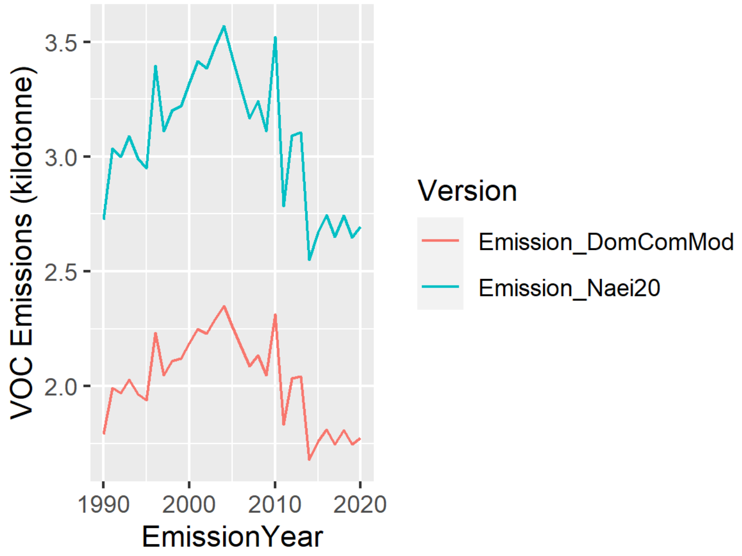
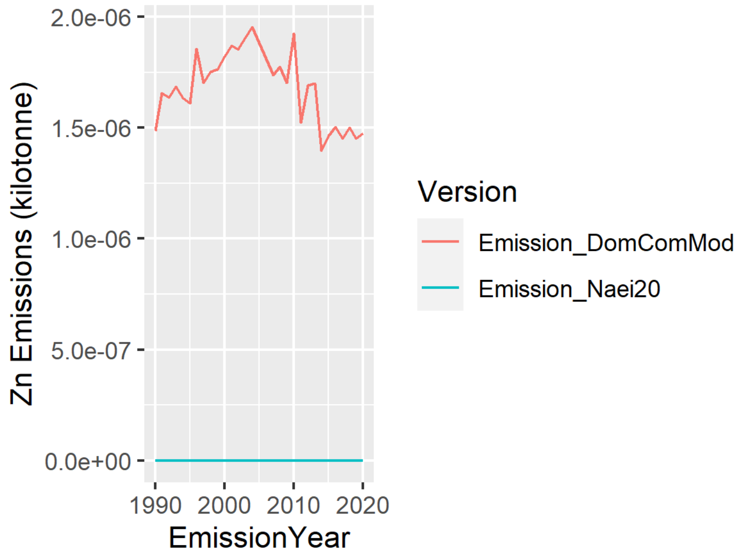


Figure 13-46 Comparison of emissions of zinc from gaseous fuel combustion in the residential sector by fuel as calculated by the domestic combustion model versus NAEI20.



APPENDIX 3 – LIQUID FUEL EMISSIONS COMPARISONS

This section provides a comparison between a number of different pollutants as estimated by the improved liquid fuel boiler and heater model against the current estimations of the NAEI.

Figure 13-47 Comparison of emissions of (starting top-left going clockwise) arsenic, benzo[a]pyrene, benzo[b]fluoranthene, cadmium, black carbon, benzo[k]fluoranthene from liquid fuel combustion in the residential sector by fuel as calculated by the domestic combustion model versus NAEI20.

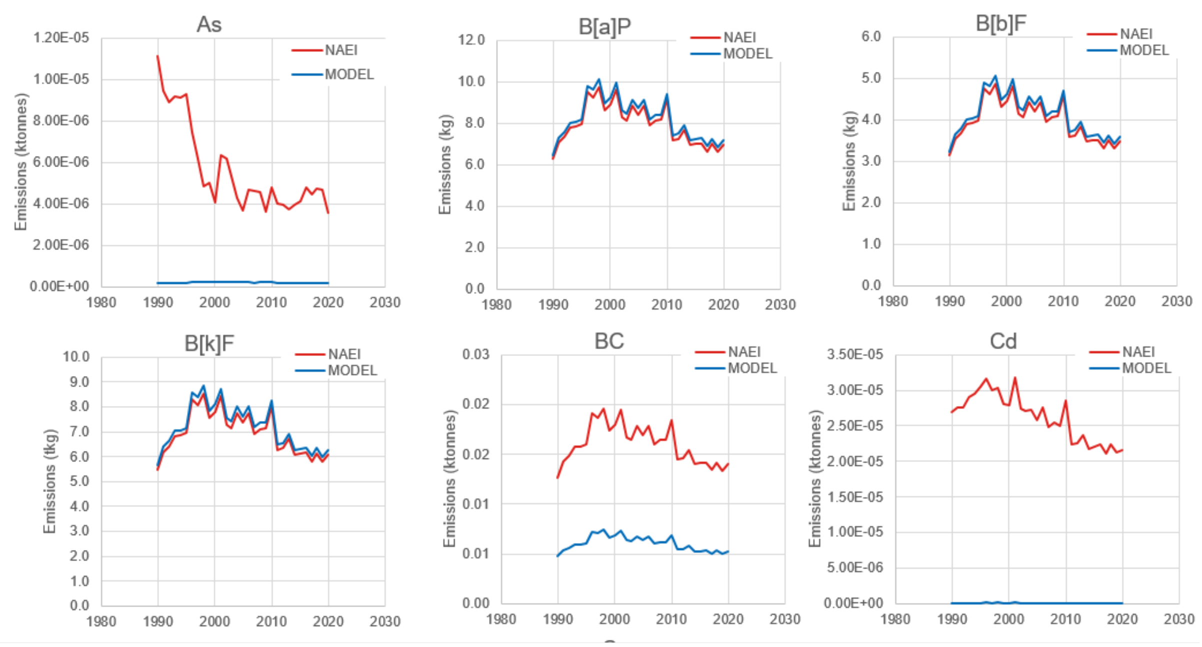


Figure 13-48 Comparison of emissions of (starting top-left going clockwise) carbon monoxide, chromium, copper, nickel, indeno(123-cd)pyrene, mercury from liquid fuel combustion in the residential sector by fuel as calculated by the domestic combustion model versus NAEI20.

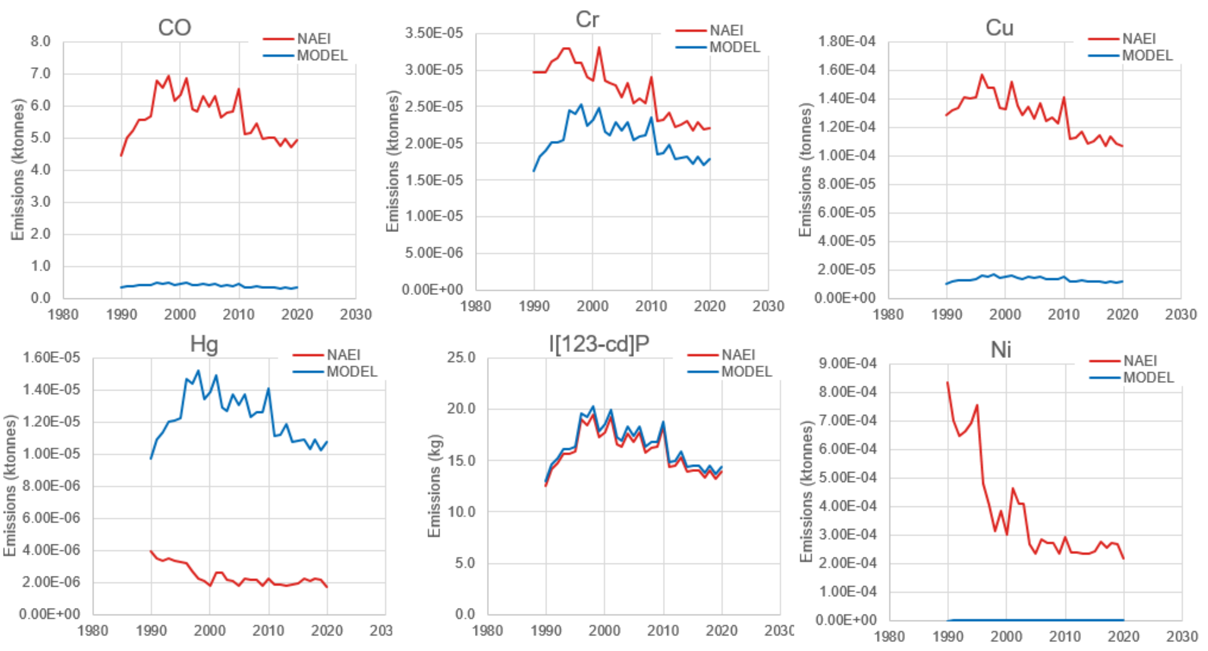


Figure 13-49 Comparison of emissions of (starting top-left going clockwise) non-methane volatile organic compounds, nitrogen oxides, particulate matter < 2.5 µm, dioxins, lead, particulate matter < 10 µm from liquid fuel combustion in the residential sector by fuel as calculated by the domestic combustion model versus NAEI20.

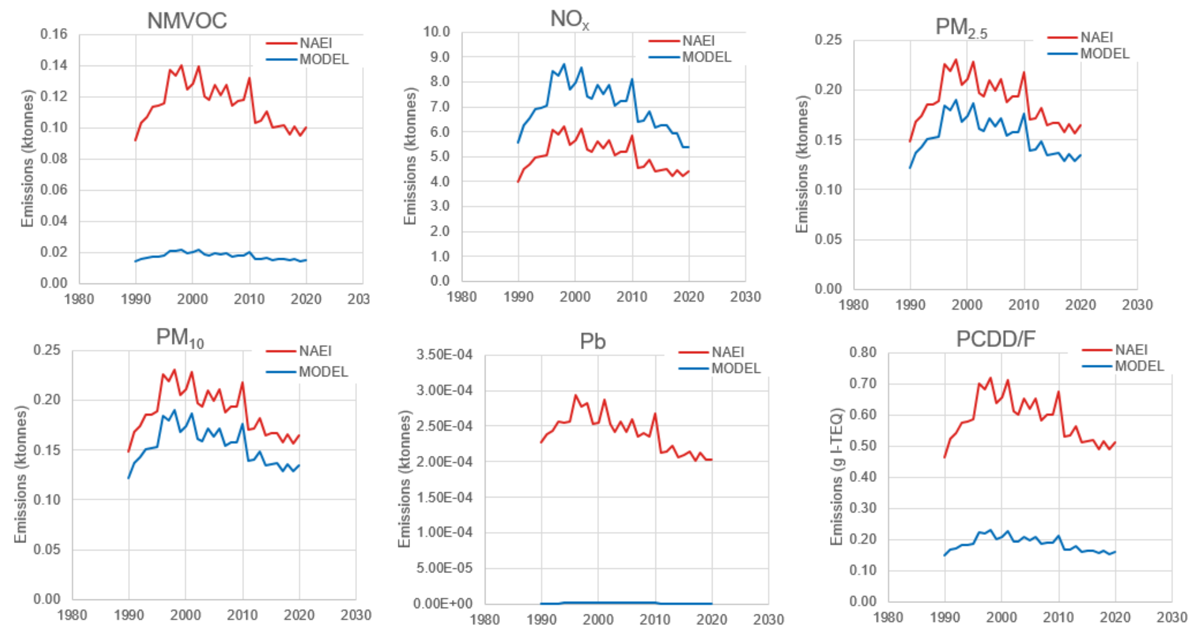
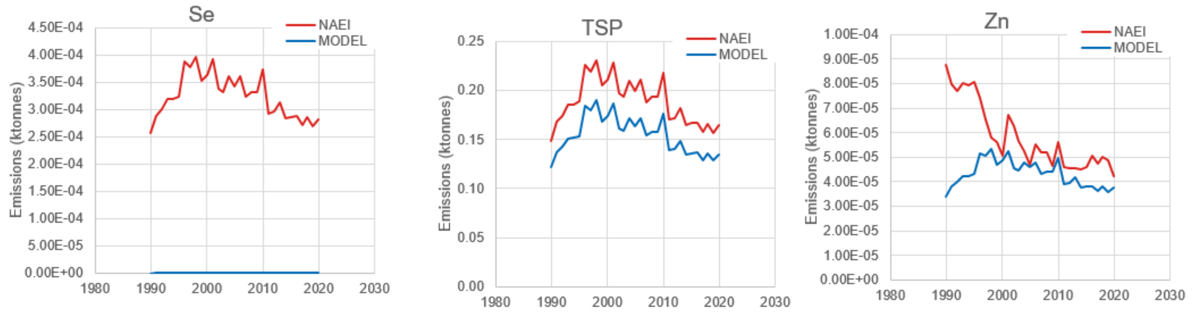


Figure 13-50 Comparison of emissions of (from left to right) selenium, total particulate matter, zinc from liquid fuel combustion in the residential sector by fuel as calculated by the domestic combustion model versus NAEI20.



APPENDIX 4 – TOTAL DOMESTIC COMBUSTION EMISSION COMPARISONS

Figure 13-51 Comparison of emissions of arsenic from all fuel combustion in the residential sector by fuel as calculated by the domestic combustion model versus NAEI20.

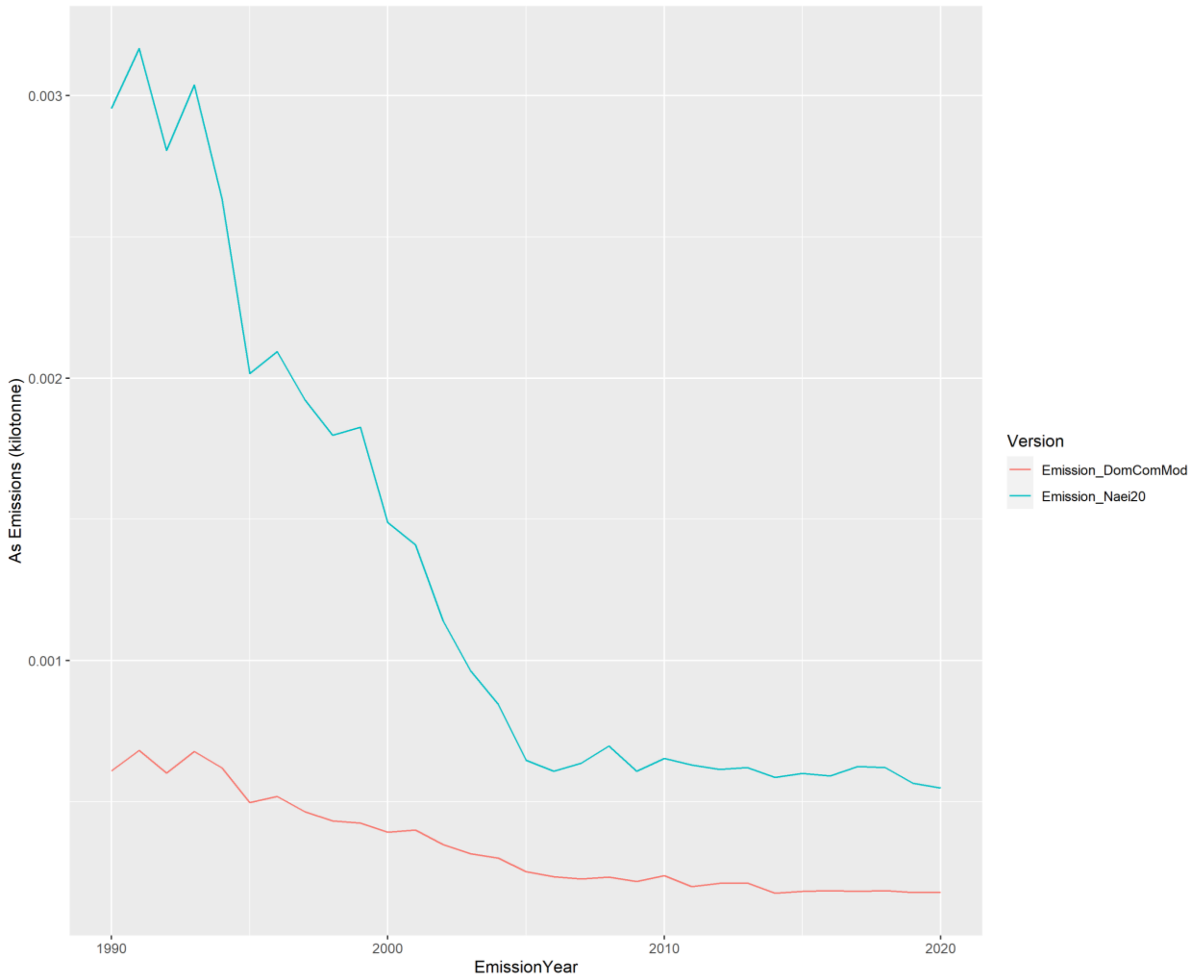


Figure 13-52 Comparison of emissions of benzo[a]pyrene from all fuel combustion in the residential sector by fuel as calculated by the domestic combustion model versus NAEI20.

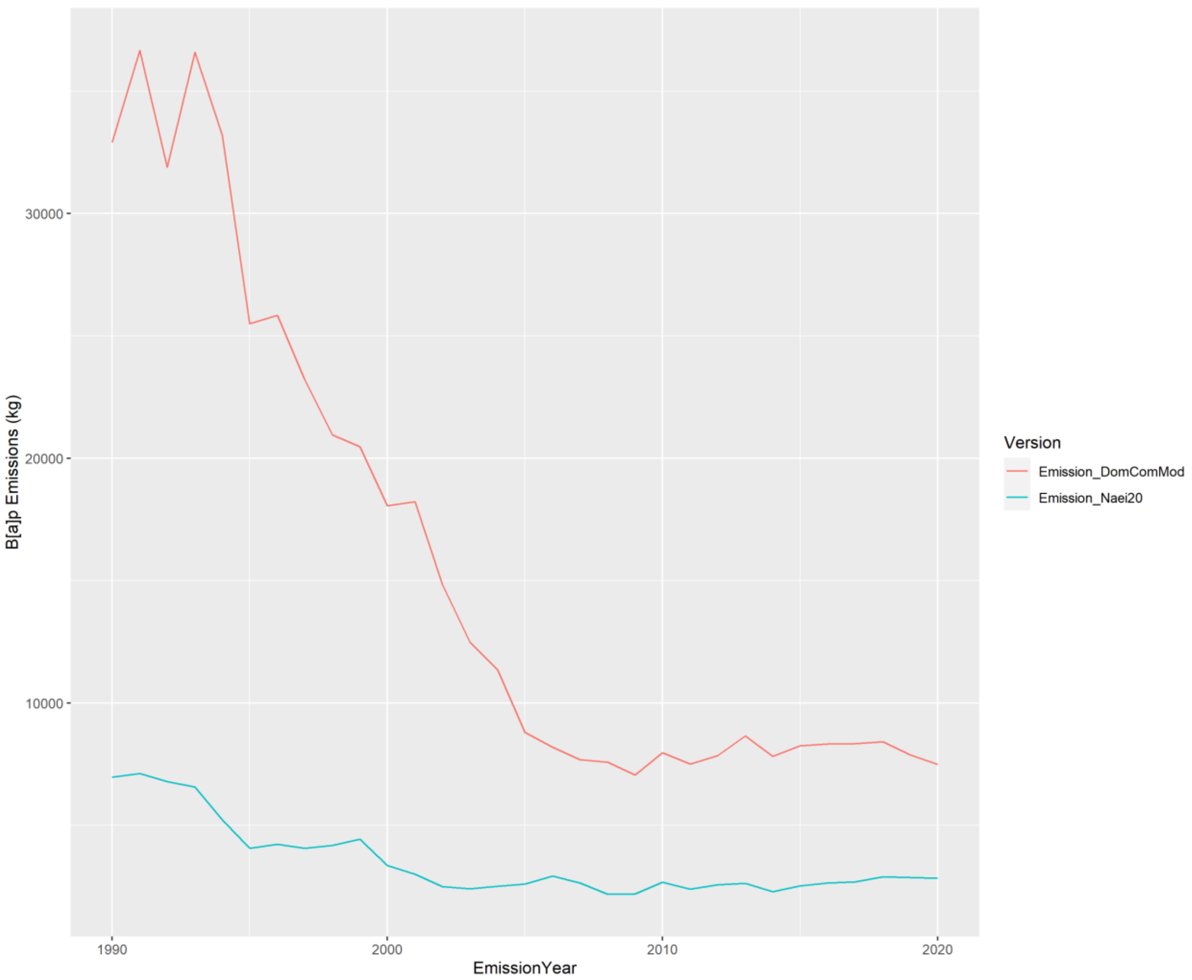


Figure 13-53 Comparison of emissions of benzo[b]fluoranthene from all fuel combustion in the residential sector by fuel as calculated by the domestic combustion model versus NAEI20.

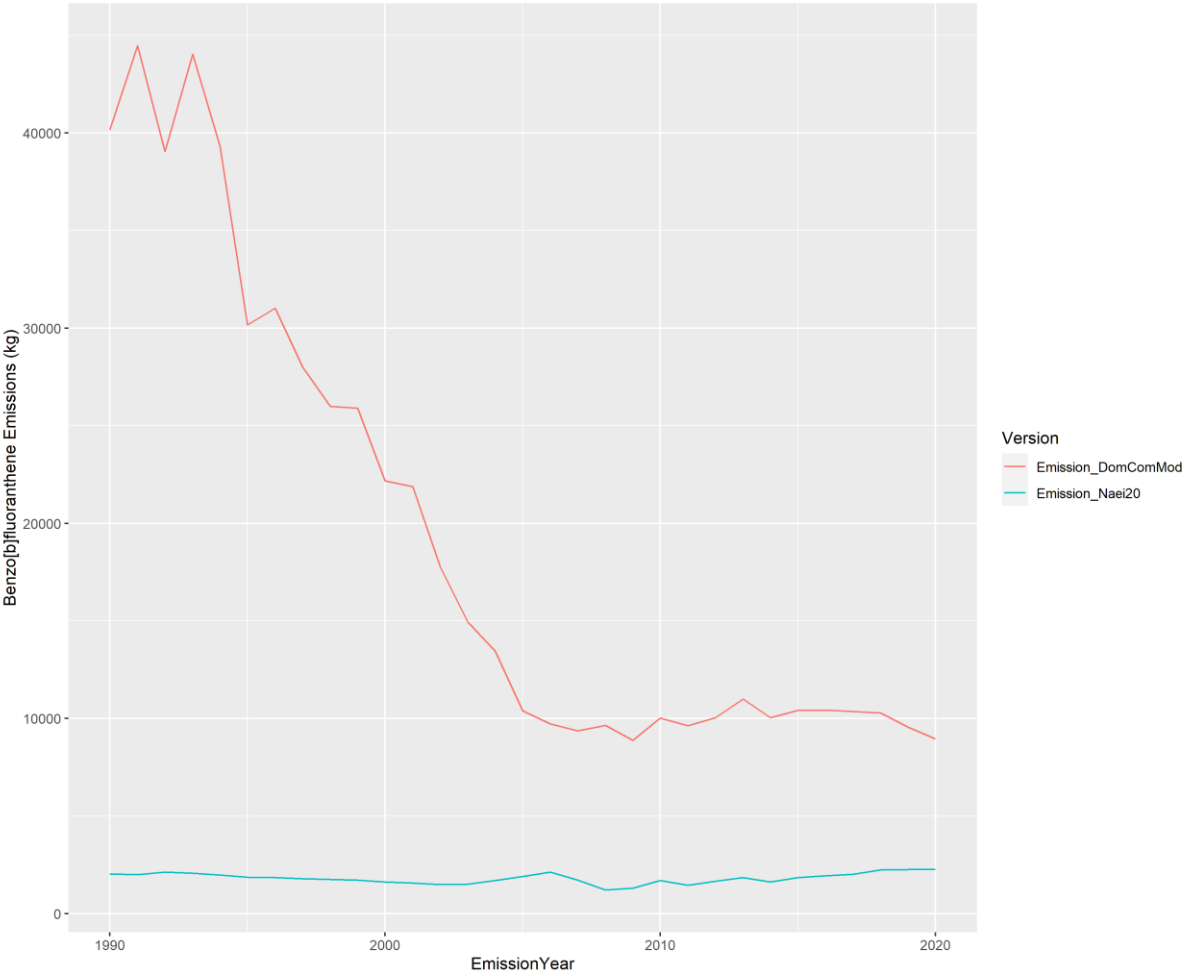


Figure 13-54 Comparison of emissions of benzo[k]fluoranthene from all fuel combustion in the residential sector by fuel as calculated by the domestic combustion model versus NAEI20.

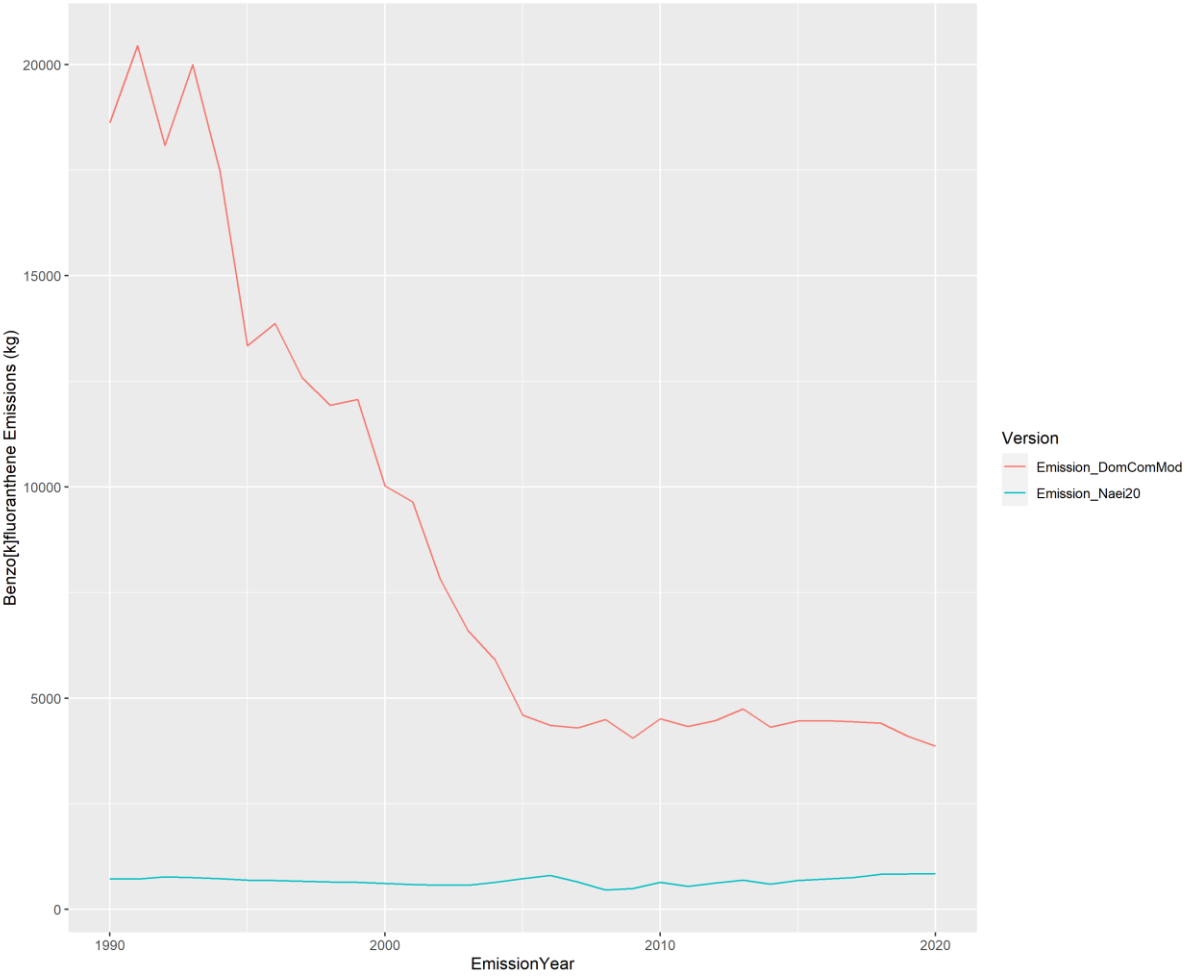


Figure 13-55 Comparison of emissions of black carbon from all fuel combustion in the residential sector by fuel as calculated by the domestic combustion model versus NAEI20.

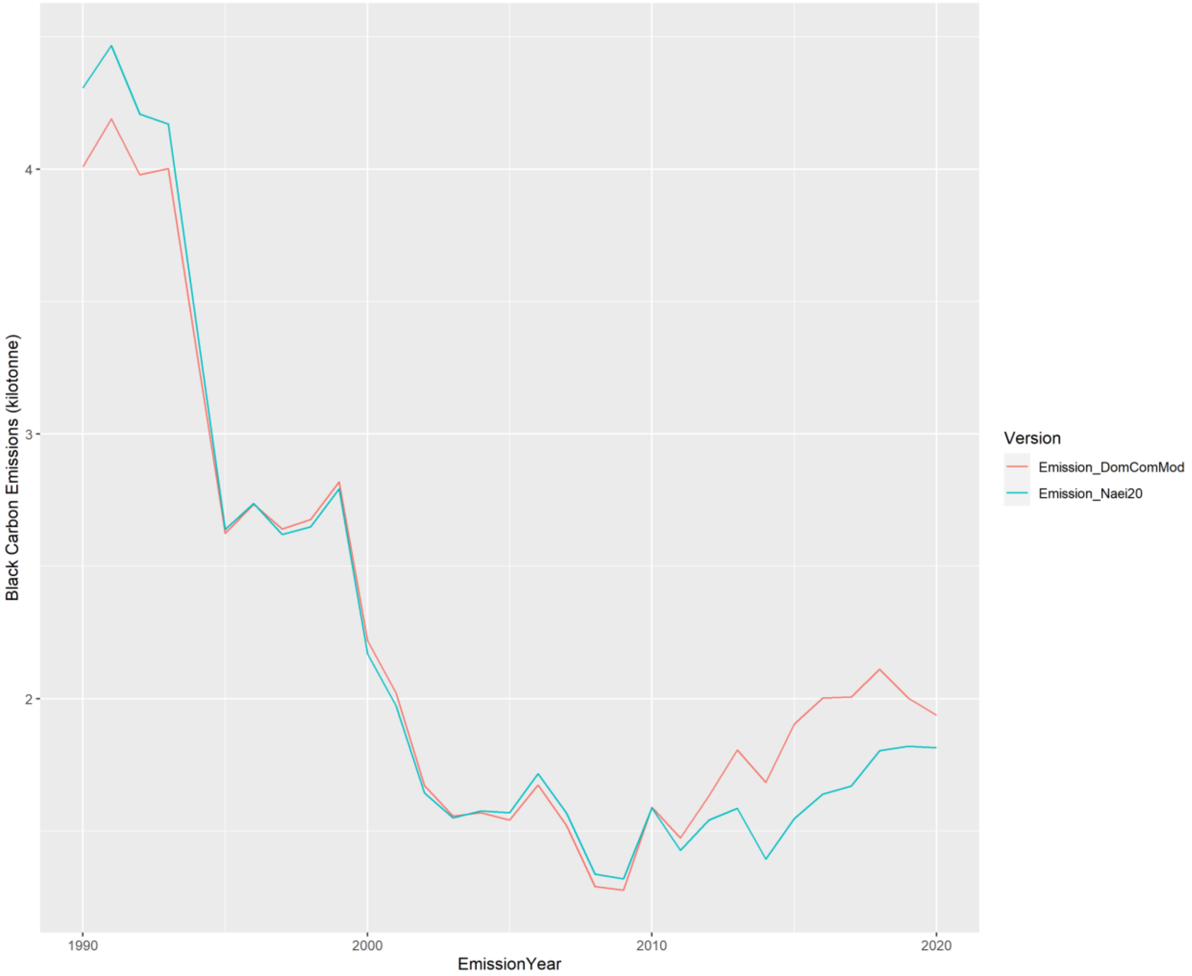


Figure 13-56 Comparison of emissions of cadmium from all fuel combustion in the residential sector by fuel as calculated by the domestic combustion model versus NAEI20.

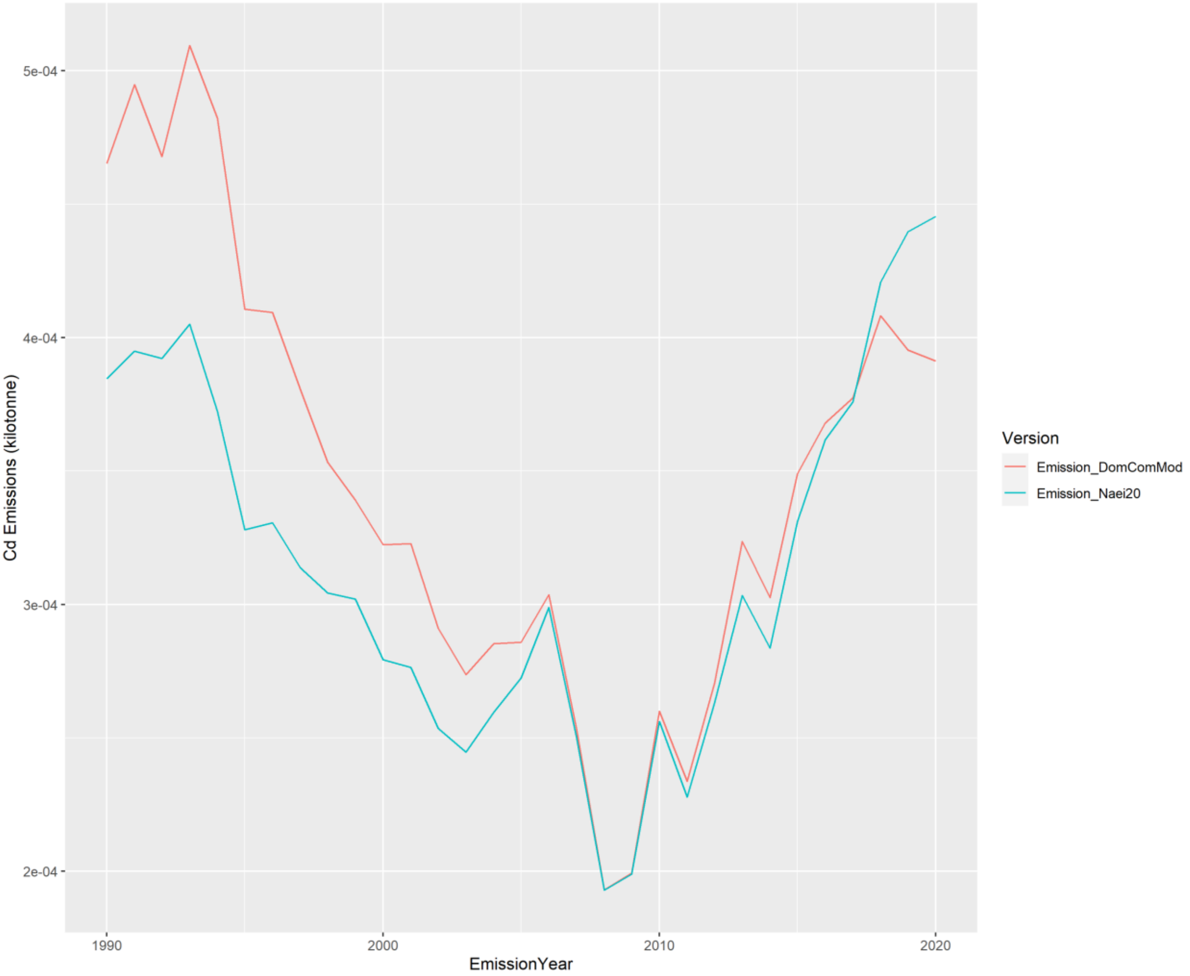


Figure 13-57 Comparison of emissions of carbon monoxide from all fuel combustion in the residential sector by fuel as calculated by the domestic combustion model versus NAEI20.

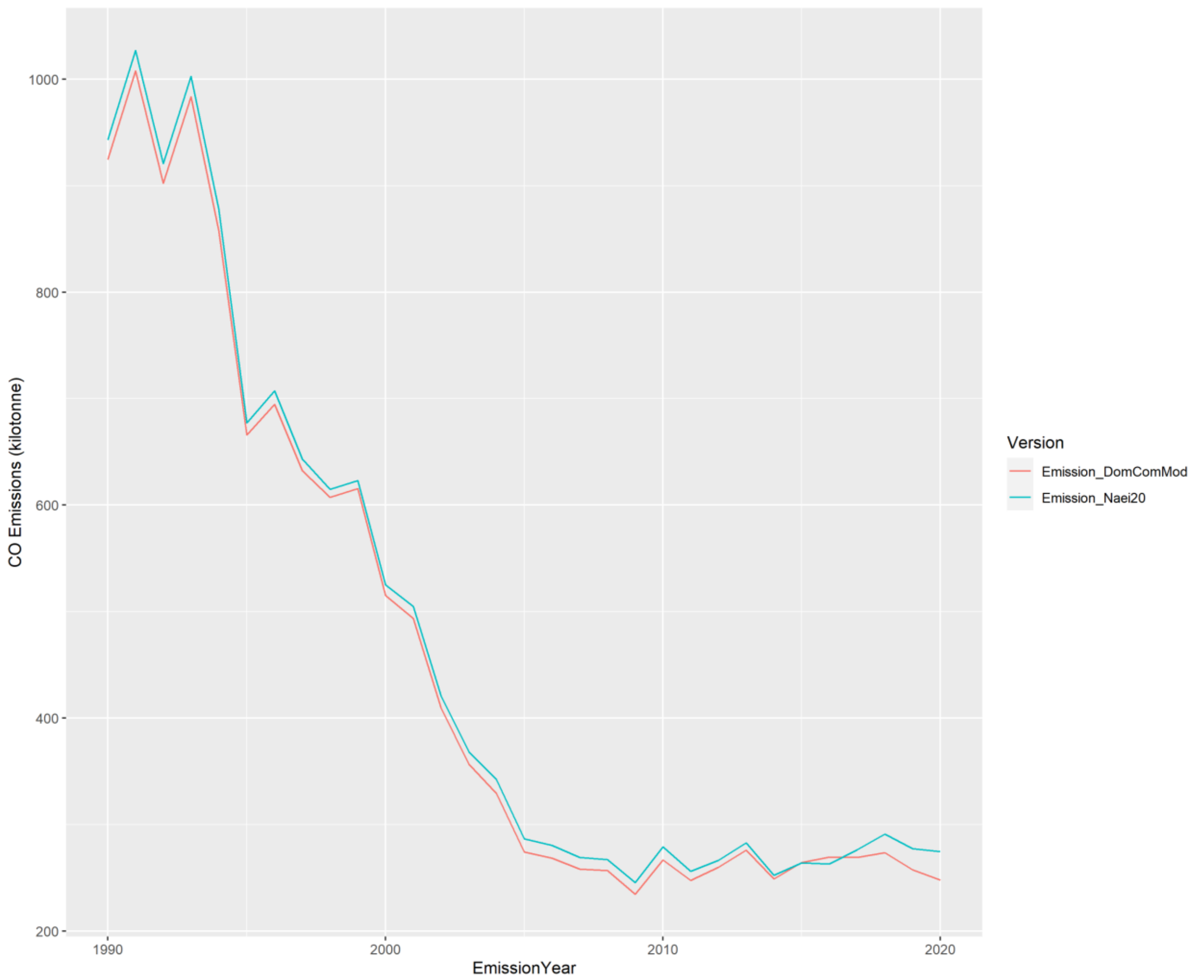


Figure 13-58 Comparison of emissions of chromium from all fuel combustion in the residential sector by fuel as calculated by the domestic combustion model versus NAEI20.

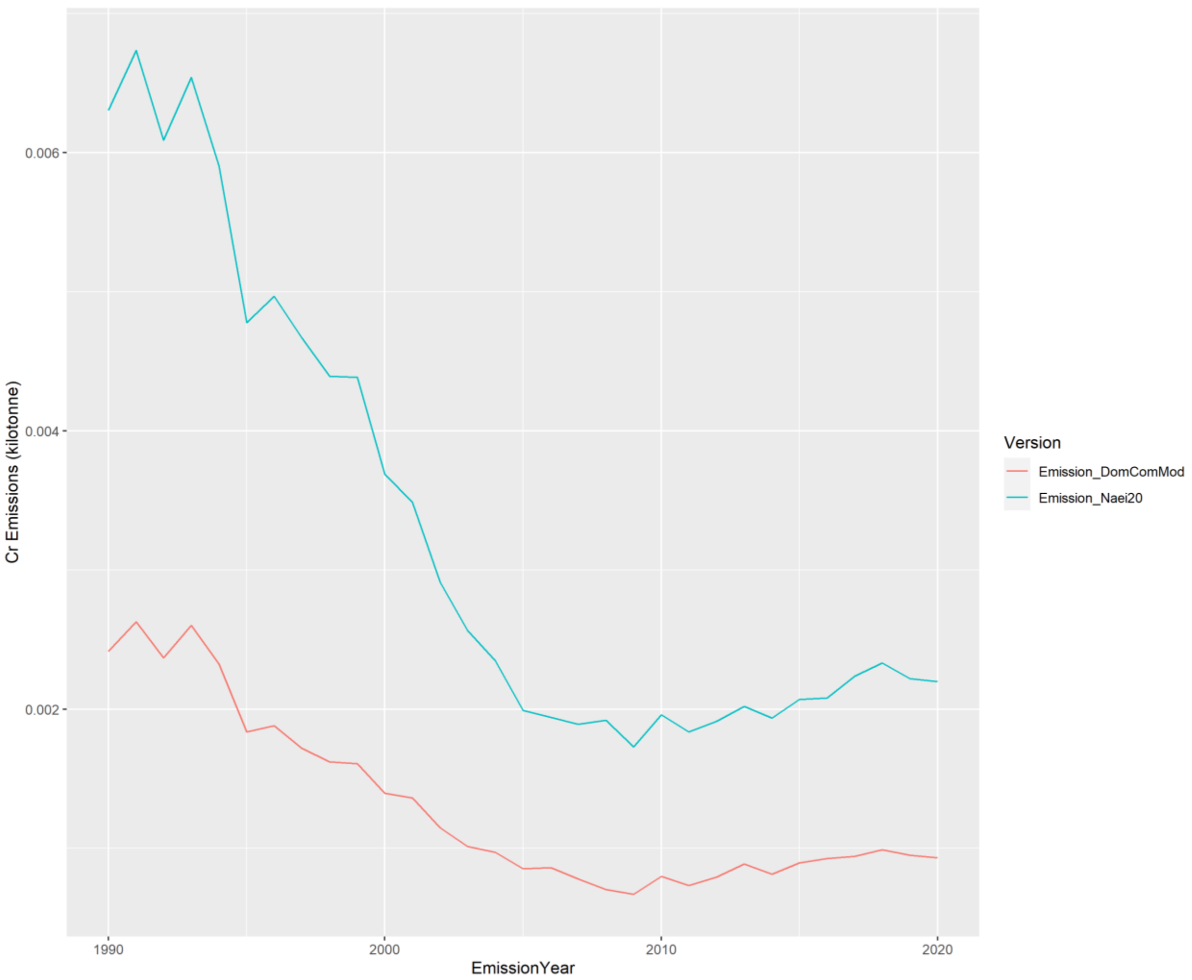


Figure 13-59 Comparison of emissions of copper from all fuel combustion in the residential sector by fuel as calculated by the domestic combustion model versus NAEI20.

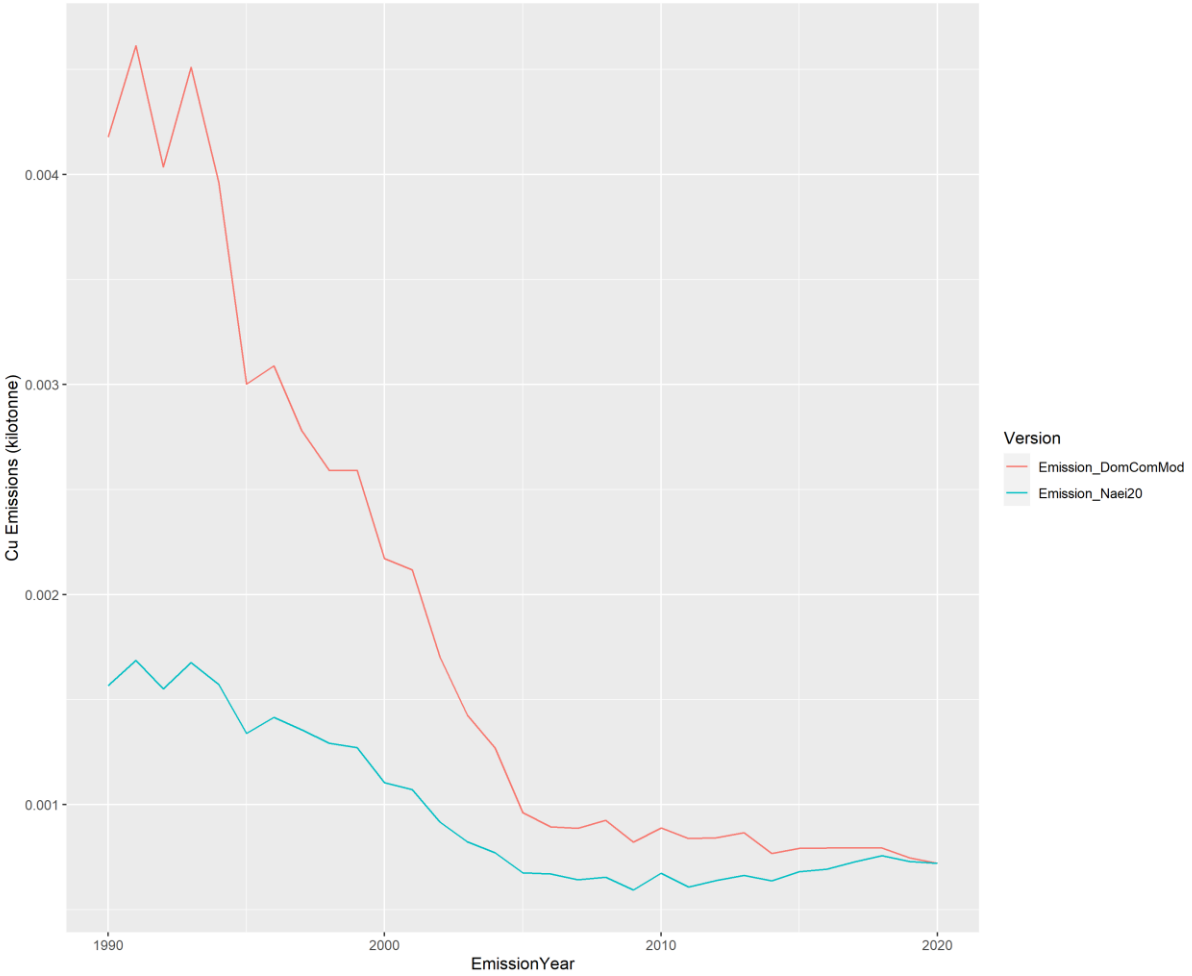


Figure 13-60 Comparison of emissions of dioxins from all fuel combustion in the residential sector by fuel as calculated by the domestic combustion model versus NAEI20.

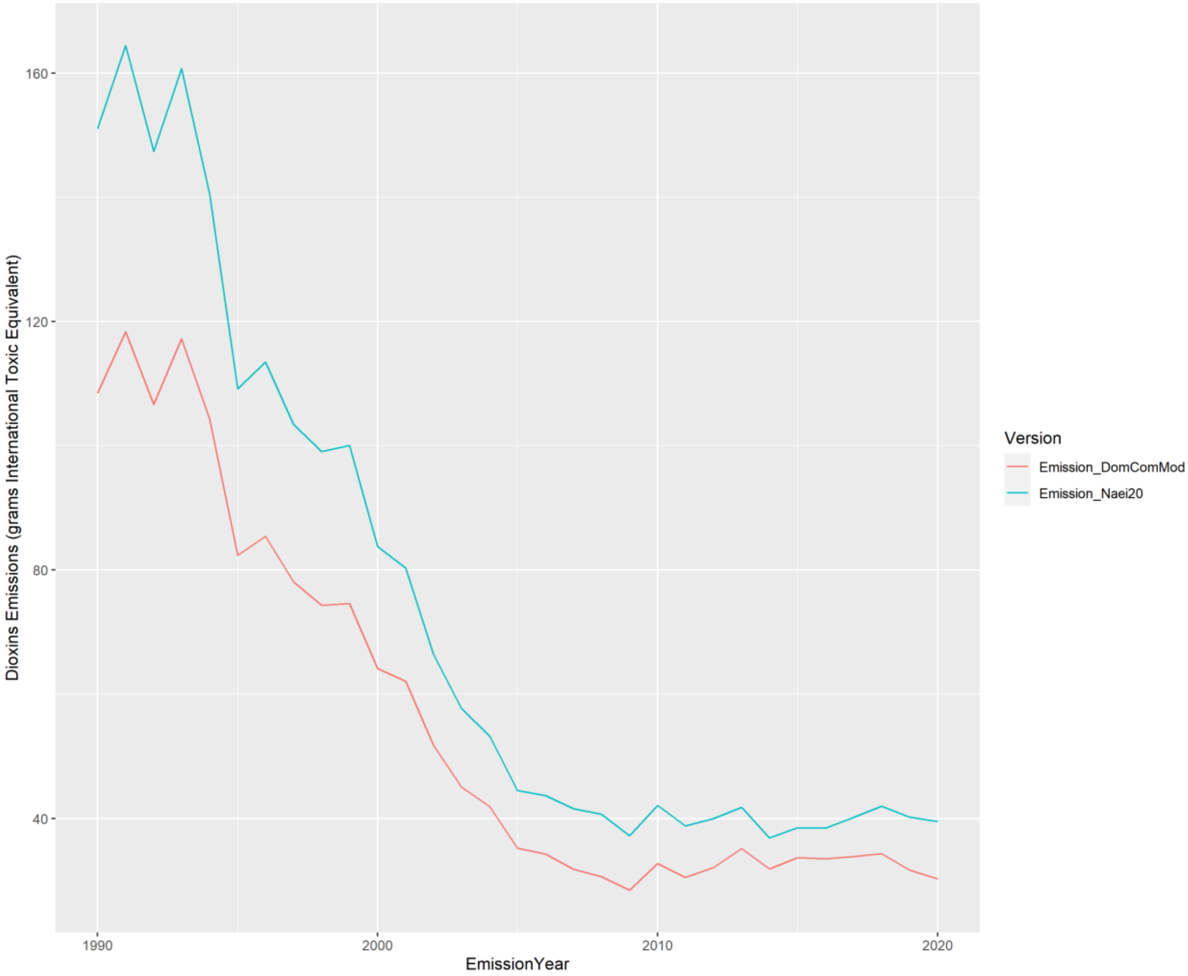


Figure 13-61 Comparison of emissions of hexachlorobenzene from all fuel combustion in the residential sector by fuel as calculated by the domestic combustion model versus NAEI20.

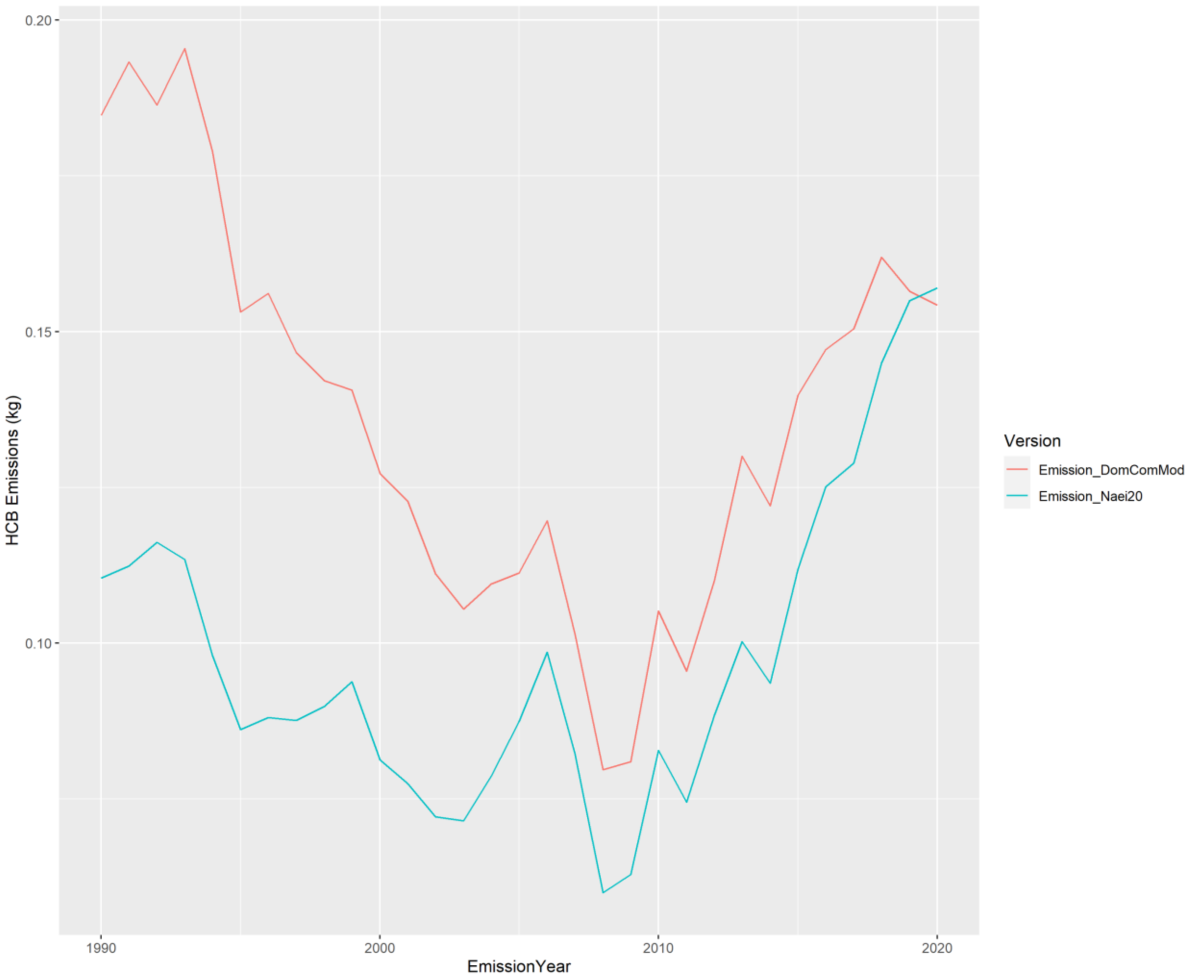


Figure 13-62 Comparison of emissions of mercury from all fuel combustion in the residential sector by fuel as calculated by the domestic combustion model versus NAEI20.

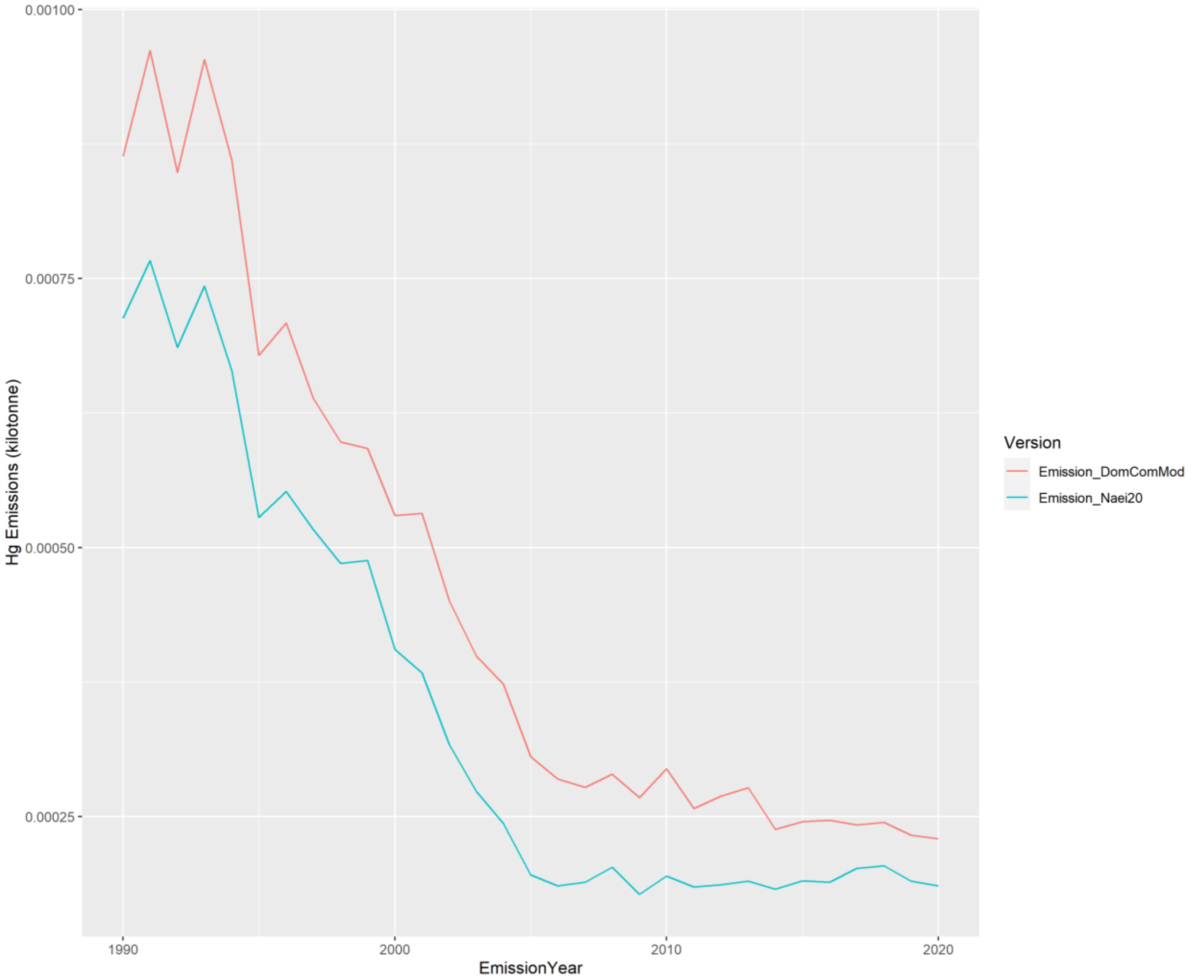


Figure 13-63 Comparison of emissions of indeno(123-cd)pyrene from all fuel combustion in the residential sector by fuel as calculated by the domestic combustion model versus NAEI20.

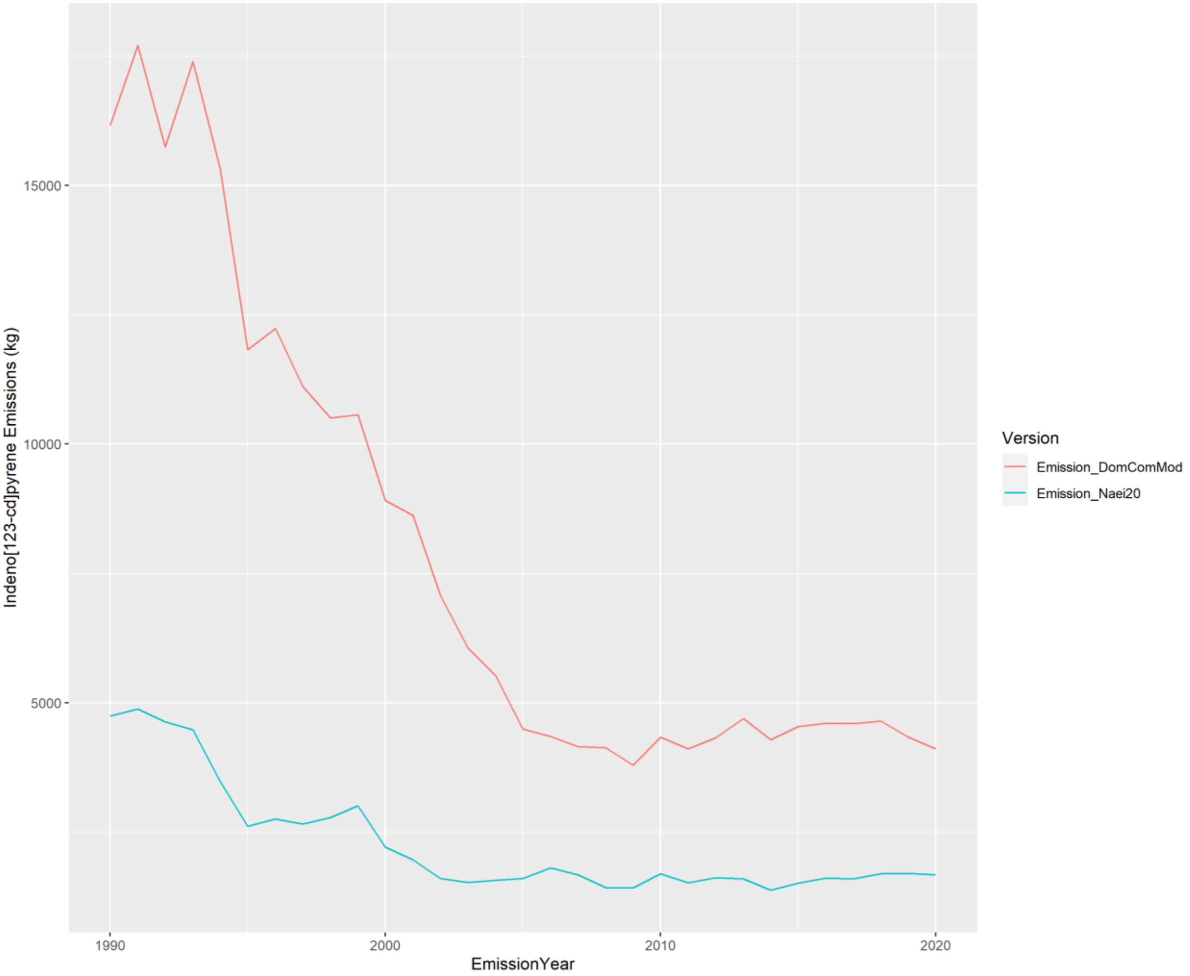


Figure 13-64 Comparison of emissions of nickel from all fuel combustion in the residential sector by fuel as calculated by the domestic combustion model versus NAEI20.

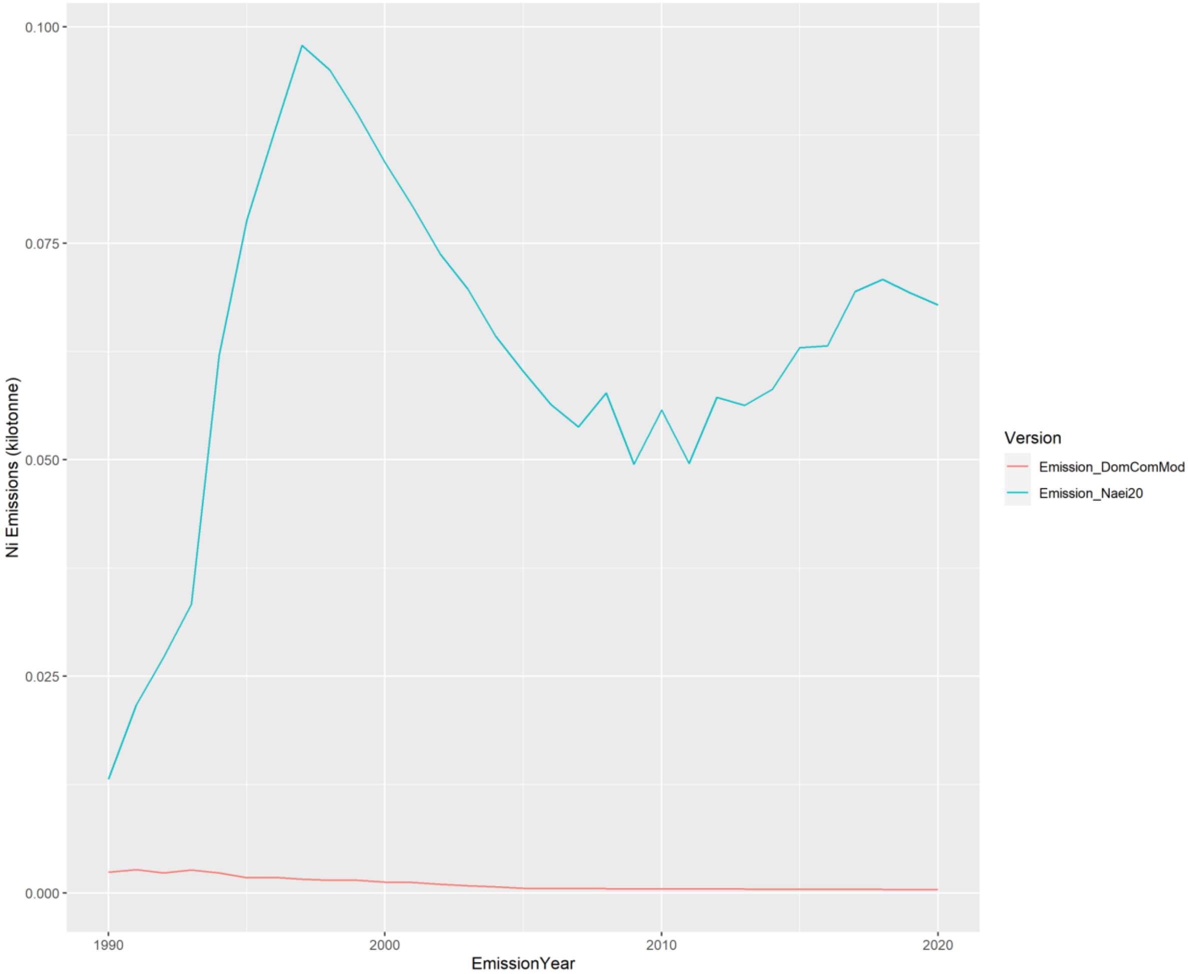


Figure 13-65 Comparison of emissions of lead from all fuel combustion in the residential sector by fuel as calculated by the domestic combustion model versus NAEI20.

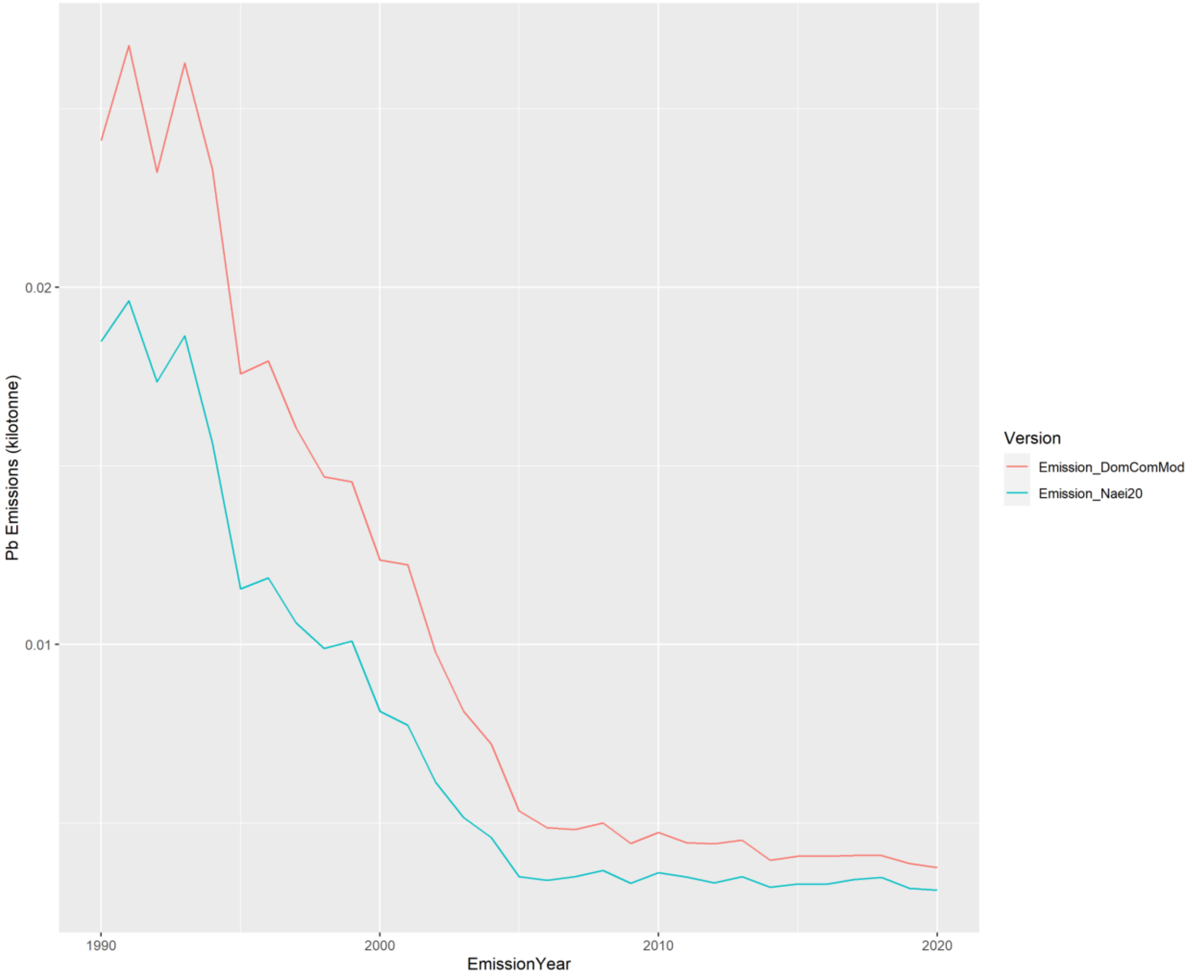


Figure 13-66 Comparison of emissions of polychlorinated biphenyls from all fuel combustion in the residential sector by fuel as calculated by the domestic combustion model versus NAEI20.

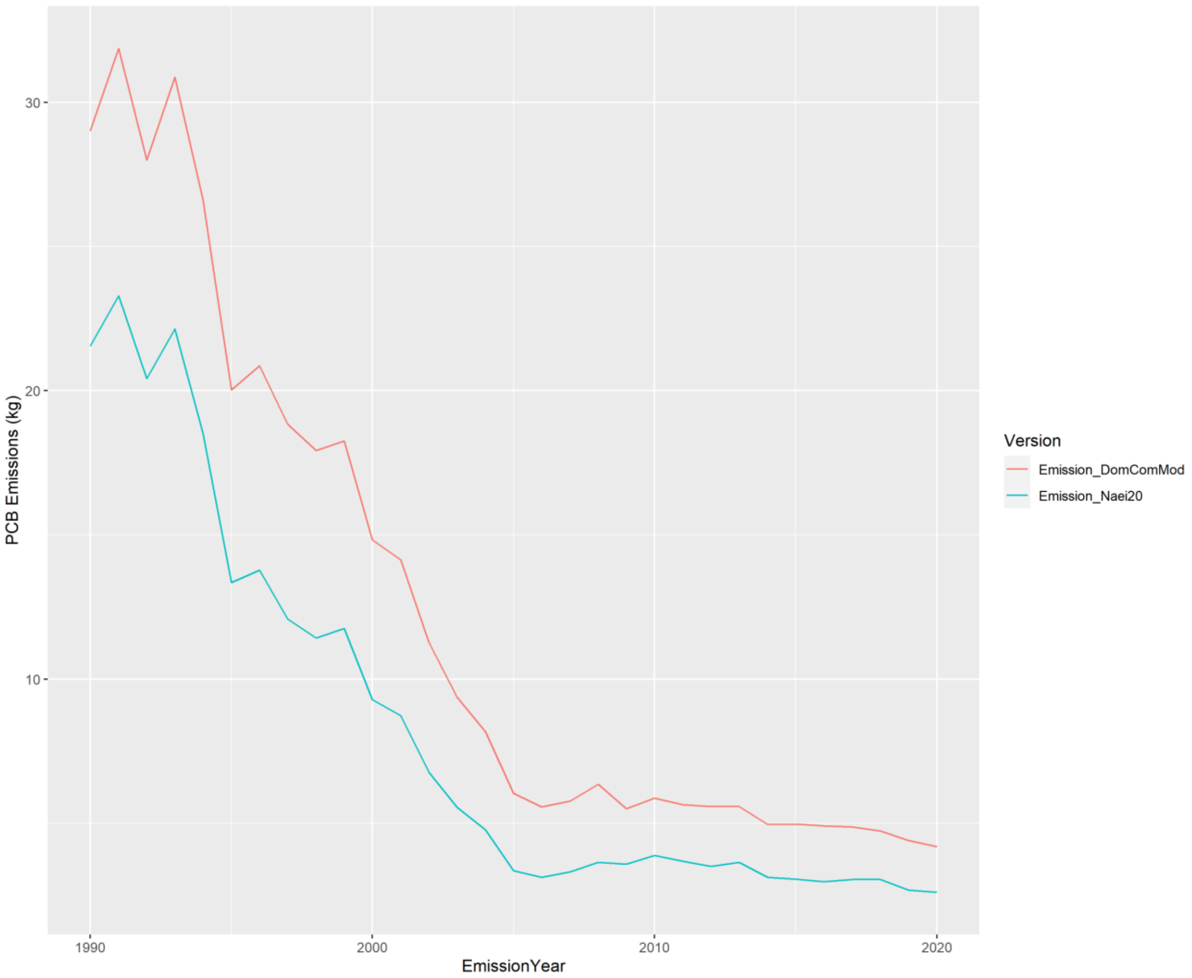


Figure 13-67 Comparison of emissions of selenium from all fuel combustion in the residential sector by fuel as calculated by the domestic combustion model versus NAEI20.

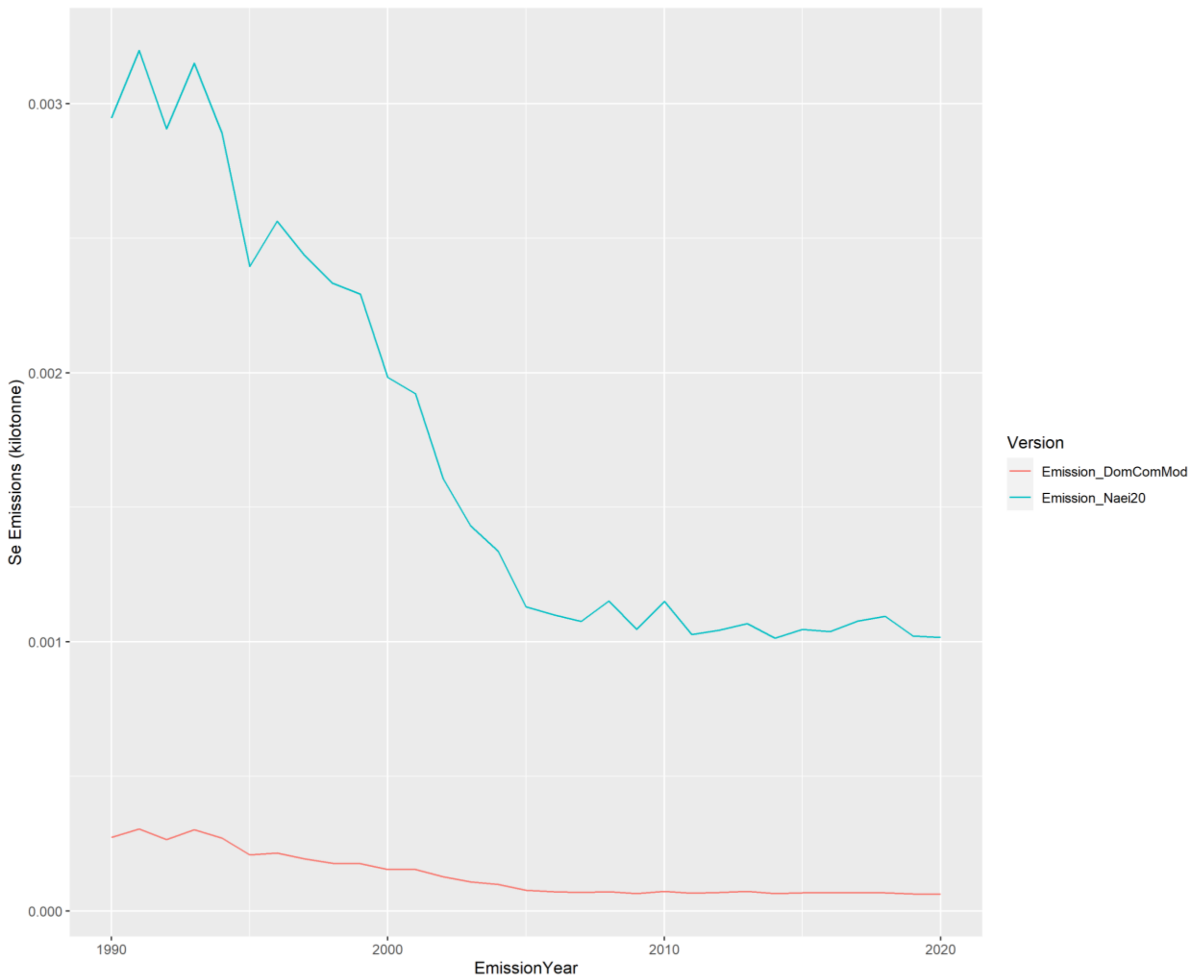


Figure 13-68 Comparison of emissions of total particulate matter from all fuel combustion in the residential sector by fuel as calculated by the domestic combustion model versus NAEI20.

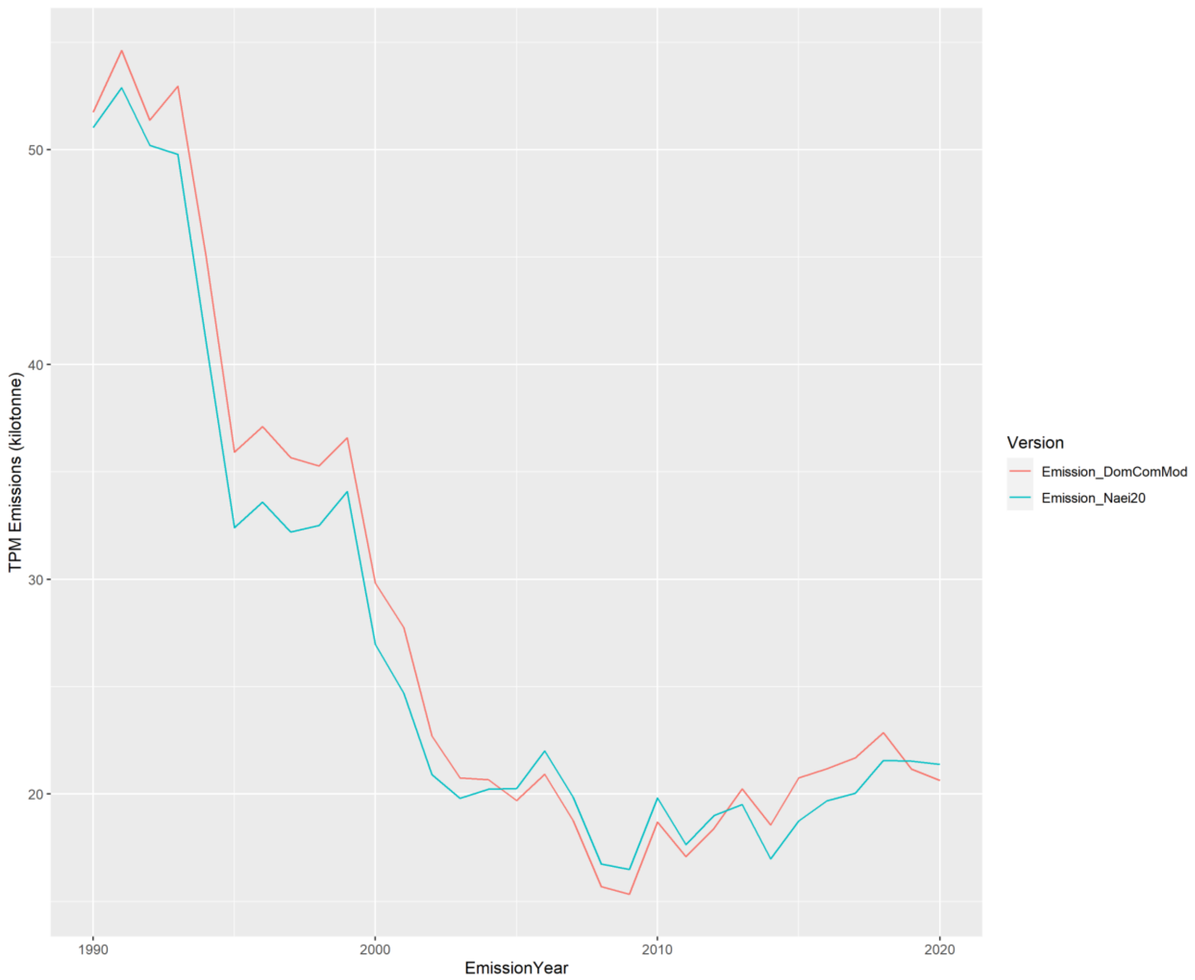
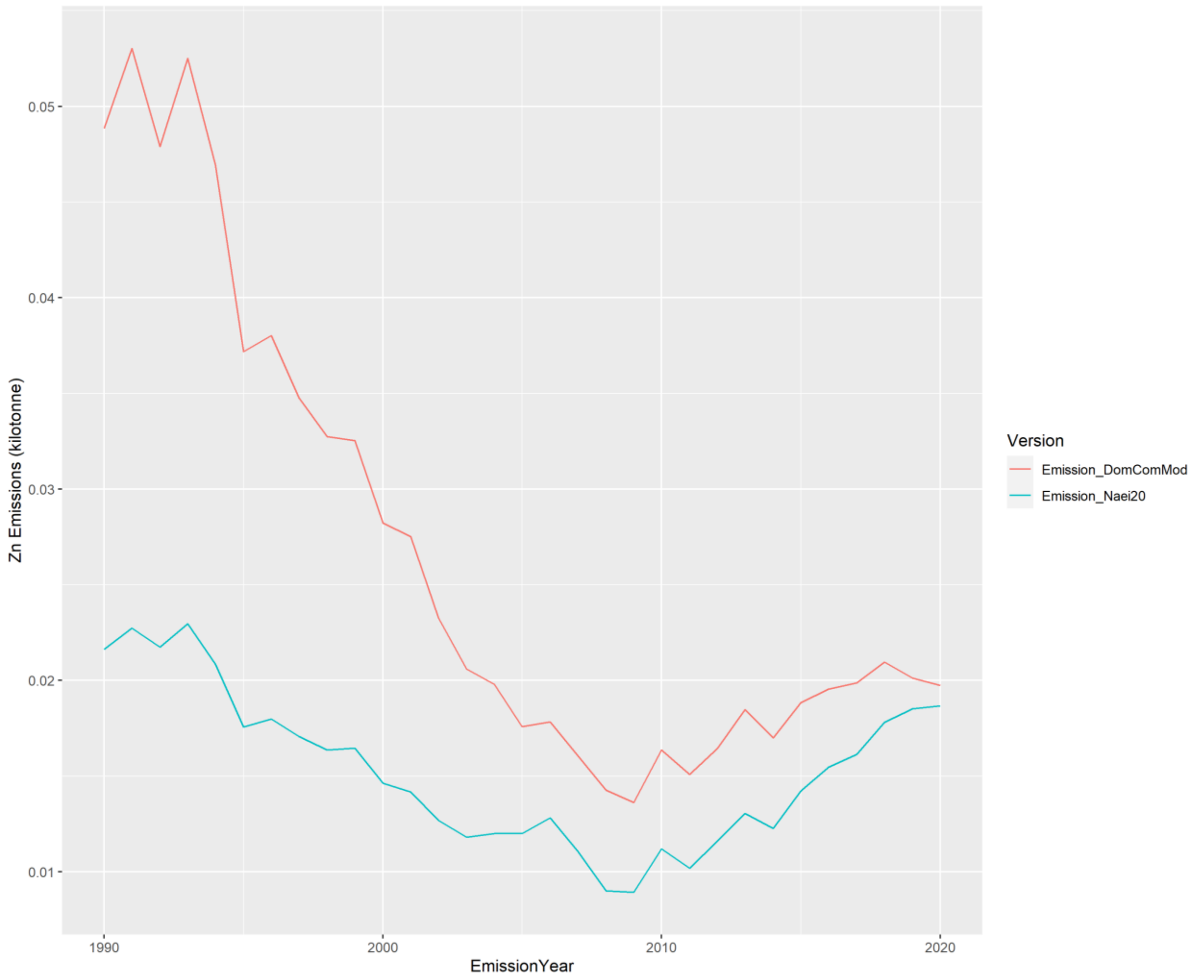


Figure 13-69 Comparison of emissions of zinc from all fuel combustion in the residential sector by fuel as calculated by the domestic combustion model versus NAEI20.



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