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Contact:
Rachel Yardley, Gemini Building, Fermi Avenue, Harwell, Didcot, OX11 0QR, UK

T: +44 (0) 1235 753630
E: rachel.yardley@ricardo.com

Author: Judith Bates, Joanna McCarthy, Yvonne Pang, Eirini Karagianni, Peter Brown

Approved by:
Rob Stewart
Signed

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This project has been led by Ricardo.

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EXECUTIVE SUMMARY

The Department for Energy Security and Net Zero (DESNZ) is undertaking a rolling programme of improvements to the UK Greenhouse Gas Inventory (GHGI), which is part of the National Atmospheric Emissions Inventory (NAEI). The GHGI provides a comprehensive estimate of national emissions of GHGs since 1990 and is used to fulfil national and international GHG reporting requirements. DESNZ have commissioned a consortium, led by Mott MacDonald, to carry out the improvement programme. This bioenergy improvement project, led by consortium member Ricardo, aimed to provide a more accurate representation of activity and emissions from bioenergy use in the GHGI. As bioenergy is also a substantial contributor to emissions of some air quality (AQ) pollutants, the project was also supported by the Department for Environment, Food & Rural Affairs (Defra), and looked at improving modelling of emissions of 13 air pollutants where the UK has international reporting requirements or pollutants where bioenergy makes a large contribution to national emissions.

The project began with a scoping and review phase. This mapped and critically reviewed the processes used within the NAEI to model bioenergy and identified where potential improvements could be made to improve data flows or ensure that the full granularity of existing data was exploited. In parallel with this, there was extensive external consultation with stakeholders through a webinar and interviews to ensure that the wider bioenergy landscape was understood, and potential new sources of data were identified. A selection of National Inventory Reports (NIRs) for GHG and Informative Inventory Reports (IIRs) for AQ pollutants for other countries were also reviewed to identify additional data sources or examples of best practice which would be appropriate for use in the UK NAEI. This phase concluded that several of the workbooks within the NAEI that dealt with bioenergy should be consolidated to create a new ‘bioenergy model’, where all relevant activity data would be processed. It also identified several new data sources which should be investigated further and several instances where current data sources could be exploited more fully.

In the main phase of the work, the new bioenergy model was developed using a process that followed DESNZ QA guidance on model development[1], including development of a scope and specification document, which in its final form also includes a user guide for the model[2]. Prior to model development commencing, the new data sources identified in the review phase were evaluated in more detail. Unfortunately, it was found that either the data could not be made available to the inventory team due to restrictions around permitted use of the data (Major Power Producers Survey, Combined Heat and Power QA scheme data), or were not fully suitable for inclusion (Renewable Heat Incentive data and Ofgem biomass sustainability data). Nevertheless, through an improved understanding of existing data sources, enabled through detailed discussions with data providers, improvements were possible in the treatment of waste fuels, wood, liquid biofuels, plant and animal biomass, with minor improvements for landfill gas, sewage gas and biogas.

Overall, the project has resulted in an improvement of the granularity of the NAEI where the data supports it, and removal of some minor double counts. The set up of the model is now more transparent, allowing for future changes to data availability to be more easily incorporated. As a result of user feedback, the way that biomass fuels are identified in the inventory has been changed so that users interrogating the NAEI database will in future be able to extract emissions data related to all biomass fuels with a single query rather than needing to select each biomass fuel separately.

A trial integration of the improved bioenergy model into the inventory suggests that the overall impact of the improvements on the national estimate of biogenic CO_2 is likely to be modest. The impact varies over the time series but is in the range of -1.2 to +1.4 Mt CO_2. The revision has a higher relative impact in earlier years as biogenic CO_2 emissions are substantially lower then, resulting in a reduction in 1990 emissions of 24%, compared to an increase in 2022 emissions of only 3%. For AQ emissions, there are some small changes brought about by improvements in activity data. This is particularly so in early years of the time series where the reallocation of biomass between end use sectors, or from a general biomass category to specific biomass types has meant that the emission factor associated with that biomass use has changed. This is particularly the case for NO_X emissions as a result of updated activity data for wood. VOC emissions have changed due to the identification of a more appropriate emission factor.

[1] https://www.gov.uk/government/publications/energy-security-and-net-zero-modelling-quality-assurance-qa-tools-and-guidance

[2] GHGIIP: Bioenergy Model – Scope, Specification and User Guide. Report by Ricardo for DESNZ, 2024.

The project also led to improvements in other areas of the areas of the inventory. The discussions on biofuels held with the Renewable Transport Fuel Obligation (RTFO) unit in the Department for Transport, and the DUKES led to the full range of biofuels used in road transport now being included in the NAEI's road transport model, giving better representation of biofuel use. The aviation model was also adapted to allow the inclusion of biofuels in aviation. The work carried out in this project which led to a greater understanding of biomass use and the use of more granular data on industrial use of biomass led to a separate improvement task being taken on the air quality side to improve the $PM_{2.5}$ emissions factors used for biomass combusted in industry.

There are a number of areas where the study has identified further work would be useful to ensure that there is continuous improvement of the new bioenergy model. For activity data these include:

- Maintaining close liaison with the energy statistics team at DESNZ, the Renewable Energy Statistics Team and the Renewable Transport Fuels Obligation team at the Department or Transport to ensure that changes in methodologies are communicated so that any necessary adjustments to the bioenergy model and associated parts of the inventory can be made.
- Continuing discussions with the DESNZ energy statistics team to see if some of the primary data sets used in DUKES compilation – the Major Power Producers (MPP) Survey and CHPQA data can be made available to the NAEI in the longer term.

For emissions factors these include:

- Continuing to develop a clearer understanding of the types of solid biomass used in the UK, areas of application and technology as this could allow adoption of literature emission factors or inform a focussed measurement programme for key sources and pollutants.
- Developing a clearer understanding of the types of liquid biofuels used in stationary sources and areas of application to allow adoption of literature emission factors or development of a focussed measurement programme for key pollutants (NO_x and PM species).
- A measurement programme for metals for biogenic energy sources to help develop representative emission factors for the UK.
- For biogas, assessing whether emission monitoring associated with regulation may provide a means to develop more appropriate NO_x emission factors. A measurement programme may need to be developed to obtain more representative emission factors for other pollutants.
- A clearer understanding of the use of charcoal between domestic and commercial uses could allow a focussed measurement programme for key pollutants (PM species but also PAH, PCDD/F and metals).
- Developing size differentiated emissions factors for biomass boilers, based on type approval data for PM and potentially NO_x emission limit values derived from Ecodesign type approval controls, and review of medium combustion plant (MCP) emission monitoring data could allow development of emission factors for regulated pollutants (NO_x, PM and SO_2). Implementation of size-differentiated emission factors for a wider range of pollutants would require development of a measurement programme.

1. INTRODUCTION

1.1 BACKGROUND

The Department for Energy Security and Net Zero (DESNZ) is undertaking a rolling programme of improvements to the UK Greenhouse Gas Inventory (GHGI), which is part of the National Atmospheric Emissions Inventory (NAEI). The GHGI provides a comprehensive estimate of national emissions of GHGs since 1990 and is used to fulfil national and international GHG reporting requirements. The aim of the improvement programme is to maintain an inventory that is scientifically robust, and that is transparent, complete, and accurate, and fit to track progress towards net zero emissions. This is to be done through the identification and development of methodological and data improvements to the quantification of GHG emissions.

DESNZ have commissioned a consortium, led by Mott MacDonald, to carry out the improvement programme. One of the first projects in the improvement programme, which is also supported by the Department for Environment, Food & Rural Affairs (Defra), was to improve the representation of bioenergy within the GHGI and NAEI. This bioenergy project was led by consortium member Ricardo. This report summarises the work undertaken in that project.

1.2 SCOPE AND AIMS OF BIOENERGY GHGI IMPROVEMENT PROJECT

The aim of the bioenergy improvement project was to provide a more accurate representation of activity and emissions from bioenergy use in the GHGI. As bioenergy is also a substantial contributor to emissions of some air quality (AQ) pollutants, the project also looked at improving modelling of emissions of the following air pollutants:

- Nitrogen oxides (NO_x)
- Sulphur dioxide (SO_2)
- Volatile organic compounds (VOC)
- Ammonia (NH_3)
- Particulate matter <2.5µm ($PM_{2.5}$)
- Particulate matter <10µm (PM_{10})
- Black Carbon
- Benzo[a]pyrene (B[a]P)
- Hexachlorobenzene (HCB)
- Arsenic (As)
- Cadmium (Cd)
- Mercury (Hg)
- Dioxins

These pollutants were selected by the bioenergy project team in conjunction with the steering group of the project as pollutants where the UK has international reporting requirements, or pollutants where bioenergy makes a large contribution to national emissions, see Table 1-1 for rationale.

Table 1-1 Rationale for inclusion of pollutants

Pollutant	Contribution to national total from bioenergy		Reason for inclusion
	2005	2021	
Nitrogen oxides (NO_x)	2%	9%	NECR pollutant
Sulphur dioxide (SO_2)	0%	5%	NECR pollutant
Volatile organic compounds (VOC)	1%	3%	NECR pollutant
Ammonia (NH_3)	0%	0%	NECR pollutant
Particulate matter <2.5µm ($PM_{2.5}$)	15%	41%	NECR pollutant
Particulate matter <10µm (PM_{10})	9%	24%	Yes (as is underlying data for PM2.5)
Black Carbon	6%	38%	Increasing attention to this in NECR
Benzo[a]pyrene (B[a]P)	6%	26%	Named in air quality standard.
Hexachlorobenzene (HCB)	14%	78%	Highly uncertain but may be limited other data
Arsenic (As)	48%	65%	Activity data used as basis for estimate becoming more uncertain over time
Cadmium (Cd)	11%	42%	Highly uncertain but may be limited other data
Mercury (Hg)	4%	22%	Covered under international legislation (e.g. Minamata convention)
Dioxins	7%	21%	Key POP

The project had two main phases, a scoping and review phase, and a model development phase. The scoping and review phase is described in Section 2. Section 3 gives an overview of the approach to developing a new model, and improvements to the treatment of activity data in the model and in emissions factors are given in sections 4 and 5 respectively. Section 7 summarises improvements made in the treatment of bioenergy flows outside of the main bioenergy model.

The overall impact of the improvements on emission estimates as discussed in Section 6 and Section 7 gives recommendations for future work to ensure continuous improvement of the representation of bioenergy in the future.

2. PHASE 1: PROJECT SCOPING

The aims of the first scoping phase were:

- to establish the range of current bioenergy activities in the UK energy system and identify those that are likely to enter it in the next 5 to 10 years.
- to review sources currently used to supply activity data and emissions factors for these activities, to the NAEI, to ensure these are being used appropriately (e.g. is the granularity of sectoral or fuel type classification used, are there any gaps or limitations to the data that are not fully understood) and identify additional data sources which may provide greater resolution or accuracy.
- to consider if the methodology used to estimate emissions from activity data can be improved.
- to produce a scope and specification document for any new bioenergy models which are deemed necessary.

These aims were achieved through:

- a mapping of the current process used to represent bioenergy in the NAEI, including examination of data sources used by the NAEI for bioenergy activity data. This mapping was extended to also examine the data sources used to produce one of the key data inputs to the NAEI - the Renewable Energy Statistics (RESTATS) part of the Digest of UK Energy Statistics.
- reviewing the wider bioenergy landscape.
- consulting with stakeholders through a webinar and interviews.
- reviewing how bioenergy is dealt with in other countries by assessing a selection of National Inventory Reports (NIRs) for GHG and Informative Inventory Reports (IIRs) for AQ pollutants.

The review identified that many different fuels fall under the heading of bioenergy, and they are used across a number of sectors: for power generation, within industry for heat and power generation, for heat production in the commercial, public and domestic sectors, as part of the natural gas system, and in transport. The mapping of the current NAEI process identified that due to the multi-fuel, cross-cutting use of bioenergy it was modelled across a large number (15) of master workbooks or model streams[3]. The review therefore proposed that:

- Several of the workbooks that dealt with bioenergy should be consolidated to create a new 'bioenergy model', where all relevant activity data would be processed.
- Where bioenergy is used in a 'blended' way with fossil fuels e.g. liquid biofuels added into road transport fuel supply and biomethane injected in the natural gas grid, then bioenergy use would continue to be treated within those existing models.
- Some emissions factors data for bioenergy would be retained within other associated systems within the NAEI e.g. the database used to hold data on pollutant emissions received from the regulators.
- To facilitate easier interrogation and interpretation of the NAEI around bioenergy we propose to rename biogenic fuels more clearly and also to 'tag' biogenic and partially biogenic fuels within the NAEI system, so that data can be made more accessible for users wishing to obtain an overview of emissions associated with bioenergy.

The review also suggested that better resolution around emissions associated with bioenergy could potentially be achieved by maintaining some of the disaggregation available in the original data sources. For example, DUKES contains a breakdown of renewable and non-renewable waste, which has been grouped in the NAEI to a single "MSW" category. This could lead to more specific fuel types, and to better sectoral resolution. It was identified that in some cases this might require either full access to the original data source, or for greater resolution to be passed on to the NAEI by the Renewable Energy Statistics (RESTATS) team or the Digest of UK Energy Statistics (DUKES) team. In other cases, the aggregation is made within the inventory compilation process so that changing the way the data is processed could lead to improved resolution.

[3] The compilation of the NAEI is built around a series of excel based models known as Mastersheets, or master workbooks, and coded or database model streams for more involved calculations. Bioenergy us currently handled in 15 of these model streams.

A report was prepared on the findings of Phase 1 and was peer reviewed, before finalisation and submissions to DESNZ[4]. The report formed the basis for the development of the new bioenergy model.

[4] Bioenergy GHGIIP. Task 1: Scoping Report. Report for DESNZ by Ricardo, July 2023.

3. PHASE 2: DEVELOPMENT OF NEW BIOENERGY MODEL

3.1 OVERVIEW OF DEVELOPMENT PROCESS

As indicated in Section 2, the main improvement identified in Phase 1 of the work was to consolidate existing models, where this made practical sense, with an expansion of the output dataset to retain more granular detail that already exists, or with a view to populating in future as new processes/emission sources become relevant. Processing of data in other already existing models would be retained in cases where this preserves a detailed approach and ensures consistency with other areas of the inventory. This approach (as opposed to a new model which incorporated all bioenergy sources, or adding in additional detail for outputs to the existing 15 models that deal with bioenergy) was considered a best fit, as it balanced the amount of time needed to improve the outputs and incorporate new data, with the level of effort needed to re-do modelling that already exists (e.g. processing of Regulators' inventory data, and road transport modelling). It also enables a significant proportion of the bioenergy data handling and processing to be conducted in a consistent way within the one model.

The Phase 1 report identified that there were two main options for the development of the new bioenergy model, using MS Excel or building a coded model[5], and evaluated the benefits and drawbacks of each, also taking into account the proposed (now ongoing) digital transformation of the NAEI. At the start of Phase 2, after discussion, it was agreed with DESNZ, that on balance it would be better to develop the model in MS Excel, but to take particular care to structure it in a way which would facilitate its translation to a coded solution in the future. The key factors which influenced the decision were:

1. The data series used for bioenergy are diverse and in some cases immature. Levels of granularity in the data series vary across time, and there are inconsistencies between overlapping datasets. This meant that the initial design and development of data flows and solutions to overcome these imperfections in the data were likely to be implemented and tested in MS Excel, before a coded version of the model was developed. Building the model in MS Excel allowed full use to be made of this Excel based development process and therefore allowed the proportion of the budget to be spent improving the underlying data and the science of the inventory method versus building a model to be maximised.
2. At the time the decision was made, the new digital framework for the NAEI was not yet fully defined, and as such any new model might have required re-working as part of the digital transformation. Guidance on coded model development and on QA of coded models was also relatively undeveloped, compared to a well-established and proven system for Excel models within the NAEI.
3. Consideration of the end-to-end data flow for a coded model would be best achieved through incorporation of the processing of upstream data into the model system. However, many of the bioenergy data sets are a subset of larger data sets, so there is a question around either fully handling (e.g. the ETS dataset, which would include out of scope fossil data) or partially dealing with these data, which would be inefficient in the context of the imminent digital transformation of the NAEI system.

Once this decision had been reached, a scope and specification document was started for the model based on the initial considerations set out in the Phase 2 report. This was based on a format for a scope and specification report developed by Ricardo, and is designed to include all of the aspects recommended by DESNZ QA guidance on model development[6]. The scope and specification model was a 'living document' which was added to as model development progressed and in its final form as well as defining a scope and specification of the model, includes a user guide for the model[7]. It is available separately to this report but key elements of the scope and specification are summarised below in Section 3.3.

The next step in model development was to investigate further data sources identified in the Scoping Report as potentially offering more granular or more accurate data on bioenergy usage. The evaluation of each new data source is detailed in Section 3.2, below, but it became apparent that elements of the data could not be available to the inventory team or were not fully suitable for inclusion.

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[5] The current suite of NAEI models includes Excel based models, databases, or models coded in R. An R based model was considered for the bioenergy project.

[6] https://www.gov.uk/government/publications/energy-security-and-net-zero-modelling-quality-assurance-qa-tools-and-guidance

[7] GHGIIP: Bioenergy Model – Scope, Specification and User Guide. Report by Ricardo for DESNZ, May 2024.

Once this had been established, attention was focussed on ensuring that current data sources were being utilised to their full extent (e.g. the sectoral breakdown available is not maintained – in part due to changes in the granularity available across the time series in DUKES) and, in particular, that any granularity in the original data set was not lost in processing. This involved a detailed examination of both DUKES and RESTATs data and extensive discussions with both the energy statistics team that produce DUKES and the RESTATs compilation team to understand the basis of the data sets that are produced, and any preprocessing or assumptions that go into compiling the data sets. In particular it was important to identify where assumptions changed over the time series, as only a few years (typically 3-5) of the historic time series are revised in the annual DUKES publication (whereas the NAEI is required to maintain a consistent time series going back to 1990 for most pollutants). As a result of these discussions, improvements were made in the treatment of activity data for a number of bioenergy fuels. These are detailed in Section 4.

In parallel with this investigation of data sources, potential overlaps between the bioenergy model and other mastersheets that process bioenergy data within the NAEI were examined in detail. Decisions were then made, on a case by case basis on where processing of the particular bioenergy activity data and emissions factors should be dealt with, depending on interactions with other parts of the NAEI. This resulted in some 'double counts' in the existing NAEI being removed. Some data processing has been moved from other mastersheets into the bioenergy model, this is the case for landfill gas and sewage gas (moved from the gas mastersheet), charcoal (from the charcoal and peat mastersheet) and municipal solid waste (MSW, from the MSW incineration mastersheet). This consolidation brings together the processing of all landfill gas, sewage gas and waste fuels that are part of the renewables chapter of DUKES, aligning the approaches taken to the treatment of these fuels. Where the NAEI also has sectorally-aligned workbooks (e.g. cement, lime) the fuel inputs to these workbooks were examined in consultation with the RESTATs team to understand the overlaps, and changes made either to the bioenergy workbook, or sectoral workbooks to remove any double counts identified.

As understanding of the data sources grew, the data flows for the model could be defined and the model structure was developed further. Data inputs were clearly separated from calculations, and from outputs, and the model outputs were structured to be at the most granular level that the input data allowed. The model was developed by a member of the NAEI team, following DESNZ and NAEI best practice guidance. It then underwent a systematic review by the principal researcher for the Bioenergy GHGIIP and a senior expert from the NAEI which led to a number of further improvements and streamlining of the model. It was then passed to an expert within the NAEI team who specialises in QA/QC for a QA audit. Errors and cases of poor practice which were identified were corrected and this draft final version of the model was then used for integration testing with the NAEI. This integration testing, as well as checking that the integration process itself would function, also allowed for the emissions series from 1990 to 2022 to be compiled. Inspection of these emission time series and comparison with emissions time series from the current NAEI also facilitated verification and validity testing, a critical component of the QA process specified in DESNZ guidance. Once this had been completed and any identified errors rectified, the model was resubmitted to the QA auditor for final scoring using the DESNZ QA template and log. As a model within the NAEI, a QA score of 90% is required. The model scored 96%. As an additional QA step the QA log has been checked and validated by the lead partner of the GHGIIP consortium Mott MacDonald[8].

In addition to improvements to the activity data, a review was carried out of existing bioenergy emissions factors and a number of these were improved. Appropriate emissions factors were also identified for subsectors where activity data has become more disaggregated. This is discussed in detail in Section 5. These new emissions factors were included in integration testing described above.

It is planned that the new bioenergy model and new emissions factors will be integrated into the 2024/5 annual NAEI update cycle[9].

3.2 NEW DATA SETS INVESTIGATED FOR INCLUSION

A number of data sets were identified in Phase 1 as potentially providing additional or better sources of data. These, and the reasons why it was not possible to include them are listed below.

[8] Full QA of the model by Mott McDonald was not possible due to the inclusion of confidential data in the model.

[9] Subject to approval and instruction by DESNZ to the Inventory Agency.

3.2.1 The Major Power Producers survey

It was considered likely that interrogation of the Major Power Producers survey, which underpins data in DUKES on electricity supply and fuels used for electricity generation, would allow a better representation of power station fuel use, which in the NAEI is based on data from the Emissions Trading Scheme (ETS) and the operational incinerators data set. Access to this data source would allow for a better understanding of how the available data for electricity production aligns between DUKES, ETS, and the operational incinerators data set. It may also have allowed for additional granularity of fuel types in use, as fuel classification in the ETS can be quite generic. It was not possible to access this data set, as the mechanism (the Electricity Act 1989) under which it is collected by the Energy Statistics Agency within DESNZ does not allow for onward sharing of the data for the purpose of emissions inventories.

3.2.2 Combined Heat and Power QA scheme data

For combined heat and power (CHP), the CHPQA scheme data set contains a very detailed breakdown of the fuels used for CHP which would allow greater granularity of the fuel types reported. It has not been possible to access this data set, as the privacy notice which is sent out when requesting data from scheme operators, specifies that the data will be used for the purpose of the CHPQA scheme, including collection and collation of national statistics and administration and development of government schemes. It was considered by the Energy Statistics team at DESNZ that this would not permit its use within the NAEI, and that the privacy notice would need to be changed to allow the data to be passed to the NAEI.

3.2.3 Renewable Heat Incentive (RHI) data

Statistics collected that relate to the Renewable Heat Incentive (RHI) were also considered[10]. These provide data on the GWh of heat paid for under the non-domestic RHI, so give data on GWh of heat from small (< 200 kW), medium (200-1000 kW) and large (>1000 kW) solid biomass boilers supported under the scheme in commercial, public sector and industrial settings. This RHI data is used by the RESTATS team in compiling bioenergy data for DUKES and is converted back to biomass fuel consumption by assuming a typical boiler efficiency. However, information was not available from the DUKES and RESTATS teams on how exactly this data is combined with data on biomass use in boilers which is not supported by the RHI (e.g. boilers installed before the start of the RHI in 2011) and how this data is mapped to different industry sectors. This would mean that any conclusions that could be drawn from the RHI data, for example the breakdown of boiler sizes, would be uncertain as the coverage is not complete and the mapping to categories is not known. In addition to this, the emission factor review undertaken as part of this study found that almost all emissions factors for biomass boilers were not differentiated by boiler size, so even if it were possible to incorporate the breakdown by size that this data set offers, there would be limited impact on overall emissions estimates.

3.2.4 Ofgem biomass sustainability dataset

The Ofgem biomass sustainability dataset was also considered. Since 2009, the Renewables Obligation Order introduced the requirements for generating stations using biomass fuels to report against sustainability criteria, and this data set is published annually[11]. It requires a description of the fuel type used, so it was considered that this might allow the generic 'plant biomass' category used in DUKES to be broken down further into specific fuel types, and for example to allow differentiation between different fuel forms (e.g., wood chips and wood pellets). However further investigation found that this was not possible as it was not possible to match the fuel use reported here exactly to DUKES fuel categories and also to DUKES consumption categories (electricity generators, auto generators and industrial use), partly because some generators may not be receiving incentives payments so do not need to report. The data set would also require considerable preprocessing - generators may choose their own fuel descriptor (over 100 different fuel names are reported) which would need to be allocated to specific fuel types, and also reporting is on a financial year basis (April to March) rather than a calendar year as used by DUKES. While larger power stations report monthly so construction of a calendar year using sequential annual reports would be possible, smaller stations (under 1MW) only report an annual figure. Finally, fuel consumption is only given in tonnes, with no reporting of moisture content or heating

[10] Non-Domestic and Domestic Renewable Heat Incentive (RHI) monthly deployment data (Great Britain), published by DESNZ and available at https://www.gov.uk/government/collections/renewable-heat-incentive-statistics#deployment-data

[11] https://www.ofgem.gov.uk/publications/biomass-sustainability-dataset-2021-22-scheme-year-20

value of the fuel, so a considerable number of assumptions would be required to convert the data to energy content.

Within the NAEI, consumption of solid biomass in power stations is derived from additional sources other than DUKES and is categorised as either wood, straw, poultry litter and meat and bonemeal (with the latter two being combined for reporting as animal biomass to prevent disclosure of information relating to single sources. An analysis of the Ofgem sustainability data for 2021/22 (Table 3-1) gives confidence that these categorisations do cover the main fuel types and that only a very small percentage (1.3%) of fuel consumption falls outside this category.

Table 3-1 Estimated split of solid biomass fuel consumption (on energy basis) in Ofgem sustainability data set

Fuel type	% of total reported	Sub-fuel type	% of total reported
Wood based fuels	83.8%	Wood pellets	50.6%
		Wood chip	24.2%
		Waste wood	6.6%
		Sawmill residues	2.3%
'Woody' type fuels	4.0%	Arboricultural arisings	2.5%
		Forestry residues	1.1%
		Bark	0.4%
		SRC	<0.1%
Straw	5.6%	Straw	5.6%
Animal biomass	5.3%	Meat and bonemeal	2.1%
		Poultry litter	3.2%
Other	1.3%	Oat pellets	0.4%
		Miscanthus	0.3%
		Sunflower husk pellets	0.2%
		Sludge	0.3%.
		Other	0.2%

3.3 MODEL SPECIFICATION

The overarching aim for this work has been to improve the accuracy, transparency and granularity of the bioenergy modelling in the inventory. The bioenergy model produced as an output from this work is one component of this – it consolidates data that relates solely to bioenergy activity data. The final output – updated bioenergy emissions for the NAEI - draws from several models within the NAEI so as not to lose the complex modelling that is already included, e.g., for regulated emissions sources and road transport.

3.3.1 Outputs

The outputs from the model are a more granular and transparent data set for bioenergy. This has been achieved primarily via the building of a new bioenergy model to capture and consolidate a number of existing data flows, and a re-defined set of outputs to retain the most granular level of data available through the process. The existing data flows that have been consolidated are the treatment of data from DUKES across all bioenergy fuels, and the operational incinerators data set from the Environment Agency, which will be achieved through the consolidation of models for Thermal Renewables (which considered Wood, Waste Wood, Plant Biomass, Animal Biomass, and Biogas), MSW Incineration (which considered Renewable and Non-Renewable Waste), and the portions of the Gas model (related to Landfill Gas and Sewage Gas). The model also includes data for Charcoal, taken from the Charcoal and Peat model, although the calculations for this are a separate module, since these data sit outside of DUKES).

Table 3-2 sets out the new reporting categories for outputs from the bioenergy model. This reflects the most detailed breakdown by fuel and technology type that is possible using the available source data.

Table 3-2 Reporting categories for the new bioenergy model

	Wood	Wood - Dry	Wood - Seasoned	Wood - Wet	Plant Biomass	Straw	Animal Biomass	Liquid biofuels	Biogas	Landfill gas	Sewage gas	MSW: biomass fraction	MSW: non-biomass fraction	Non-municipal solid waste: biomass fraction	Non-municipal solid waste: non-biomass fraction	Charcoal use	Charcoal produced
Power stations	Y					Y	Y	Y		Y	Y	Y	Y				
Autogenerators									Y								
Iron and steel - combustion plant	Y				Y		Y	Y	Y					Y	Y		
Non-Ferrous Metal (combustion)	Y				Y		Y	Y	Y					Y	Y		
Chemicals (combustion)	Y				Y		Y	Y	Y					Y	Y		
Pulp, Paper and Print (combustion)	Y				Y		Y	Y	Y					Y	Y		
Food & drink, tobacco (combustion)	Y				Y		Y	Y	Y					Y	Y		
Mineral products (other): combustion	Y				Y		Y	Y	Y					Y	Y		
Mechanical Engineering (combustion)	Y				Y		Y	Y	Y					Y	Y		
Electrical engineering (combustion)	Y				Y		Y	Y	Y					Y	Y		
Textiles and leather (combustion)	Y				Y		Y	Y	Y					Y	Y		
Construction (combustion)	Y				Y		Y	Y	Y					Y	Y		
Vehicle manufacture (combustion)					Y		Y	Y	Y					Y	Y		

	Wood	Wood - Dry	Wood - Seasoned	Wood - Wet	Plant Biomass	Straw	Animal Biomass	Liquid biofuels	Biogas	Landfill gas	Sewage gas	MSW: biomass fraction	MSW: non-biomass fraction	Non-municipal solid waste: biomass fraction	Non-municipal solid waste: non-biomass fraction	Charcoal use	Charcoal produced
Other industrial combustion	Y				Y		Y	Y	Y	Y	Y			Y	Y		
Miscellaneous industrial/commercial combustion					Y		Y	Y	Y					Y	Y		
Public sector combustion					Y		Y	Y	Y					Y	Y		
Agriculture - stationary combustion						Y	Y	Y	Y					Y	Y		
Domestic combustion	Y															Y	
Domestic Fireplace - Standard		Y	Y	Y													
Domestic Closed Stove - Basic		Y	Y	Y													
Domestic Closed Stove - Upgraded		Y	Y	Y													
Domestic Closed Stove - EcoDesign		Y	Y	Y													
Domestic Outdoor																Y	
Charcoal production																	Y
Incineration												Y	Y				

3.3.2 Key inputs / assumptions

Following a detailed review of available data and consultation with data providers, the bioenergy model is underpinned by the following key data sets:

- DUKES Renewables and waste data sets (tables 6.1 and 6.4) – informs activity data for all biofuels, excluding charcoal
- Supplementary data from RESTATS – informs activity data for all biofuels, excluding charcoal
- ETS data – informs activity data for large sites, such as power stations
- Environment Agency and other Regulators' data for operational incinerators – informs activity data for biomass incinerators, treated as power stations in the NAEI
- Environment Agency and other regulators Pollution Inventory data – this is point source emissions data as reported by operators. This is used for bottom up estimates for air quality pollutants, and in a limited way, for gap filling of data for operational incinerators. The CO_2 factors for the EPR power stations are also based on Pollution Inventory data.
- Data from Energy Power Resources (EPR) on their power station operations – these are operator reported data, direct to the NAEI, providing activity data for biomass power stations
- Data from the Mineral Products Association (MPA) – activity data for cement kilns

Key assumptions are:

- DUKES data are complete for the fuels that are reported
- The hierarchy of data choices is[12]:
  - Operator data (MPA or EPR), ETS, Environment Agency incinerator data
  - Where there are inconsistencies between DUKES Table 6.1 and 6.4, the higher total is used.

3.3.3 Functionality and structure of the new bioenergy model

As indicated above the main purpose of the model is to produce consistent time series of activity data for bioenergy use, disaggregated as far as the data will allow by fuel and industry sector.

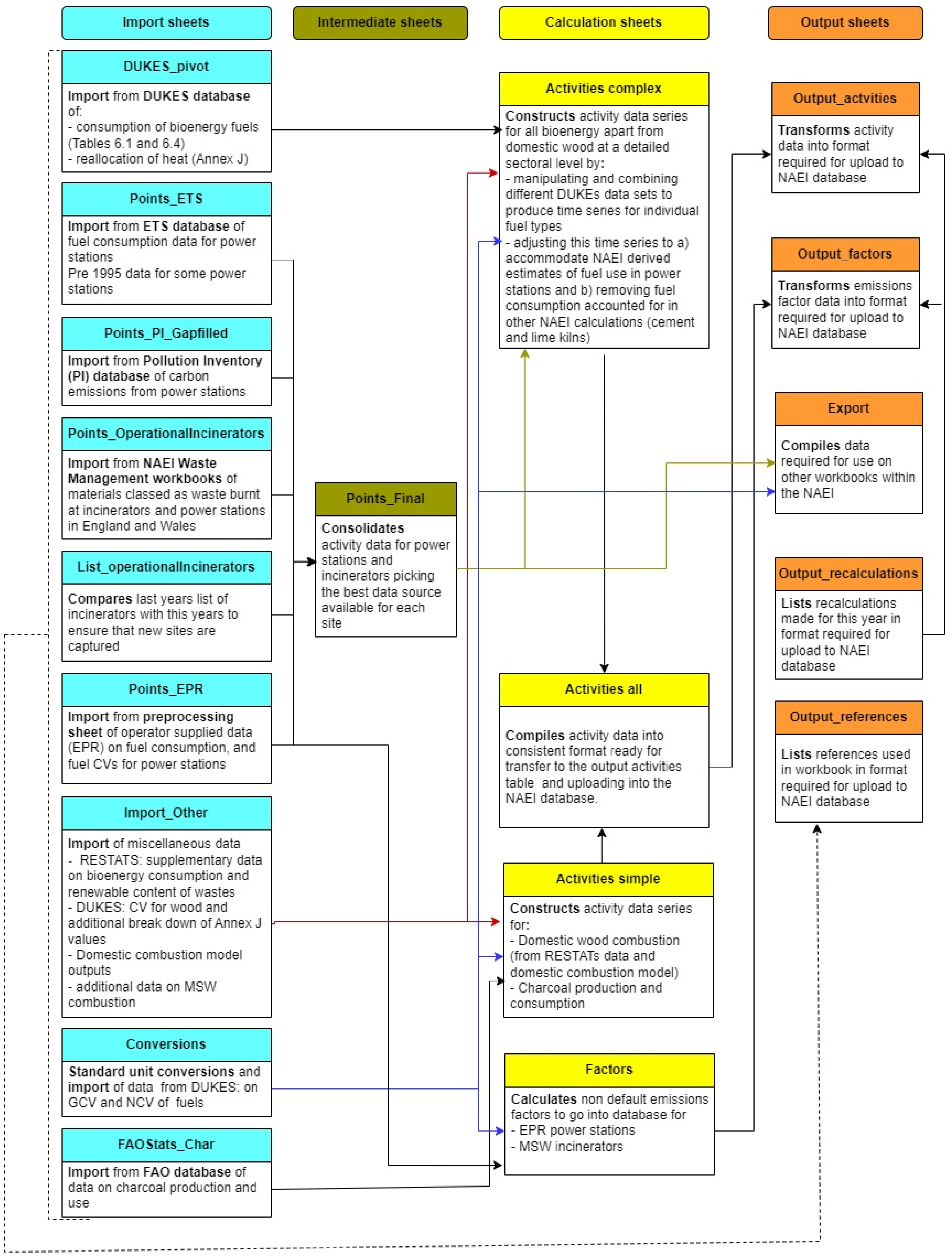
The main actions carried out in the model are:

(1) Combine data from relevant sources to create the most accurate representation of fuel use (activity data) for all power stations and energy from waste plant. Use this time series rather than data from DUKES for power stations, as it enables linkage to actual reported emissions from power stations, rather than the use of generic emissions factors.
(2) Create timeseries from 1990 to current day for all fuels reported separately in DUKES
(3) Where data supports it, use the split of industrial fuel use provided for 2015 to current day to split out industrial fuel use for 1990 to 2014 which is allocated to a single industry subsector – 'unclassified'
(4) Make adjustments to this DUKES data set to:
    a. Reconcile fuel allocated by DUKES to major power producers and autogenerators to fuel use identified from other sources for power stations.
    b. Reallocate fuel allocated in DUKES against heat generation to appropriate industry sectors
    c. Remove fuel use accounted for elsewhere in the inventory
(5) Use information from the domestic combustion model to split wood use in the domestic sector into a number of detailed technology and fuel specific categories.
(6) Create a time series for charcoal production and use from the underlying FAO data set.

[12] There is an exception for plant biomass in 2008 where the sum of known sources (power stations, agriculture straw use, plant biomass based fuels used in the mineral products sector) is greater than the total plant biomass available in DUKES. In this year, the known sources are all accounted for and for all other sources, an interpolated value is used to maintain time series consistency

An overview of the structure of the model is given in Figure 3-1.

Figure 3-1 Overview of model structure



3.3.4 Data manipulation within the model

Bioenergy use in DUKES is reported in two tables:

- Table 6.1: Renewables and Waste: commodity balances (1998 to current year)
- Table 6.4: Renewable sources used to generate electricity and heat and for transport fuels (1990 to current year)

DUKES Table 6.1 details use of each fuel for energy transformation (electricity generation and centralised heat generation) and final consumption in 13 industry sectors, transport, and five other sectors (domestic, public administration, commercial, agriculture and miscellaneous). It also includes data on transfers of gaseous biofuels to the national gas grid. Electricity generation is further subdivided into major power producers (electricity generation sites belonging to companies with a portfolio of over 100 MW of generation) and autogenerators (companies who produce electricity, but whose main business is not electricity generation). This latter category will include both dedicated power stations below 100 MW which are not part of a larger portfolio mix and CHP plants embedded in industry or other sectors.

The level of disaggregation provided in DUKES Table 6.1 has increased significantly over the years - the level of detail provided in more recent years is not present in earlier years. The level of disaggregation by fuel type over time is listed in Table 3-3. In terms of disaggregation by sector, pre 2015 all use in the industry sector is allocated to a single sector 'unclassified', and a split by industry sector is only included between 2015 and current day. It should be noted that there are some obvious discontinuities in the time series, where it appears that fuel use has been reallocated from one sector to another, but the change has not been applied over the whole time series[13].

In contrast, DUKES Table 6.4 includes data over the whole required time period (from 1990 to current day) but only splits fuels between use for electricity, use for heat (which includes the heat generation category in DUKES Table 6.1 and all final consumption sectors) and use for transport. Fuels listed in DUKES Table 6.4 include all of those in DUKES Table 6.1 but also an additional category – co-firing with fossil fuels – where the type of biomass is not specified (Table 3-4).

Table 3-3 Coverage of biomass fuel types in DUKES Table 6.1

	1990 to 1998	1998 to 2003	2004 to 2014	2015 to 2018	2018 to current
Solid biomass	No	Yes	No	No	No
Plant biomass	No	No - included as solid biomass	Yes	Yes	Yes
Animal biomass	No	No - included as solid biomass	No - includes Anaerobic digestion	Yes	Yes
Liquid biofuels	No	No	No	No	Yes
Renewable waste	No	Yes	Yes	Yes	Yes
Non-renewable waste	No	Yes	Yes	Yes	Yes
Anaerobic digestion (biogas)	No	No - included as solid biomass	No - included with animal biomass	Yes	Yes
Landfill gas	No	Yes	Yes	Yes	Yes
Sewage gas	No	Yes	Yes	Yes	Yes
Waste wood (industry and other non-domestic sectors)	No	Yes	Yes	Yes	Yes
Wood (domestic sector only)	No	Yes	Yes	Yes	Yes

[13] Typical practice in DUKES when changes are implemented is to only implement the change for a few historic years.

Table 3-4 Coverage of biomass fuel types for electricity and heat in DUKES Table 6.4

Fuel type	Used for electricity generation	Used for heat generation
Plant biomass	Yes	Yes
Animal biomass	Yes	Yes
Landfill gas	Yes	Yes
Sewage gas	Yes	Yes
Anaerobic digestion	Yes	Yes
Bioliquids	Yes	Yes
Biodegradable energy from waste	Yes	Yes
Non-biodegradable wastes	Yes	Yes
Co-firing with fossil fuels	Yes	No
Waste wood	No	Yes
Wood	No	Yes

Through inspection of the data, comparisons between the two data sets, and discussions with the DUKES and RESTATS it was possible to create a time series that is considered to represent the most disaggregated and consistent time series available given limitations of the data. The actions which are taken within the model to achieve this are listed in Table 3-5.

Table 3-5 Key assumptions made in using DUKES data

Fuel type	Assumptions
Plant biomass, animal biomass and biogas	Where these categories are aggregated as solid biomass, and data for electricity generation is drawn from DUKES Table 6.1, this is all allocated to Major Power Producers; The DUKES categories of Major Power Producers and Autogenerators are summed together to allow reconciliation with data on power stations from other sources, so this does not have an impact on final results
Plant biomass	From inspection of the data and communication with the RESTATs team, it is known that the fuel categorised as solid biomass, pre-2004, which is consumed in agriculture is plant biomass (straw) so this is all allocated to this category. As this value matches the total heat use of plant biomass in these years, use of plant biomass in all other end use sectors pre 2004 is set to zero. As the agriculture line has been adjusted the TOTAL other line is replaced with a sum rather than directly reading the Table 6.1 value
Animal biomass	From inspection of the data and communication with the RESTATs team, it is known that the pre 2015 biogas was included with animal biomass in DUKES Table 6.1, appearing in electricity generation, in heat use in agriculture and in transfers. The biogas for electricity generation and heat generation and use pre 2015 from DUKES Table 6.4 are therefore subtracted from the values for electricity generation and for agriculture from Table 6.1 to give a time series that is solely for animal biomass. The animal biomass transfer is known to be biogas injected to the grid and is therefore subtracted from animal biomass in agriculture as well. As the agriculture line has been adjusted the TOTAL other line is replaced with a sum rather than directly reading the DUKES Table 6.1 value.
Waste wood	From discussion with the DUKES team this fuel category refers only to wood used for heat production in non-domestic sectors. From inspection of the data, wood use in period 1998 to 2014 is almost exclusively allocated to unclassified industry. For the pre-1998 period, waste wood used for heat from DUKES Table 6.4 is therefore assigned to the unclassified industry category.
Liquid biofuels	Data series in DUKES Table 6.1 begins in 2005 but non-zero entries only begin in 2019. Table 6.1 shows no use for heat or electricity generation in period 1990 to 2005.

Fuel type	Assumptions
Biogas	Data from DUKES Table 6.1 are only available from 2015, Biogas used for electricity generation pre 2015 is taken from DUKES Table 6.4 and is allocated to autogenerators rather than major power producers, both because biogas generation plant are typically small, and because the data series from 2015 suggests this is the case. Pre 2015 data on heat use is available from Table 6.4, this is adjusted to remove heat supplied via injection to the grid.
Landfill gas	Data from DUKES Table 6.1 available from 1998. Data from 1990 to 1998 taken from Table 6.4; heat use distributed according to pattern of use in 1998.
Sewage gas	Data from DUKES Table 6.1 available from 1998. Data from 1990 to 1998 taken from Table 6.4; heat use distributed according to pattern of use in 1998.
Renewable waste	Data from DUKES Table 6.1 available from 1998. Data from 1990 to 1998 taken from Table 6.4; heat use distributed according to pattern of use in 1998.
Non-renewable waste	Data from DUKES Table 6.1 available from 1998. Data from 1990 to 1998 taken from Table 6.4; heat use distributed according to pattern of use in 1998.

3.3.5 Interaction of the model with the wider inventory system

Linkages between the bioenergy model and other NAEI mastersheets have been limited as far as possible.

Key exceptions are:

- Scrap tyres: the use of scrap tyres within cement and lime kilns, and as part of the power generation sector are included within the cement, lime and power station models. Scrap tyres forms part of the renewable and non-renewable waste fuels in DUKES (and the assumptions for the reconciliation within the non-renewable and renewable waste fractions differ across the time series). Scrap tyre use from the cement, lime and power stations models are imported into the bioenergy model so that these data can be removed from the renewable and non-renewable waste fuel processing to avoid a double count.
- Paper / plastic / profuel: This is a fuel category reported by the MPA and is modelled as part of the cement mastersheet. Consultation with the RESTATS team has confirmed that this is captured in the plant biomass category of DUKES. This fuel use is imported into the bioenergy model to be removed from the plant biomass category of DUKES, to avoid a double count.
- Domestic wood combustion: Domestic combustion is modelled based on appliance type, population and age profile, and then normalised to the DUKES totals. Outputs from the Domestic combustion model are imported into the bioenergy model so that the percentage breakdown by appliance type can be applied to the DUKES total.

The fuel use outputs from the bioenergy model are imported into the NAEI database and combined with outputs from other models to produce the emissions outputs. This does not require linkages between mastersheets, simplifying the data flows.

Key models for emission factors are:

- The Emission Factors database – this model constructs time series of emission factors, usually from literature sources
- Carbon Factors – collates data for carbon contents of fuels including biofuels
- Regulated Industry database (RIDB) – calculates data based on the regulators' inventories. The more complex point source data processing that was previously in the MSW model will now be in the RIDB, the bioenergy model handling only the split of fuel data into source categories

Road transport biofuels and aviation biofuels are processed entirely separately from the bioenergy model (both fuel use and emission factors). Up to 2022, the latest year for which energy data is available there is no recorded use of biofuels in rail within DUKES. This is because the RTFO data set used to determine biofuels use in transport in DUKES, does not record the end use sector for biofuels, so biofuel use cannot be allocated between the potential transport sectors which might use the fuels – road, rail, and non-road mobile machinery.

All biofuels use is therefore assumed to be in the most significant end use sector, road transport, despite there almost certainly being some use in the other two sectors[14].

For cement, the emissions for most pollutants (not carbon) are based on operator reported totals in the Regulators' Inventories. These do not provide a breakdown by fuel type and do not distinguish process and energy/combustion emissions. This is why, where possible, known fuel allocations for cement have been removed from the bioenergy model rather than removing the relevant fuels from the cement model, to avoid double counts.

[14] RTFO data does identify "off road biodiesl" which includes non-rebated uses such as rail.

4. IMPROVEMENTS IN TREATMENT OF ACTIVITY DATA

As part of the model development, activity data have been reviewed and rationalised. This included further consultation with data providers, to ensure a complete understanding of the data, particularly focussing on where there may be gaps or double counts. These improvements are summarised below, by fuel.

4.1 WASTE FUELS

4.1.1 Current method

The current NAEI (as reported in 2024) has emissions categorised against a single fuel (labelled MSW). This is based on the total fuel data in DUKES for renewable and non-renewable waste, and these are aggregated, so it is not possible to report the biogenic fraction of the activity data separately. The only adjustment made to the DUKES data within the current methodology is to separate out data for scrap tyres, which are included in the DUKES totals for waste, but are reported separately in the inventory for power stations, cement, and lime kilns. The scrap tyres data for all categories is subtracted from the power stations total.

For carbon dioxide, the emission factor for MSW is used to split out the biogenic and non-biogenic component of the emissions data.

DUKES data is reported as in units of ktoe (gross). Default emission factors for most pollutants are in TJ (net) and the conversion in DUKES between gross and net for MSW is 70%. To apportion the CO_2 emissions between fossil, and biogenic, it has been assumed that the non-renewable component has a gross to net conversion of 95%. An inferred value for the gross to net conversion for the biogenic portion has been calculated, maintaining the overall ratio at 70%, leading to a gross to net ratio for biogenic waste of between 40 and 57% (variable across the time series).

As DUKES is only concerned with waste incineration with energy recovery, a separate estimate is made for waste incineration without energy recovery in the early 1990s, since this is outside of the scope of DUKES.

Use of MSW is reported only in power stations and commercial/miscellaneous combustion. The latter source is allocated to 1A1ai_Public_Electricity&Heat_Production – as heat production.

4.1.2 New method

Waste combustion in power stations is now reported as biogenic and non-biogenic MSW, and is calculated as DUKES total for biogenic and non-biogenic waste, (excluding scrap tyres) used in power stations only.

Other categories are reported as Non-municipal solid waste: biomass fraction and Non-municipal solid waste: non-biomass fraction.

The mineral products and unclassified lines in DUKES are adjusted for known use of scrap tyres in cement and lime production. Assumptions for biomass fraction of scrap tyres has been aligned with DUKES.

DUKES allocates some waste fuels to the domestic category, this is reallocated to commercial and public use - this is heat from Eastcroft Incinerator in Nottingham which is supplied to a mix of domestic, public and commercial buildings, and fuel use associated with production of this heat has all been allocated to domestic sector. In 2016, this consumption is moved in DUKES to the heat generation line, and (DUKES Annex J) is then allocated to public administration and commercial rather than domestic. To ensure a consistent time series, this reclassification from the domestic sector to public administration and commercial is applied across the whole timeseries.

The calorific value in DUKES of 10 GJ/t (gross) and 7 GJ/t (net) has been reviewed. This is labelled as renewable in DUKES and as such we have assumed that this was misinterpreted in the current NAEI, as it was considered to be the calorific value for total waste. For the new method, we have replaced the calorific values as follows, based on data from WRATE:

Table 4-1 Calorific Values for Waste (on an as received basis)

	GCV (GJ/t)	NCV (GJ/t)	Ratio NCV:GCV
Bio-fraction MSW	8.7	7.0	0.81
Fossil fraction MSW	16.1	14.7	0.92

The impact of the changes on the activity data and on biogenic CO_2 emissions is illustrated in Figure 4-1 to Figure 4-3 below. The granularity of the reporting has improved, and through the use of the renewable and non-renewable waste fuel categories directly in DUKES the allocation between fossil and biogenic CO_2 has been improved. The change to the CVs has increased the NCV to GCV ratio for total waste (with a smaller ratio for fossil and a much higher ratio for biogenic waste). The change to this ratio means that when converting from gross energy in DUKES to net units, the total activity data is higher. For power stations, the change to the calorific values, in addition to now making the adjustments for scrap tyres from the relevant DUKES total, means that the overall activity data for 2022 is higher. For other sources, the impact of the change to the CV ratio is offset by the removal of scrap tyres from the mineral products line, making the change smaller. The data have also been better aligned with DUKES data in the early time series (pre 1996).

However, the overall biogenic CO_2 emissions have shown a more notable change, owing to the more accurate split between fossil and biogenic fractions, and the changes to the calorific values. The main change is the ratio between the gross and net CV for biogenic waste meaning biogenic CO_2 in particular is higher than the current inventory. This is in addition to more accurately apportioning the total scrap tyres use between biogenic and fossil carbon, aligning the assumptions with those used in RESTATS and DUKES. The previous methodology assumes that scrap tyres are fully non-biogenic and removes the total scrap tyres burnt for energy from the amount of non-biogenic waste combusted in powers stations. The new method uses a time series of the split between biogenic and non-biogenic carbon in tyres (as supplied by RESTATs) and subtracts this from the relevant DUKES fuel use (i.e. from the renewable and non-renewable waste components respectively).

In depth analysis of the waste data in DUKES and consultation with the team responsible for supplying the data has confirmed that clinical and chemical waste incineration, which is currently treated as additional to DUKES in the NAEI, is included in the DUKES totals. As such, the emissions from the incineration of these fuels that are currently calculated using emission factors will be removed, to avoid a double count with the DUKES data. For air quality pollutants, bottom-up analysis using operator reported data will be retained to ensure accuracy of local reporting, where the data supports this. Note that chemical and clinical waste is not classed as biogenic within DUKES[15], and is therefore not discussed further here.

[15] It is likely that chemical and clinical waste may include a small proportion of biogenic material, however in order to maintain consistency with DUKES, the same assumption i.e. that the waste is entirely fossil based has been retained.

Figure 4-1 Power station waste activity data on use of municipal solid waste for 2022

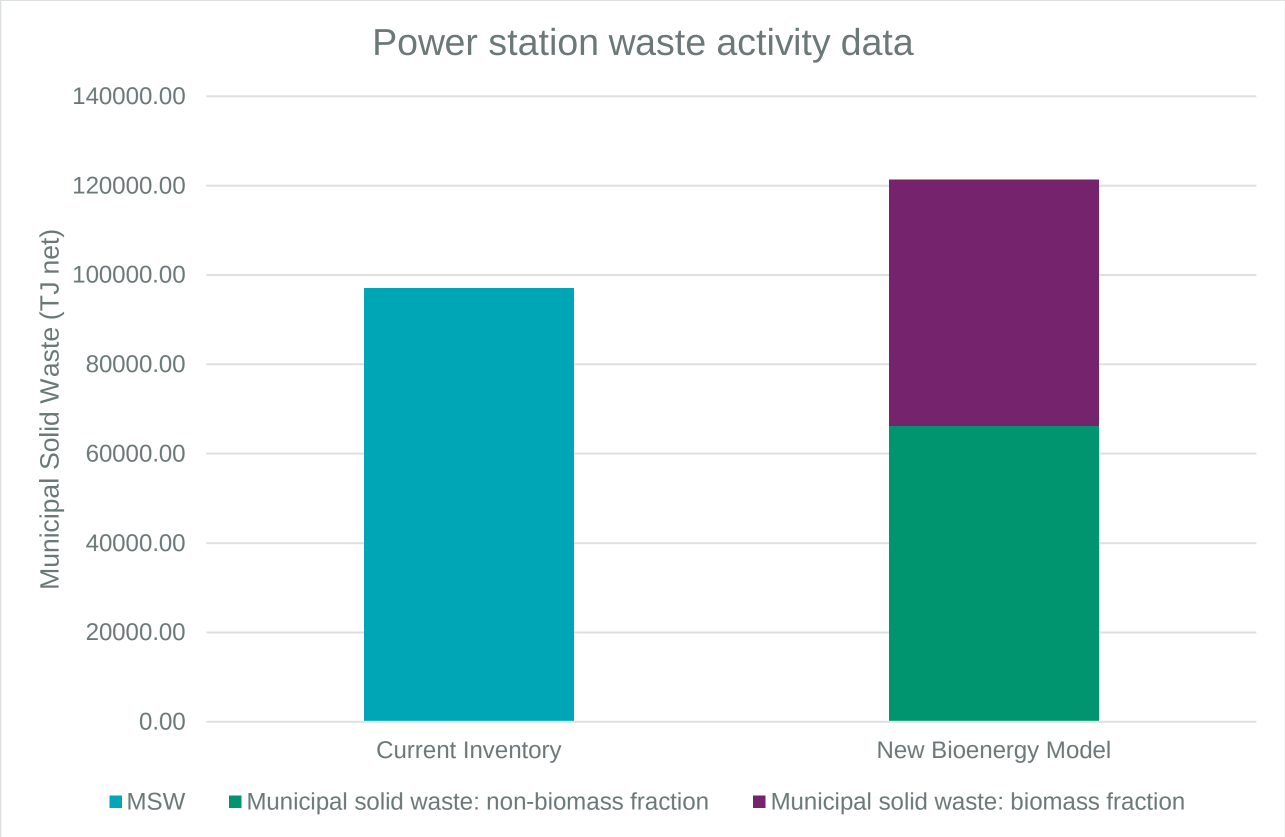


Figure 4-2 Non-municipal solid waste activity data for 2022

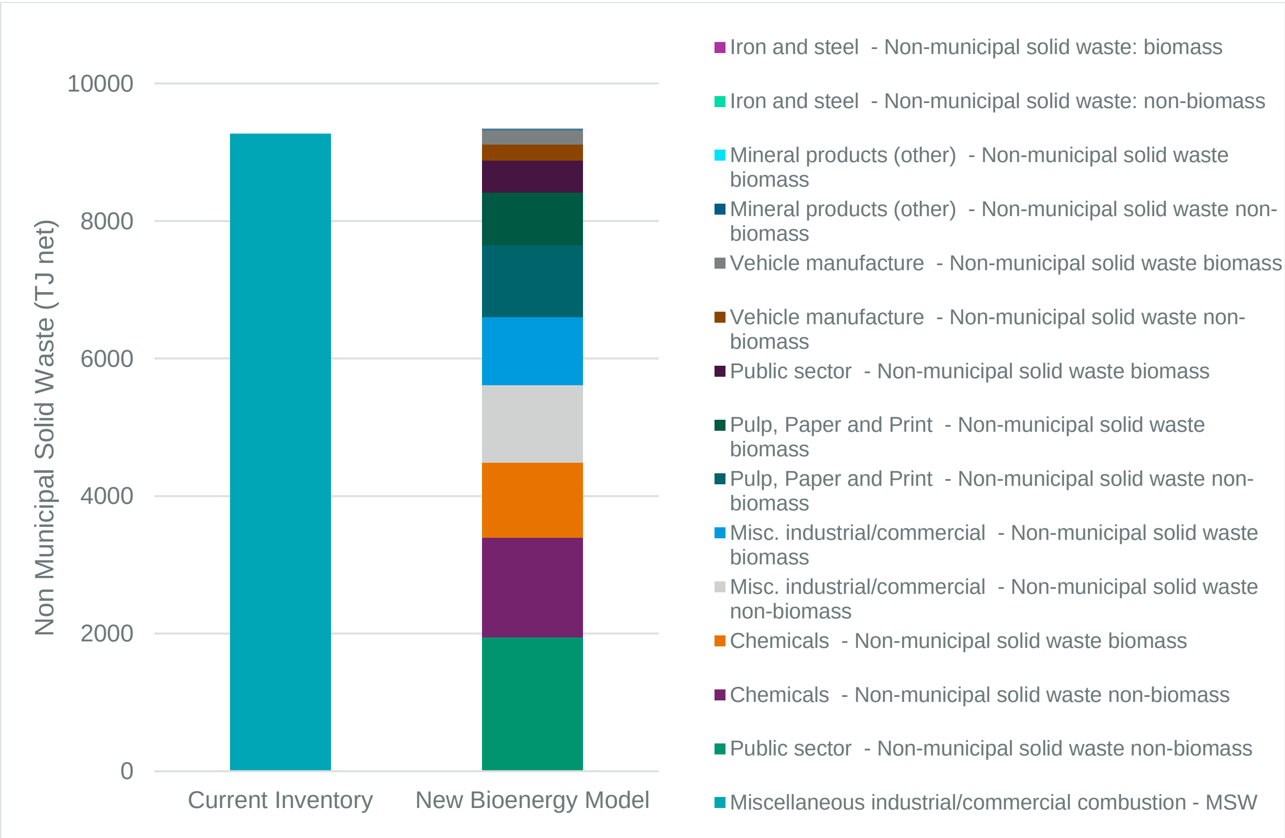
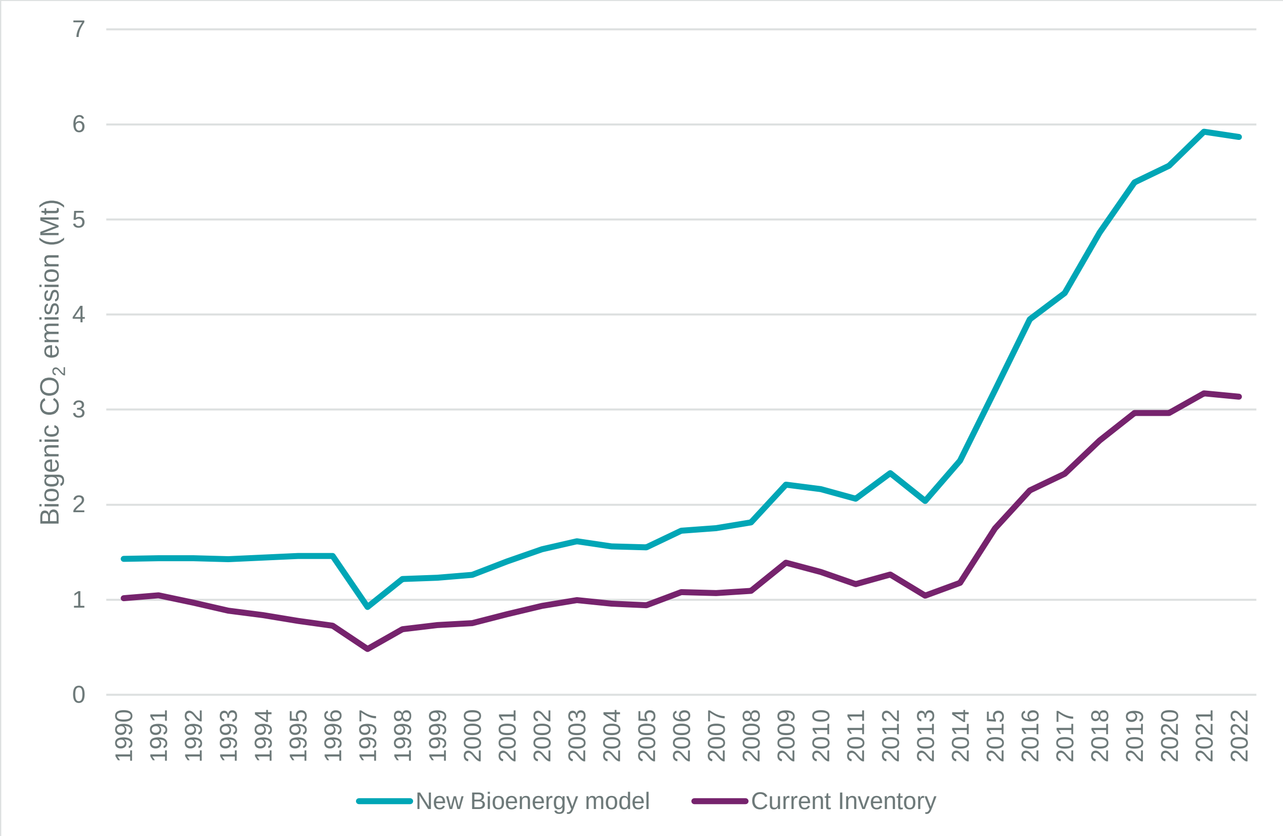


Figure 4-3 Time series of biogenic CO_2 from municipal and non-municipal solid waste



4.2 WOOD

4.2.1 Current method

In the current NAEI, as used for reporting 2024, all "Waste wood" in DUKES[16] is reported as other industrial combustion of wood, under the IPCC category 1A2gviii, however the time series is supplied directly to the Inventory Agency by RESTATS, and this has some minor differences with the DUKES time series.

The NAEI also makes estimates for wood use in power stations, based on operator reported data to the UK ETS. These data are part of the "Plant biomass" category in DUKES.

The DUKES fuel category "Wood" is all allocated to domestic combustion, in both DUKES and the NAEI. The NAEI disaggregates this fuel by moisture content, and the source category by appliance type.

4.2.2 New method

The approach for power stations and domestic wood is unchanged. Industrial wood in DUKES is now allocated consistently with the categories and totals in DUKES (i.e. split out across sources, subject to the available granularity in DUKES). Small differences in the overall total are due to differences between DUKES and RESTATS. From 1990 – 1993 the NAEI was applying data from later years, however, the long term time series available from DUKES table 6.4 does not show industrial wood use in these years, as such this assumption has been removed.

Figure 4-4 and Figure 4-5 show the granularity changes for industrial wood, and the overall time series comparison for all fuels classified as wood in the NAEI.

[16] The Energy Statistics team at DESNZ is currently seeking to improve the data on waste wood/industrial wood use.

Figure 4-4 Industrial wood biogenic CO_2 emissions in 2022

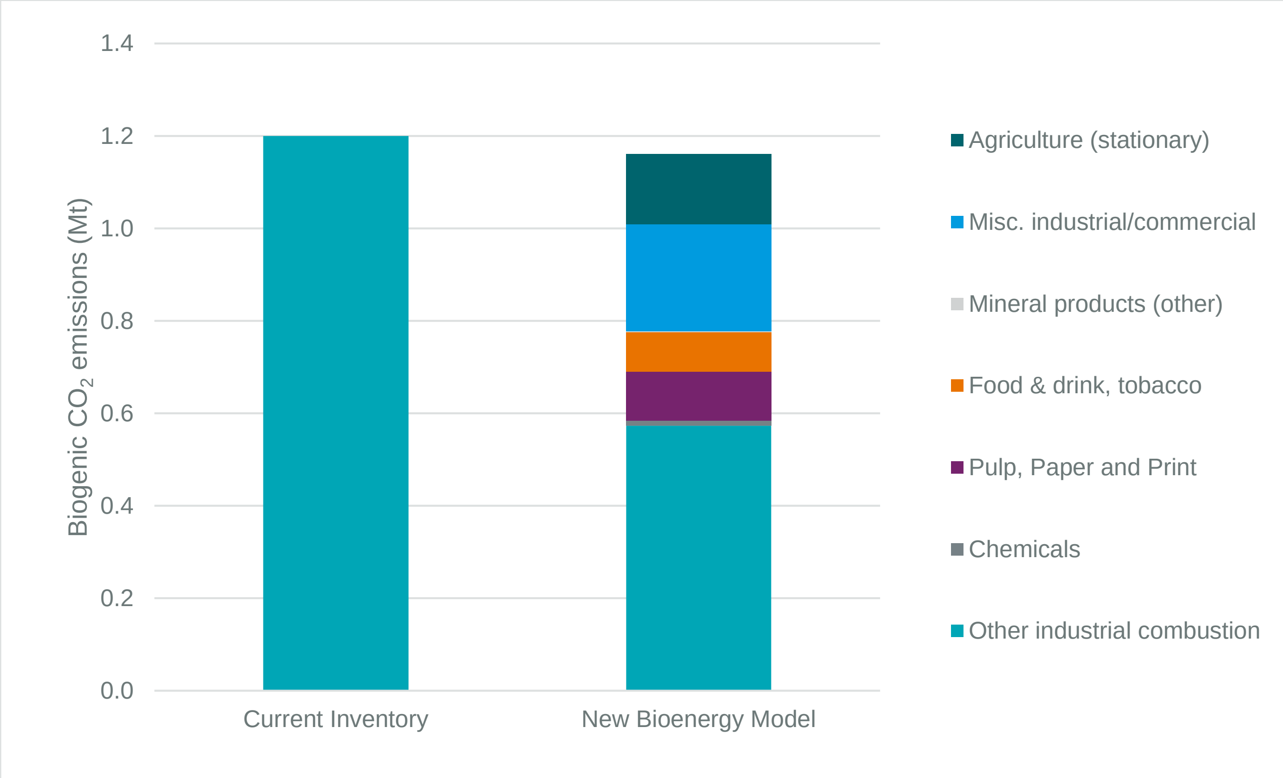
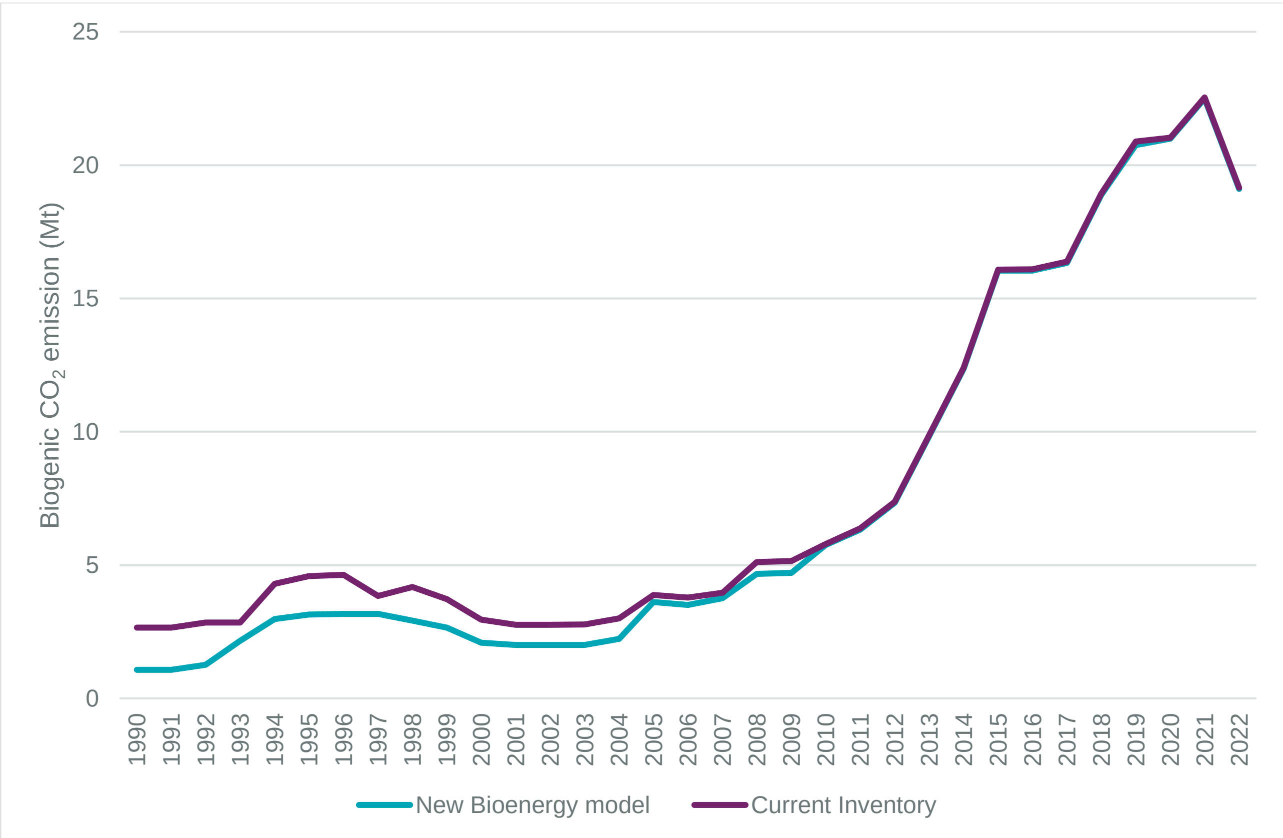


Figure 4-5 Time series of biogenic CO_2 from industrial wood combustion



4.3 LIQUID BIOFUELS

4.3.1 Current method

The methodology for the current NAEI, used for reporting in 2024, estimates liquid biofuel use for power stations based on ETS data, and for other sources based on DUKES. For plant biomass, animal biomass, and liquid biofuels fuel categories in DUKES, the NAEI approach allocates known fuel use for each of those categories to suitable sources, and then uses "other industrial combustion – biomass" as the balance to ensure completeness. This means that there is not currently full transparency across fuel types in the NAEI, but that completeness is ensured.

4.3.2 New method

Biofuel use in power stations is clearly shown in the ETS data set and so continues to be used and allocated to the power stations category. However, there is no allocation of liquid biofuel use for major power producers in DUKES and after consulting with relevant stakeholders and data providers, we were not able to confirm where this fuel was being included[17]. Therefore, as a conservative estimate, the new model treats the use of liquid biofuels in power stations as additional to DUKES. The NAEI no longer reports a single biomass category, as such the reconciliation across fuels is no longer carried out. This means that at an aggregate level, more fuel has been added into the inventory, however, a direct comparison of liquid biofuel outputs from the two models will not show this difference.

Other stationary combustion of liquid biofuels is now all allocated to other industrial combustion. Previously the category "autogenerators" was reported separately. The IPCC category for autogenerators, as defined in the IPCC 2006 Guidelines, is for "*undertakings which generate electricity/heat wholly or partly for their own use, as an activity that supports their primary activity.*" In DUKES, the autogenerators category is based on a calculated split of electricity versus heat generation for CHP plant, which does not fit the IPCC definition of autogeneration, as such this category has been reallocated to other industrial combustion.

For road transport, modelling takes place in the road transport model, and for Sustainable Aviation Fuel, the modelling is carried out in the aviation model. Road transport biofuels data are supplemented by information from the Renewable Transport Fuel Obligation (RTFO)[18].

4.4 PLANT AND ANIMAL BIOMASS

4.4.1 Current method

DUKES has (in the latter part of the time series) two categories for these fuels: Plant Biomass, and Animal Biomass. The NAEI reports fuels from within these categories as: Straw, Poultry Litter, Wood (in power stations), and "Biomass" (which does not distinguish between plant and animal sources).

Power station estimates are based on point source data from the Environmental Regulators, plant operators, and the EU and UK ETS. Estimates are allocated to "wood," "straw," and "poultry litter" (poultry litter includes animal biomass).

Straw in agriculture is based in part on RESTATS, but with a lower assumed value pre-2015, this assumption was to make available additional biomass for other categories.

The current NAEI treats packaging, refuse-derived fuel (RDF), profuel, paper and plastic (used in cement), based on MPA data, as additional to DUKES.

For all other sources, plant and animal biomass is reported as a combined value, across sources as per DUKES, with the difference in the total between the known sources in the NAEI, and DUKES totals (including for liquid biofuels and biogas) allocated to Other industrial combustion – biomass.

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[17] It is possible that historically this was included with soild biomass but no definitive time series was available.

[18] The allocation of biodiesel in DUKES has changed since the completion of the work to improve the model, such that no liquid biofuel is now allocated to "unclassified industries" and liquid biofuels are allocated to "agriculture" – this has been confirmed as for use in NRMM by the DUKES team. The NAEI has ongoing improvement work to handle the allocation of biodiesel, and the allocation for agriculture NRMM will be handled as part of this and the wider gas oil reallocation. The model will automatically pick up the change in allocation away from unclassified industries, and will be amended to no longer account for the agriculture allocation (which in the current set up would be allocated to stationary combustion in this category.

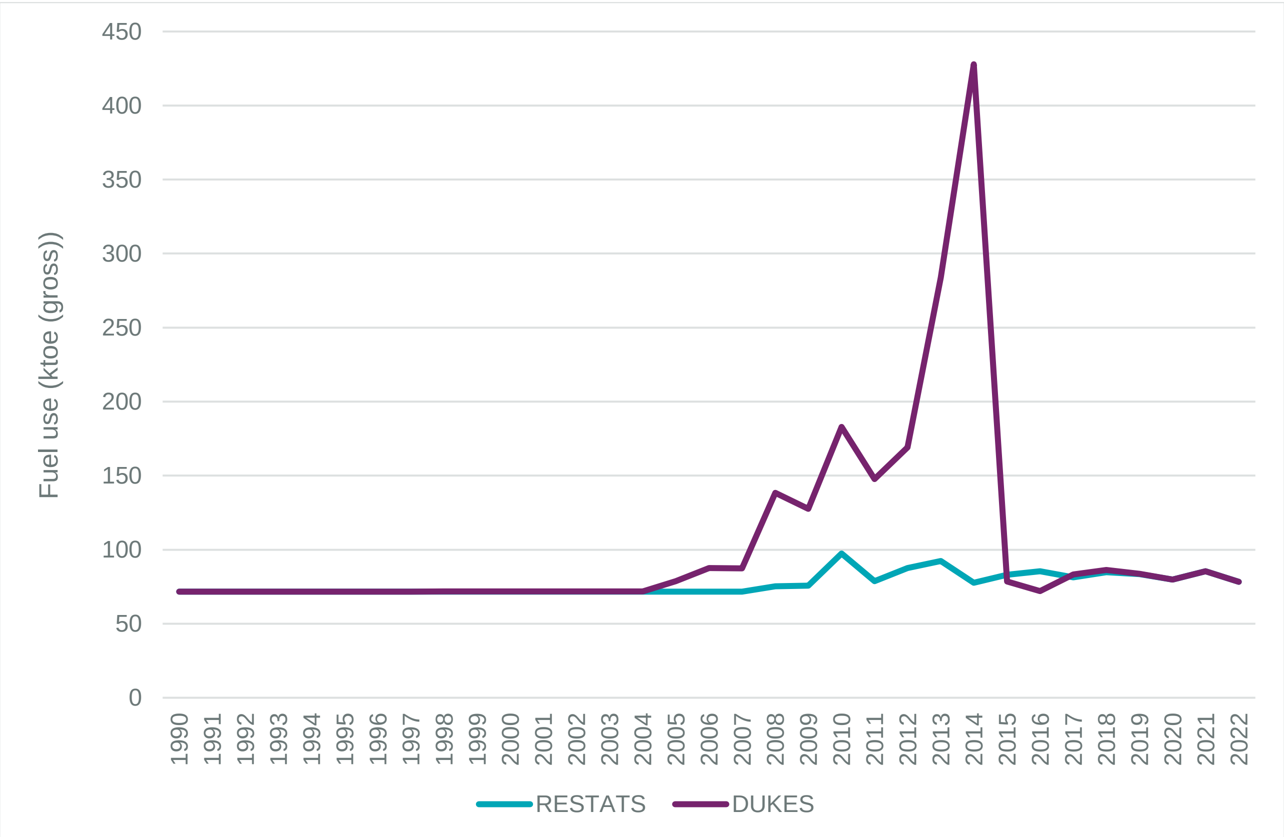
4.4.2 New method

Plant and animal biomass are no longer combined within the NAEI, and there is no cross allocation with biogas or liquid biofuels.

For power stations, plant biomass estimates are still allocated as straw, and wood, based on point source data from the Environmental Regulators, plant operators, and the EU and UK ETS. It has not been possible to further break down the fuels beyond these two categories as it was not possible to access the major power producers survey due to constraints related to the mechanism for data collection by DESNZ. The difference between the NAEI estimates, and DUKES data for total electricity production (i.e. major power producers plus autogenerators) is allocated to industry. Animal biomass replaces the category “poultry litter”, this is for transparency as the poultry litter category previously included meat and bonemeal. For years before 2006, the NAEI uses DUKES data directly, as this should be the same as the NAEI since the sites covered are identical between the bottom-up point source data and DUKES. Comparison between the two data sets shows close correlation, and alignment to DUKES means that there is no further reconciliation of the data between categories. Post 2006, NAEI estimates are used in preference to DUKES and the difference in the fuel allocation between the NAEI bottom-up estimates for power stations, and the DUKES allocation for total electricity generation, is allocated to industry.

For agricultural straw use, a comparison (Figure 4-6) has been made between the RESTATS data and the DUKES time series (for plant biomass in agriculture). There is close agreement between the two data sources for years prior to 2005 and post 2014. Where the two data sets are close, the NAEI uses the DUKES data set, to minimise the need for reallocations between categories. Where there is significant deviation between the two, the RESTATS data is used in preference as this is a much more consistent time series. The difference is allocated to industrial sources.

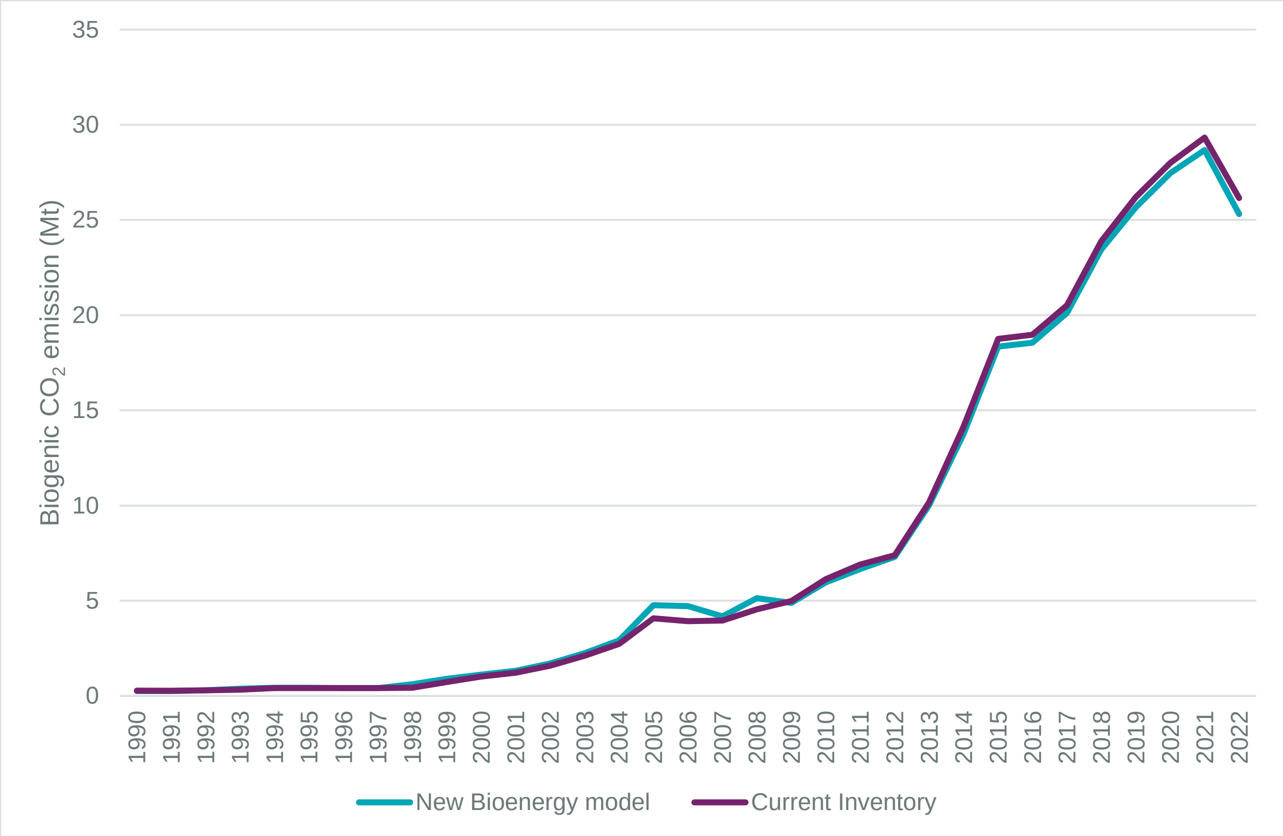
Figure 4-6 Straw use in agriculture - data DUKES and RESTATS



Consultation with the RESTATS team on how data from the Mineral Products Association, or from UK ETS, for the cement industry feeds into the data set has confirmed that the line for “Packaging, RDF, profuel, paper and plastic” is included in the DUKES total for plant biomass. In some years this has been aligned with the unclassified industries line and in others the mineral industries line. These categories have now been adjusted, removing the value for these fuels from the plant biomass total.

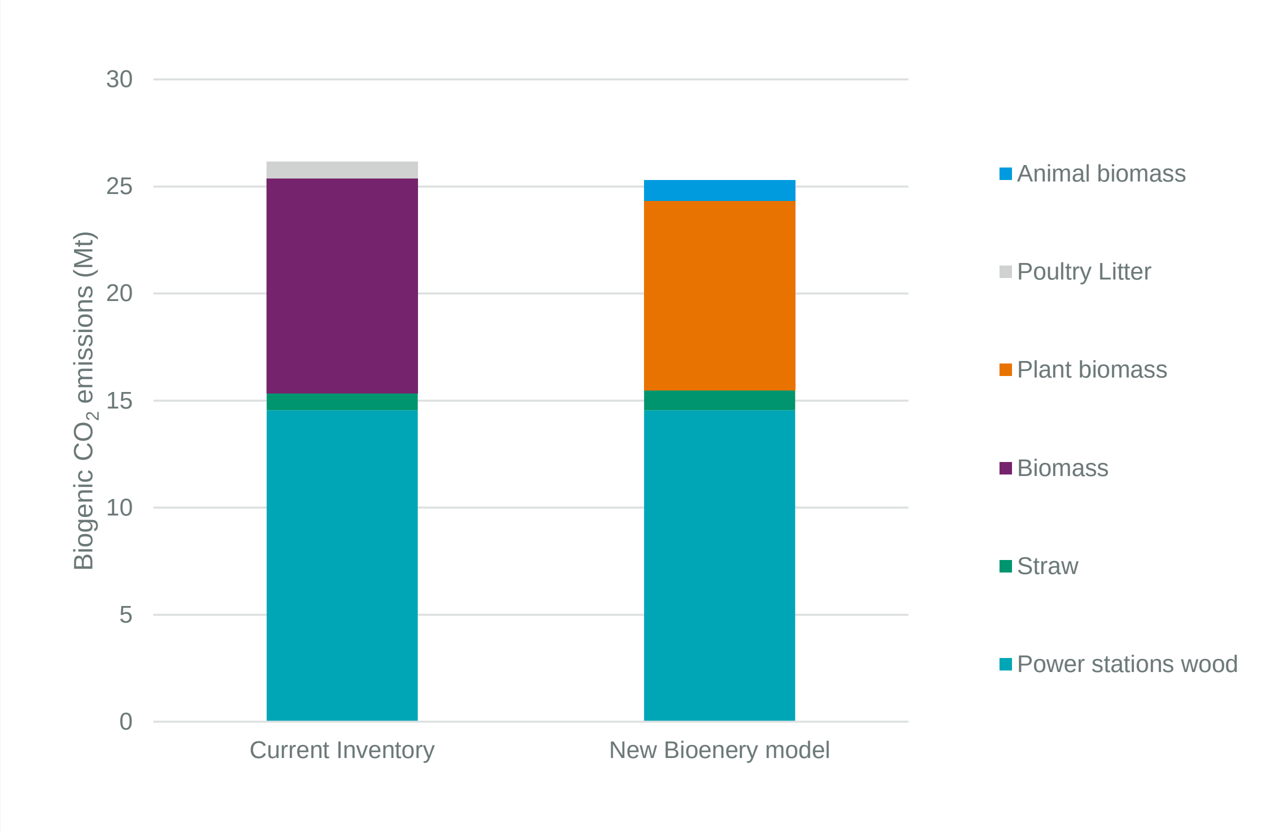
As shown in Figure 4-7, the overall difference in the time series of biogenic CO_2 emissions from plant biomass is small, these relate to the removal of the double count, and alignment with DUKES directly in the cases where the comparison between bottom-up and top-down data are small.

Figure 4-7 Time series of biogenic CO_2 from plant and animal biomass combustion



The changes to the fuel category breakdown, for 2022, are illustrated below. Plant and animal biomass have been reported separately although as the bulk of animal biomass was previously reported as "poultry litter" under power stations, the overall change has been modest – mostly a swap between the "biomass" and "plant biomass" categories.

Figure 4-8 Plant and animal biomass biogenic CO_2 emissions in 2022



4.5 LANDFILL GAS AND SEWAGE GAS

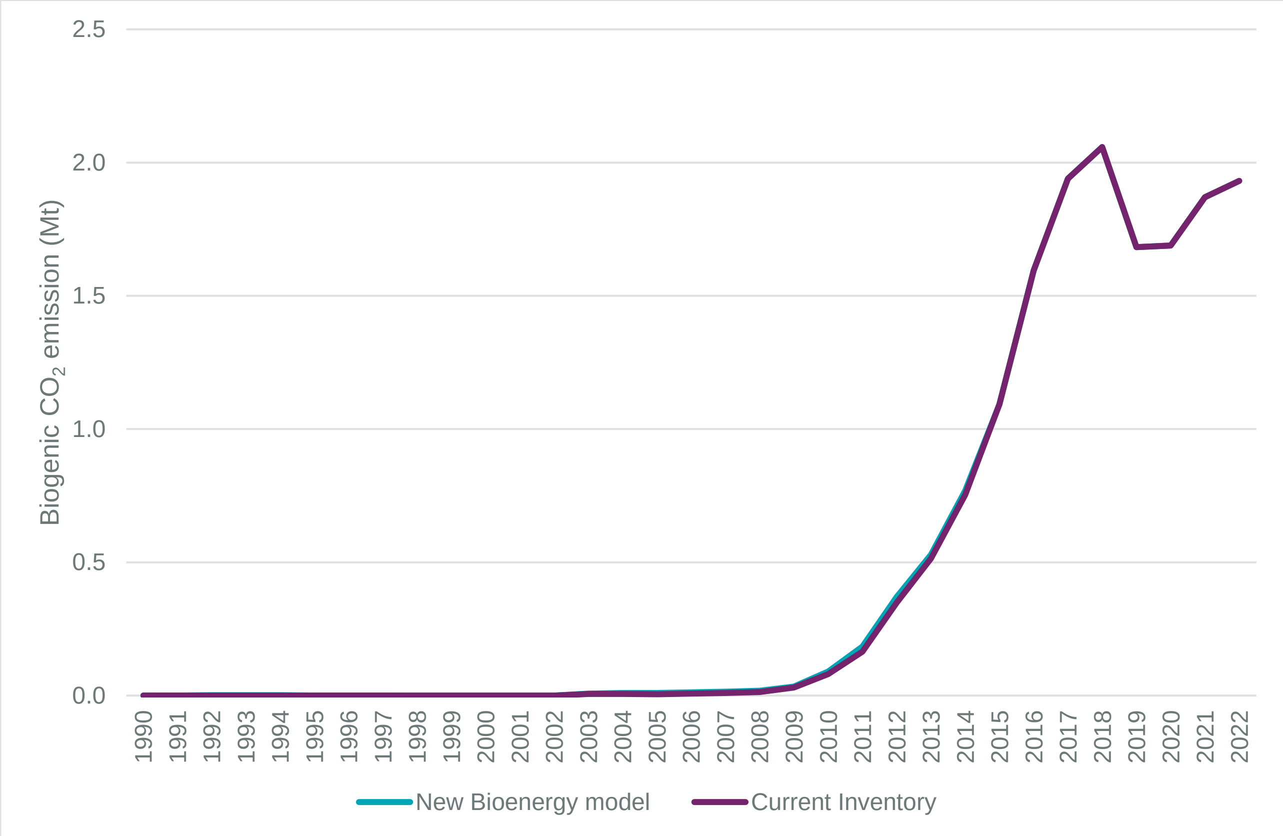
For landfill gas and sewage gas the only change has been to reallocate the estimates that were allocated to heat networks to industrial combustion, as further analysis of the data and consultation with data suppliers did not support the assumption that these fuels were being used for heat networks.

4.6 BIOGAS

The current inventory uses DUKES data directly post 2015, and between 2003 and 2015, estimates for categories other than autogenerators are estimated reflecting the proportions of fuel use allocated in 2015. Autogenerators for all years are based on DUKES. For years prior to 2003, the small amount of biogas reported in DUKES table 6.4 as heat generation is not accounted for as biogas and is instead picked up in the reconciliation of other biomass.

The new bioenergy model is similar except for accounting for the non-autogenerator data prior to 2003. This is a very small change but means that there is no longer any cross allocation of biogas between the biogas and plant and animal biomass categories.

Figure 4-9 Time series of biogenic CO_2 from biogas combustion



5. IMPROVEMENTS IN EMISSIONS FACTORS

5.1 GREENHOUSE GASES

All of the emissions factors (EFs) for methane (CH_4) and nitrous oxide (N_2O) used currently in the NAEI are based on IPCC default emissions factors, as are the majority of the biocarbon factors. These are often generic factors e.g. for 'solid biomass' rather than for a specific biomass fuel. A review was therefore carried out to check if more fuel- or technology- specific factors were available.

This was done by:

- Reviewing other countries' National Inventory Reports (NIR) to identify if they used alternative CH_4 and N_2O EFs relevant to the identified sources/fuels/pollutants;
- Conducting a wider literature review to identify appropriate factors;
- Reviewing default factors from the 2006 IPCC Guidelines for National Greenhouse Gas Inventories to establish if the most appropriate factors were being used;
- Examining Tier 3 CO_2 EFs from biomass use reported under the ETS.

5.1.1 Methane and nitrous oxide emission factors

For CH_4 and N_2O, all of the countries whose NIRs were reviewed were using default EFs from the 2006 IPCC guidelines. The wider literature review did not yield any new data sources. Since all of the NIRs, and the literature review, did not uncover an alternative data sources, the current EFs in the NAEI which are based on the 2006 IPCC Guidelines were retained, and where emissions are now estimated on a more granular basis, appropriate EF factors were also taken from the 2006 IPCC Guidelines.

5.1.2 Bio-carbon emission factors

The default value from the 2006 IPCC Guidelines of 100 tCO2/TJ (27.2 tC/TJ) for other primary solid biomass is used in the NAEI for all solid biomass in the inventory, apart from animal biomass and straw used in power plants where data is available directly from power station operators.

A comparison of this factor was made with Tier 3 emissions factors for biomass reported under the ETS from 2020 to 2022. Only four sites reported a Tier 3 emission factor for different types of solid biomass. On average this emissions factor was very close (within 2%) of the default emission factor used in the NAEI, with a range of about +/- 12% around this value for specific types of fuel use at specific sites. Due to the small sample size and confidential nature of the ETS data, it is not proposed at present to make further use of the ETS EF data, but it does help to give confidence in the use of the default emissions factor.

For biogas, sewage gas and landfill gas reported under the ETS, all EFs were identical to the NAEI values.

5.2 AIR QUALITY POLLUTANTS

The following pollutants were considered: NO_x, PM_{10}/$PM_{2.5}$, SO_2, NMVOC, NH_3, black carbon, metals (As, Cd, Hg), Benzo[a]pyrene, dioxins and HCB.

Reporting of air quality pollutants in the NAEI is undertaken in accordance with Guidelines for Reporting Emissions and Projections Data under the Convention on Long-range Transboundary Air Pollution[19] (CLRTAP). The Guidelines set out Objectives and Scope of reporting and require countries to apply the methodologies '*in the latest version of the EMEP/EEA Guidebook*' as a minimum; in the absence of alternative, improved emission factors, the emission factors in this Guidebook are used by default to ensure completeness and comparability with other inventories reported under CLRTAP. To identify potential improvements to emission factors, the following steps were taken as part of the air quality pollutant emission factor (EF) review task:

- Screening to check the more significant NAEI emission sources using bioenergy for each pollutant. From this, prioritise effort and identify where changes may be required.

[19] Current (2023)Guidelines available here : https://www.ceip.at/fileadmin/inhalte/ceip/00_pdf_other/2022/emissions_reporting_guidelines_2023_final.pdf

- To identify the sources in the new bioenergy methods which needed assignment of EFs.
- To track down and understand the scope of some existing NAEI references.
- To identify alternative EFs relevant for the identified sources/fuel/pollutant, through the Informative Inventory Report (IIR) review for other countries (undertaken as part of Task 1) and a wider literature review. Review them against the existing NAEI references and default factors from the 2023 EMEP/EEA Guidebook.
- For the industrial combustion sector, consider whether it would be possible to identify and apply EFs that differentiate between different boiler sizes.
- Document to justify retention of current EF or replacement by an alternate emission factor. Where there are gaps and limited information available currently, recommend priority for further review in the future.

Appendix 1 tabulates the review findings for each source, activity and pollutant combination. The main findings from the IIR and literature review are:

- For **domestic combustion**, the Emission Factors for Domestic Solid Fuels (EFDSF) project will inform the update of NAEI emission factors for NO_x, PM_{10}/$PM_{2.5}$, SO_2, NMVOC, black carbon, Benzo[a]pyrene and dioxins. Information was available in IIRs but the EFDSF project provides the best opportunity for country-specific EFs for these pollutants.
- For **NH_3**, it is recommended to adopt the 2023 EMEP/EEA Guidebook EFs. Previous versions of the EMEP/EEA Guidebook had included EFs which were developed from a relationship with carbon monoxide (CO) emissions derived from research on outdoor wildfire burning but were not aligned to CO EFs for domestic combustion. The NAEI had reviewed the same research and developed a Tier 1 EF aligned to CO emission factors however, the basis of the EFs is considered unreliable and the EFs likely to be conservative. Information in the IIRs was limited however, the NH_3 EFs have been updated in the 2023 EMEP/EEA Guidebook. The new ENEP/EEA Guidebook EFs are available for different technologies and appear to be aligned with other emissions, adoption allows a higher Tier approach and will also provide consistency with other inventories.
- For **metals**, the original sources or references for the factors used by other countries like Finland, Netherland and Canada are unclear and, some types of technology used by these countries may not be relevant for the UK. The values are much lower compared to the Guidebook factors and as we could not track down the original source of these alternative factors, it will be more defensible to retain the current NAEI emission factors which are based on the 2019 EMEP/EEA Guidebook factors (and remain the same in the 2023 version of the EMEP/EEA Guidebook).
- For **HCB**, little information has been found since research in the 1990s which forms the basis of current EMEP/EEA Guidebook EFs. Technology has evolved since the 1990s so the EFs are very uncertain for current technologies but no new information has been found.
- For **charcoal** – information was available in the Netherland and Norway IIRs but the supporting report for the Netherlands data was not accessible and data for Norway was not for barbecues (the main use in UK). Consequently no change in EFs is proposed. Note that charcoal use in restaurants and commercial cooking is not specifically identified in activity data.
- For **biogas –** NAEI EFs for NO_x and SO_x are proposed for retention as they are derived from UK research and other data sources did not offer an improvement in uncertainty. However, it is noted that the regulatory regime has changed in recent years and most operations are subject to emission controls which indicates that the EFs will be increasingly uncertain. For some other pollutants the recommendation is to align with EMEP/EEA Guidebook or Danish research on Combined Heat and Power (CHP) plant.
- For **straw –** the main emission source in the NAEI is associated with combustion of straw in Agriculture; NAEI emission factors for PM emissions were not consistent with the current or previous version of the EMEP/EEA Guidebook. Alternative EFs were found in the Denmark and Norway IIRs but references were incomplete or limited. Broadly the proposal is to retain NAEI current EFs but for PM_{10}, $PM_{2.5}$ and NMVOC the proposal is to adopt the EMEP/EEA Guidebook 2023 Tier 1 EFs for solid biomass.

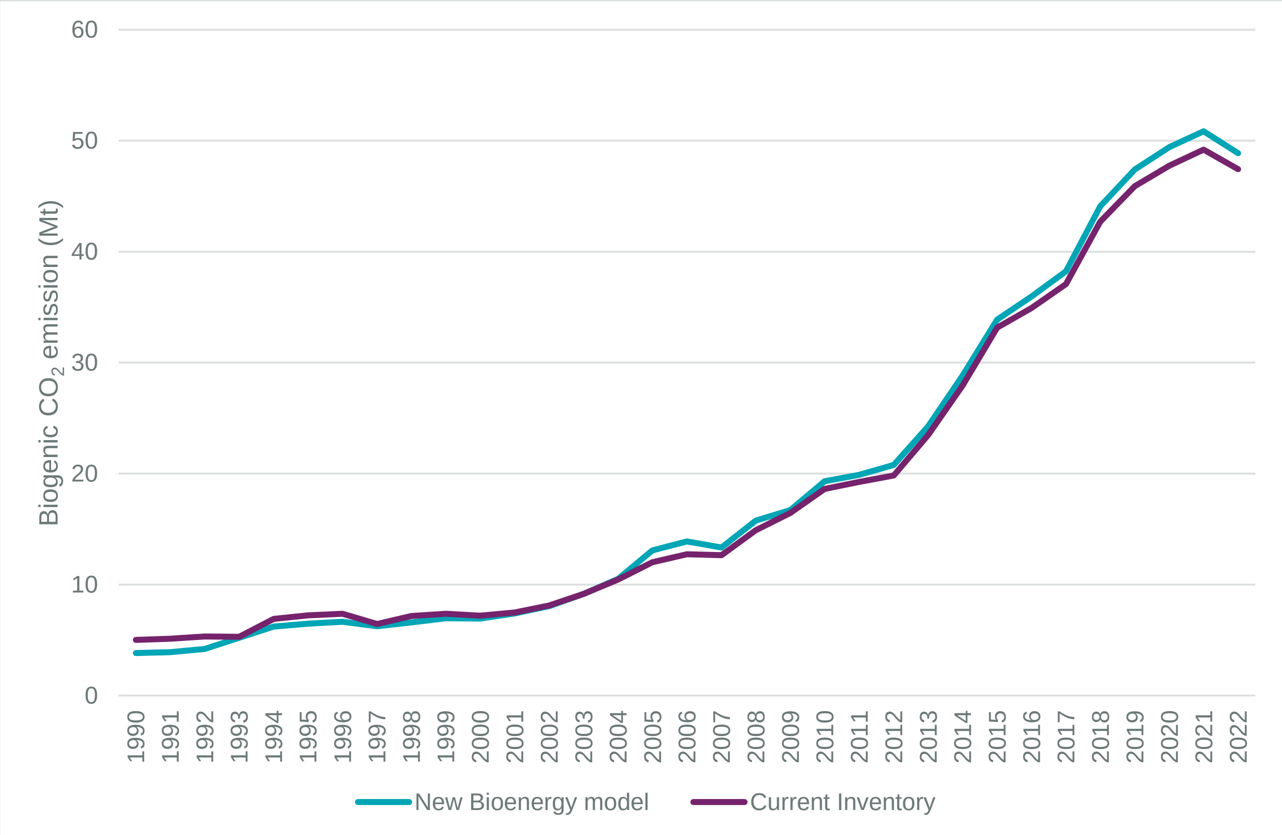
- For **PAH** (benzo[a]pyrene) emissions from wood-burning in power plant, emission factors for Denmark CHP plant were obtained through the review. The Denmark EFs are substantially lower than current NAEI emission factor (from EMEP/EEA Guidebook) and based on measurements for a small number of plant that indicated quantities below the methodology Level of Detection (LoD) but not dissimilar to EFs found for residential combustion. Although the EMEP/EEA Guidebook emission factor is limited (it is based on a US EPA emission factor for industrial wood and waste wood burning), the evidence base is too limited to justify replacement of the EMEP/EEA Guidebook EF but it is considered appropriate to apply an average of the Denmark and EMEP/EEA Guidebook EFs.
- For **plant biomass and animal biomass** – the model separately identifies plant and animal biomass activity but EFs in IIRs tend to be aligned to wood, straw or other activity. EFs for new source and activity codes have been assigned to EMEP/EEA Guidebook EFs for automatic boilers burning solid biomass, which are largely for wood combustion.
- **Liquid biofuels**- limited information was found in IIRs. EFs for new source and activity codes have been assigned to EMEP/EEA Guidebook EFs for engines or boilers burning liquid fuels, which are largely for combustion of gas oil. For SOx, an EF is proposed based an EMEP/EEA Guidebook Tier 1 EF for (solid) biomass – liquid bio-fuels are likely to have a sulphur content less than gas oil.
- **Emission factors for different biomass boiler size categories –** although the non-domestic RHI provided information to allow disaggregation biomass use into three size categories and a recent study[20] on performance of RHI boilers provides more detailed size classifications, this could not be implemented into the bio-energy model within this project. Limited emission factor information is available to use with such information but type approval data was identified which could allow size-differentiated PM and possibly NO_x emission factors. In addition, Ecodesign type approval controls apply to new wood boilers up to 500 kW output and there are controls on (clean) waste wood up to 1 MWth and; medium combustion plant (MCP) controls will apply to solid biomass use in plant equal to or greater than 1 MWth.

[20] Biomass boilers: measurement of in-situ performance, BEIS Research Paper no: 2019/022 details here : https://www.gov.uk/government/publications/biomass-boilers-measurement-of-in-situ-performance#:~:text=PDF,%20656%20KB,%2021%20pagesThis%20file%20may%20not%20be

6. IMPACT OF IMPROVEMENTS ON OUTPUTS

The overall impact on emissions of biogenic CO_2 has been modest. Further granularity has been added to the NAEI where the data supports it, and minor changes have been made to resolve double counts that have been uncovered. The set up of the model is now more transparent, allowing for future changes to data availability to be more easily incorporated.

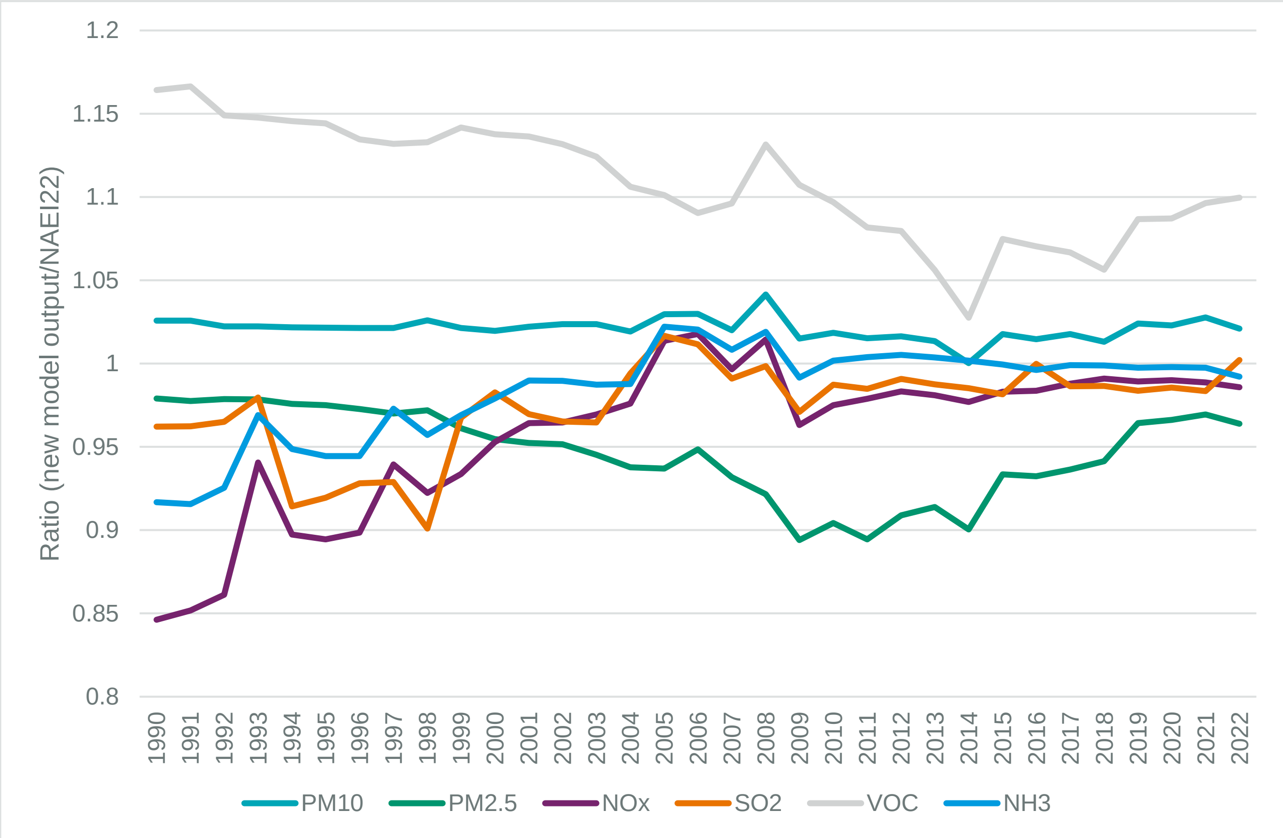
Figure 6-1 Time series of biogenic CO_2 from all biofuel combustion



Further, analysis of the data has allowed the selection of more appropriate emission factors for Particulate Matter. These are still default emission factors from the EMEP / EEA guidebook, but these now reflect the more likely technology types in use.

For key air quality pollutants, the ratio of the emissions totals for biofuels is presented below. The data for VOCs is higher across the full time series. This is predominantly as a result of the change to the straw emission factor, to align with the latest EMEP/EEA Guidebook values for biomass. For SO_2, there is a reallocation between straw and biomass in the early time series. The removal of rolled back data for wood combustion, has also led to changes in the early part of the time series. Changes to NO_x are dominated by the updated activity data for wood. Note that the absolute total is smaller for the early part of the time series, meaning that smaller changes impact the ratio to a greater degree.

Figure 6-2 Impact of changes to bioenergy combustion model on emissions of key pollutants:



The actual emissions from the NAEI22, and new bioenergy model outputs, are shown below. The data from both models are closely aligned with the large relative difference illustrated by the ratios above having a much smaller impact in absolute terms. Note that these charts consider emissions only from bioenergy, in the context of the national total, the differences are very small. The majority of the change is due to revised activity data, as opposed to revised emission factors which is why the change for VOC (where a new EF has been implemented for straw) is more notable than the changes for the other pollutants.

Figure 6-3 Comparison of new bioenergy outputs with those from NAEI22 for key pollutants

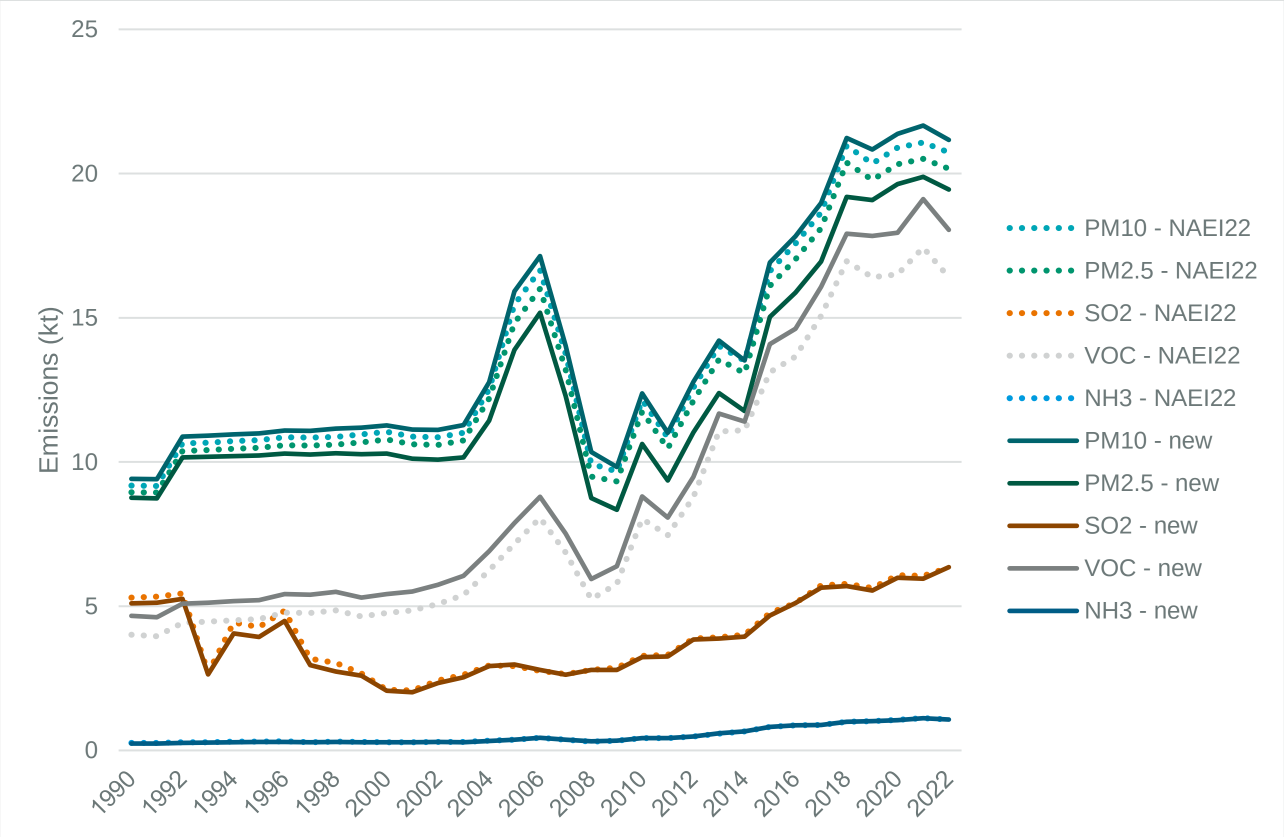
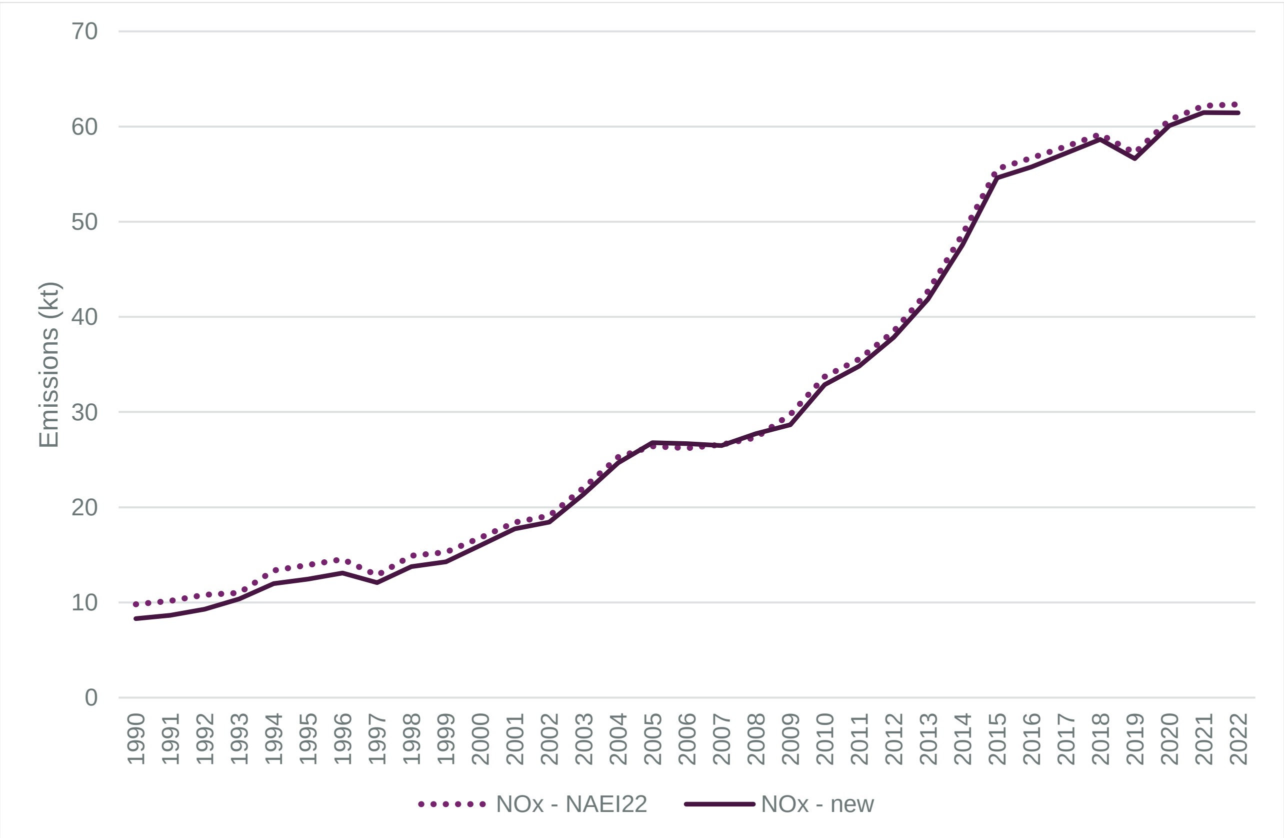
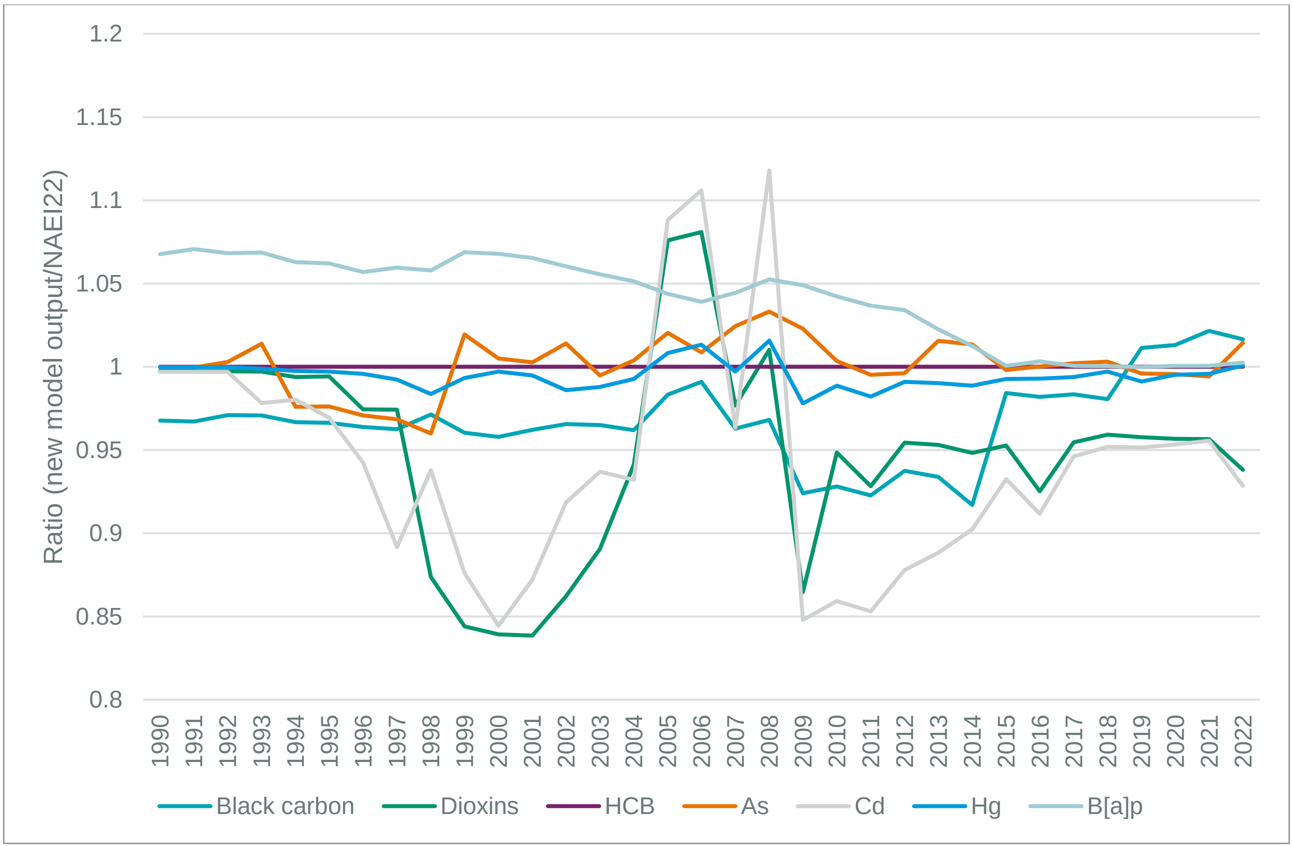


Figure 6-4 Comparison of new bioenergy outputs with those from NAEI22 for NO_x



For other pollutants, the changes are illustrated below. The magnitude of the changes is small, linked to changes to the activity data more so than the emission factors. It should be noted that these outputs are based on trial implementation of the model. Once the model is fully implemented into the NAEI system, as part of inventory compilation, there will likely be more changes to the emissions. These will be due to recalculations/revisions to DUKES data for the latest years, and the full integration of the new activity data into the associated models, in particular the RIDB which normalises total *emissions* to operator reported data, rather than applying a default or constant emission factor. The trial implementation outputs are largely based on assuming the same emission factors as for NAEI22, unless new factors have been identified and implemented.

Figure 6-5 Impact of changes to bioenergy combustion model on emissions of other pollutants:



7. IMPROVEMENTS TO OTHER PARTS OF INVENTORY

The sections above have described the new bioenergy model and the changes that have been made in other NAEI mastersheets as a result of the new bioenergy model. As discussed above and in the Phase 1 report, the use of fuels, including biofuels in transport is dealt with in separate models. The Phase 1 scoping work identified that a much wider range of biofuels was being utilised in road transport than the road transport model was allowing for and that biomass-based sustainable aviation fuels were beginning to enter the market. As a result of this the NAEI team has had further discussions with Renewable Transport Fuel Obligation (RTFO) unit in the Department for Transport, and the DUKES team on this matter and the full range of biofuels used in road transport are now included in the road transport model, giving better representation of biofuel use in this area. In addition, the aviation model has been adapted to allow the inclusion of biofuels in aviation. This is particularly important in light of the recently announced Sustainable Aviation Fuels mandate which will see increasing levels of biofuels (and other low carbon fuels) in aviation in the future.

The work carried out in this task to use more granular data on industrial use of biomass and gain a greater understanding of biomass use also led to a separate improvement task being taken on the air quality side to improve the $PM_{2.5}$ emissions factors used for biomass combusted in industry.

Engagement with stakeholders and peer reviewers over how they would like to be able to use the NAEI has also led to a change in the way that biomass fuels are identified in the inventory, meaning that users interrogating the NAEI database will in future be able to extract emissions data related to all biomass fuels with a single query rather than needing to select each biomass fuel separately[21].

[21] This change has been implemented in the NAEI DB as part of this project. Enabling this feature for 'public' users of the data will require further work as part of the proposed next step of full integration of the new model into the NAEI.

8. RECOMMENDATIONS FOR FUTURE WORK

8.1 USE OF DUKES, RESTATS AND RTFO DATA

The development process for the bioenergy model has highlighted the need for an in-depth understanding of the compilation process for bioenergy statistics to ensure that the implications of methodologies and assumptions are reflected correctly in the NAEI's use of the data. It will therefore be critical to maintain a close liaison with the RESTATS team and the DUKES energy statistics team to ensure that changes in methodologies are communicated so that any necessary adjustments to the bioenergy model and associated parts of the inventory can be made. Some documentation on the current processes used, and in particular on additional transformations made by the DUKES team to data supplied to them by the RESTATS team, was not available. Access to such information would improve transparency and provide confidence that data is used accurately in the NAEI.

As discussed in Section 3.2, some of the primary data sets used in DUKES compilation – the Major Power Producers (MPP) Survey and CHPQA data - cannot be made available to the NAEI due to respectively the legislative act under which MPP data is collected and the privacy notice accompanying CHPQA data. Access to these data sets could help to improve the quality of the NAEI on bioenergy use in power stations and industry, potentially allowing greater granularity over biomass fuel types and ensuring consistency between the NAEI and DUKES in this key sector, and it is recommended that discussions continue as to whether, in the longer term, it is possible to change the basis of the data collection so that it can be used for emission inventory purposes.

As the diversity of low carbon fuels in road transport increases, and renewable fuels of non-biological origin and fuels based on recycled carbon enter the marketplace alongside biofuels, it will be important to ensure that full use of the data available from the RTFO on the types of fuels and feedstocks they are based on is utilised. Discussions with the RTFO unit were held as part of the stakeholder engagement and peer review process for this project and this relationship should be maintained, to ensure that any changes in RTFO reporting or classification of fuels and their implications for the NAEI are fully understood.

8.2 EMISSIONS FROM BIOGAS AND BIOMETHANE PRODUCTION

Phase 1 of the project identified that as production of biogas and biomethane increases there is an increasing need to accurately assess emissions associated with its production, particularly fugitive emissions of methane. These can occur from several places in the production process, for example leakage from anaerobic digesters, unplanned releases e.g. from a need to vent the digester due to safety concerns, leakages from pipe flanges and valves, 'methane slip' due to incomplete combustion of methane in flares and CHP engines, emissions at the plant used to upgrade biogas to biomethane and emissions from the storage of digestate. Emissions are difficult to estimate accurately for a number of reasons:

- Emissions from the digester and associated pipework may depend on how well the plant is operated and maintained.
- The different types of technology which can be used to upgrade the biomethane (e.g. membrane, water wash) can have different rates of methane slip. Recovery of the CO_2 produced from the upgrading process to allow its utilisation may also affect the emissions of methane. It was identified that from the review of other countries NIRs that at least one country is accounting for emissions when biogas is upgraded to biomethane.
- The amount of undigested carbon left in the digestate, which can vary by feedstock and the retention time of the feedstocks in the digester, and the conditions under which the digestate is stored and whether, if it is closed storage, the off-gases are recycled back to the digester, can all affect the emissions associated with digestate storage.

At present fugitive emissions from anaerobic digestion (AD) are estimated in the inventory using the IPCC default emissions factors which are based on the tonnage of waste or feedstock treated. It is not clear whether these are intended to account for emissions from digestate storage as well as the digestion process, and it is unlikely that they would include emissions from biogas upgrading to biomethane.

Further investigation of this area was outside the scope of this improvement project which was focussed on the use of biomass for energy - the production of biogas through anaerobic digestion is covered in the waste management part of the inventory. However this is an area where further research would be useful. It is known that DESNZ has commissioned a measurement survey on selected AD sites. Once this project is complete, it could be useful to consider if an average value could be determined from it for use instead of the IPCC default emissions factors. Alternatively, or in addition, a detailed review of the literature could be done to assess whether more appropriate data are available and could be applied in the UK.

8.3 INJECTION OF BIOMETHANE INTO THE GRID

It is known that all biomethane injected into the grid is metered, both for fiscal reasons, but also for operational reasons around gas transmission and distribution. If access to this data could be achieved then this would provide a more robust and accurate data set. Attempts were made in Phase 1 of the project to establish who the likely owner of this data set was, but were not successful, and were not pursued in Phase 2 as the scope of the project was narrowed to production of the new bioenergy model. However this could be a useful avenue of investigation for the DUKEs/RESTATs team to pursue.

The RESTATS/DUKES teams currently estimate of biomethane injected to the grid is based on a database of anaerobic digestion plant maintained by the National Non-Food Crops Centre which includes an estimate of biomethane injection capacity[22]. This is combined with assumptions about plant availability to generate an estimate of biomethane injected. Consultation with stakeholders in Phase 1 of the project identified an alternative database produced by the Anaerobic Digestion and Bioresources Association[23] which was found to have some additional information in it. This has been passed to the RESTATS team which will be incorporating this additional data in future thus improving estimates of biogas and biomethane production.

8.4 EMISSION FACTORS

No new emission factors were uncovered for non-CO_2 greenhouse gases, however, bioenergy combustion remains a small contributor to the national total. In the absence of available literature, it is not recommended that further resource is allocated to refining the emission factors for greenhouse gases.

Areas recommended for further review in the future:

- The review has highlighted that there are substantial variations in emission factors for metals for domestic wood burning and biomass use in other sectors. The values of the country-specific emission factors found in this study are much lower than the EMEP/EEA Guidebook factors but the original sources of these alternative factors were unclear and the current NAEI emission factors (which are based on the 2019 EMEP/EEA Guidebook) have been retained. A measurement programme for metals for biogenic energy sources may be helpful to develop representative emission factors for the UK.
- Emission factors in literature are generally for wood fuels with limited coverage of other types of solid biomass much of which is not relevant for UK use (types of biomass or technologies). A clearer understanding of the types of solid biomass used in the UK, areas of application and technology could allow adoption of literature emission factors or inform a focussed measurement programme for key sources and pollutants (for example PM species from use of straw in agriculture).
- Emission factors for liquid biofuels in stationary sources are extremely limited in literature and applicability to the UK is unclear. A clearer understanding of the types of liquid biofuels used in the UK and areas of application may allow adoption of literature emission factors or development of a focussed measurement programme for key pollutants (NO_x and PM species).
- UK emission factors for use of biogas are representative of technologies applied about 20 years ago (for landfill gas) but the regulatory landscape has changed. Implementation of medium combustion plant (all UK) and specified generator controls (England, Wales and Northern Ireland) will impact NO_x emissions. Emission monitoring associated with regulation may provide a means to develop NO_x emission factors which are more appropriate for current and future use of biogases. A measurement programme may need to be developed to obtain more representative emission factors for other pollutants.

[22] https://www.nnfcc.co.uk/publications/report-anaerobic-digestion-deployment-in-the-uk-24
[23] https://adbioresources.org/resources/ad-plant-database/

- Literature emission factors for charcoal are limited and applied emission factors are essentially for domestic wood use. A clearer understanding of the use of charcoal between domestic and commercial uses could allow a focussed measurement programme for key pollutants (PM species but also PAH, PCDD/F and metals).
- Limited emission factor information is available in literature for implementation of size-differentiated emission factors for biomass boilers, but would be possible based on type approval data for PM and potentially NO_x. In addition, emission limit values may be derived from Ecodesign type approval controls apply to wood boilers up to 500 kW output and there are UK controls on (clean) waste wood up to 1 MWth and; medium combustion plant (MCP) controls which apply to biomass use in plant equal to or greater than 1 MWth. Review of MCP emission monitoring data could allow development of emission factors for regulated pollutants (NO_x, PM and SO_2) however, implementation of size-differentiated emission factors for a wider range of pollutants would require development of a measurement programme.

APPENDIX 1 SUMMARY OF PROPOSED CHANGES FROM THE AIR QUALITY EMISSION FACTORS REVIEW TASK

Summary of proposed changes from the air quality emission factors review task (proposed changes are highlighted in grey; a '-' in a cell mean that the pollutant for that specific source & activity combination has not been reviewed due to prioritisation of review on more significant emission sources.

Source Name	Activity Name	NO_x	PM	SO_x	NMVOC	NH_3	As	Cd	Hg	B[a]P	BC	Dioxin	HCB
Domestic Combustion - Open Fireplace	Wood - Dry	EFDSF project will update these	EFDSF project will update these	EFDSF project will update these	EFDSF project will update these	Adopt 2023 Guidebook EFs from Chapter 1A4 Table 3.39 (See footnote [24])	Retain current EF from 2019 Guidebook which remain the same in 2023 Guidebook (See footnote[25]).	Retain current EF from 2019 Guidebook which remain the same in 2023 Guidebook (see footnote[26]).	Retain current EF from 2019 Guidebook which remain the same in 2023 Guidebook (see footnote[27]).	EFDSF project will update these	EFDSF project will update these	EFDSF project will update these	Retain current EF from 2019 Guidebook which remain the same in 2023 Guidebook.
Domestic Combustion - Open Fireplace	Wood - Seasoned	EFDSF project will update these	EFDSF project will update these	EFDSF project will update these	EFDSF project will update these	See above	See above	See above	See above	EFDSF project will update these	EFDSF project will update these	EFDSF project will update these	See above
Domestic Combustion - Open Fireplace	Wood - Wet	EFDSF project will update these	EFDSF project will update these	EFDSF project will update these	EFDSF project will update these	See above	See above	See above	See above	EFDSF project will update these	EFDSF project will update these	EFDSF project will update these	See above
Domestic Combustion - Closed Stove (Basic)	Wood - Dry	EFDSF project will update these	EFDSF project will update these	EFDSF project will update these	EFDSF project will update these	Adopt 2023 Guidebook EFs from Chapter 1A4 Table 3.40.	See above	See above	See above	EFDSF project will update these	EFDSF project will update these	EFDSF project will update these	See above

[24] For NH_3, the 2023 Guidebook factors are 8 g/GJ for open fireplaces burning wood, conventional stoves, high-efficiency stoves and 4 g/GJ for advanced / ecolabelled stoves. These EFs are lower than the 2019 Guidebook and are based on research in Germany and similar to current UK estimates. Alternative EFs available from Finland research but it looks wider in scope, so it is more defendable to adopt EFs from 2023 Guidebook.

[25] For As, alternative EFs are available from Finland IIR but original source is not provided and the EFs are very much lower than the Guidebook EF.

[26] For Cd, alternative EFs are available from Finland IIR but original source is not provided and the EFs are very much lower than the Guidebook EF. EFs from Canada IIR are similar order to Finland ones so the Guidebook EFs could potentially be too high but details of these alternative EFs were not found. Also to note that Canada EFs cover catalysts which is not relevant to UK (stove) fleet.

[27] For Hg, alternative EFs are available from Finland IIR but original source is not provided and the EFs are very much lower than the Guidebook EF. References of alternative EFs from Netherland IIR were not clear but they are similar order to the Guidebook EFs.

Source Name	Activity Name	NO_x	PM	SO_x	NMVOC	NH_3	As	Cd	Hg	B[a]P	BC	Dioxin	HCB
Domestic Combustion - Closed Stove (Basic)	Wood - Seasoned	EFDSF project will update these	EFDSF project will update these	EFDSF project will update these	EFDSF project will update these	See above	See above	See above	See above	EFDSF project will update these	EFDSF project will update these	EFDSF project will update these	See above
Domestic Combustion - Closed Stove (Basic)	Wood - Wet	EFDSF project will update these	EFDSF project will update these	EFDSF project will update these	EFDSF project will update these	See above	See above	See above	See above	EFDSF project will update these	EFDSF project will update these	EFDSF project will update these	See above
Domestic Combustion - Closed Stove (Upgraded)	Wood - Dry	EFDSF project will update these	EFDSF project will update these	EFDSF project will update these	EFDSF project will update these	Adopt 2023 Guidebook EFs from Chapter 1A4 Table 3.41.	See above	See above	See above	EFDSF project will update these	EFDSF project will update these	EFDSF project will update these	See above
Domestic Combustion - Closed Stove (Upgraded)	Wood - Seasoned	EFDSF project will update these	EFDSF project will update these	EFDSF project will update these	EFDSF project will update these	See above	See above	See above	See above	EFDSF project will update these	EFDSF project will update these	EFDSF project will update these	See above
Domestic Combustion - Closed Stove (Upgraded)	Wood - Wet	EFDSF project will update these	EFDSF project will update these	EFDSF project will update these	EFDSF project will update these	See above	See above	See above	See above	EFDSF project will update these	EFDSF project will update these	EFDSF project will update these	See above
Domestic Combustion - Closed Stove (EcoDesign)	Wood - Dry	EFDSF project will update these	EFDSF project will update these	EFDSF project will update these	EFDSF project will update these	Adopt 2023 Guidebook EFs from Chapter 1A4 Table 3.42.	See above	See above	See above	EFDSF project will update these	EFDSF project will update these	EFDSF project will update these	See above
Domestic Combustion - Closed Stove (EcoDesign)	Wood - Seasoned	EFDSF project will update these	EFDSF project will update these	EFDSF project will update these	EFDSF project will update these	see above	See above	See above	See above	EFDSF project will update these	EFDSF project will update these	EFDSF project will update these	See above
Domestic Combustion - Closed Stove (EcoDesign)	Wood - Wet	EFDSF project will update these	EFDSF project will update these	EFDSF project will update these	EFDSF project will update these	See above	See above	See above	See above	EFDSF project will update these	EFDSF project will update these	EFDSF project will update these	See above
Domestic Outdoor	Charcoal	-	Retain current EF based on expert judgment derived from IPCC	-	Retain current EF from 2019 Guidebook which remain the same in the	Adopt 2023 Guidebook EFs for wood and open fireplace from	Retain current EF from 2019 Guidebook which remain the same in	Retain current EF from 2019 Guidebook which remain the same in	Retain current EF from 2019 Guidebook which remain the same in	Align with EFDSF PAH EFs for open fires burning wood - not	Retain current EF (based on expert judgement from IPCC 2006	Align with EFDSF PCDD/F Efs for open fires burning wood -	Retain current EF from 2019 Guidebook which remain the same in

Source Name	Activity Name	NO_x	PM	SO_x	NMVOC	NH_3	As	Cd	Hg	B[a]P	BC	Dioxin	HCB
			2006 Guidelines (see footnote [28])		2023 version (see footnote [29])	Chapter 1A4 Table 3.39 (see footnote [30])	the 2023 Guidebook, as no alternative EFs found.	the 2023 Guidebook, as no alternative EFs found.	the 2023 Guidebook, as no alternative EFs found.	ideal but consistent with previous EF. Norway EFs have large variation.	Guidelines) and align with EFDSF EF when available.	not ideal but consistent with previous EF. Norway EFs have large variation.	the 2023 Guidebook, as no alternative EFs found.
Charcoal Production	Charcoal Produced	Retain current EF from IPCC 1996 Guidelines	Retain current EF from USEP AP-42	-	Retain current EF from IPCC 1996 Guidelines	-	-	-	-	**A potential B[a]P source but no EFs identified in study, may need further review.**	-	-	-
Power Stations	Wood	No change proposed as EFs generated from Pollution Inventory	No change proposed as EFs generated from Pollution Inventory	No change proposed as EFs generated from Pollution Inventory	No change proposed as EFs generated from Pollution Inventory	Modify to adopt EF from the 2023 Guidebook for pellet boilers (Chapter 1A4 Table 3-44, or 3-48)	No change proposed as EFs generated from Pollution Inventory	No change proposed as EFs generated from Pollution Inventory	No change proposed as EFs generated from Pollution Inventory	Propose lower EF based on average of 2019 Guidebook and the Denmark EF (see footnote [31]). Need to do similar for other PAH.	-	No change proposed as EFs generated from Pollution Inventory	-

[28] For PM EF (Domestic outdoor – charcoal use), current factor is likely high but no change is proposed. Netherland data were from 1994 but report is not accessible online so cannot review the basis of those values. No data for large industrial furnace (SNAP 01) or direct stoves not barbecues.

[29] For NMVOC EF (Domestic outdoor – charcoal use), current factor is likely high but no change proposed. Netherland data were from 1994 but report is not accessible online so cannot review the basis of those values. No data for large industrial furnace (SNAP 01) not barbecues.

[30] For NH_3 (Domestic outdoor – charcoal use), the Guidebook factor for wood and open fireplace is not directly applicable but no alternative data available. Lower NH_3 EFs in 2023 Guidebook version (compared to 2019 version) and the EF is based on research in Germany.

[31] For B[a]P (Power station – wood) – Denmark and Norway EFs are much lower than the 2019 Guidebook. The 2019 Guidebook EF is for wood/wood waste boiler with 'no controls or with PM controls'. Denmark EF is for CHP for wood/wood pellets (for one plant), Norway EF is for wood pellet boilers (but basis/original source is unclear).

Source Name	Activity Name	NO_x	PM	SO_x	NMVOC	NH_3	As	Cd	Hg	B[a]P	BC	Dioxin	HCB
Power Stations	Liquid Bio-fuels[32]	-	-	-	-	-	-	-	-	-	-	-	-
Power Stations	Poultry Litter	-	-	-	-	-	-	-	-	Retain current EF from 2019 Guidebook (remain the same in 2023 version)	-	-	-
Power Stations	Straw	-	-	-	-	-	-	-	-	Retain current EF from 2019 Guidebook (remain the same in 2023 version)	-	-	-
Agriculture - stationary combustion	Straw	Retain current EF from 2019 Guidebook which remain the same in the 2023 Guidebook (see footnote [33])	Adopt 2023 Guidebook EFs from Chapter 1A4, Table 3.10 (see footnote [34])	-	Adopt 2023 Guidebook EF from Table 3.10 for consistency with other pollutant EF sources.	-	-	-	-	Retain current EF from 2019 Guidebook which remain the same in the 2023 Guidebook. No alternative sources relevant for straw identified.	-	-	-
Autogenerators	Biogas	Retain current EFs (UK specific data). Priority for further review to	Adopt 2023 Guidebook EFs from Chapter 1A4, Table 3.30.	Retain current EFs (UK specific data). UK EF is similar order to	Change EFs - align to DK CHP report for biogas engines.	-	-	-	-	-	-	-	-

[32] Activity declined in general over time and no activity reported in years 2020 and 2021.

[33] For NOx (agriculture stationary combustion – straw), Denmark EF is for CHP while Norway EF has no formal reference, so recommend to retain current EF from the 2019 Guidebook.

[34] For PM (agriculture stationary combustion – straw), NAEI EF quite high for modern technology/RHI/MCP but likely consistent with overall use. Propose to adopt 2023 Guidebook Tier 1 EF in absence of activity split between large and smaller scale appliances.

<table>
<tr><th>Source Name</th><th>Activity Name</th><th>NO_x</th><th>PM</th><th>SO_x</th><th>NMVOC</th><th>NH_3</th><th>As</th><th>Cd</th><th>Hg</th><th>B[a]P</th><th>BC</th><th>Dioxin</th><th>HCB</th></tr>
<tr><td></td><td></td><td>reflect recent regulatory changes.</td><td></td><td>Denmark EFs.</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Autogenerators</td><td>Liquid Bio-fuels</td><td colspan="2">Adopt EFs from 2023 Guidebook for liquid fuel engines (Chapter 1A4 Table 3.31). Priority for further review as little information available.</td><td>Adopt EFs from 2023 Guidebook Tier 1 EFs for (solid) biomass (Table 3.10)[35]. Priority for further review as little information available.</td><td>Adopt EFs from 2023 Guidebook for liquid fuel engines (Chapter 1A4 Table 3.31). Priority for further review as little information available.</td><td>Adopt Efs from GB2023 Ef for (solid) biomass (T3.10)[36]. Priority for further review as little information available.</td><td colspan="7">Adopt EFs from 2023 Guidebook for liquid fuel engines (Chapter 1A4 Table 3.31). Priority for further review as little information available.</td></tr>
<tr><td>Autogenerators</td><td>Plant Biomass</td><td colspan="12">New source & activity combination for the NAEI. Adopt EFs from 2023 Guidebook for automatic biomass boilers (Chapter 1A4, Table 3.48).</td></tr>
<tr><td>Autogenerators</td><td>Animal Biomass</td><td colspan="12">New source & activity combination for the NAEI. Adopt EFs from 2023 Guidebook for automatic biomass boilers (Chapter 1A4, Table 3.48).
Priority for further review as little information available.</td></tr>
<tr><td>Other Industrial Combustion</td><td>Biogas[37]</td><td rowspan="4">Retain current EFs (UK specific data). Priority for further review to reflect recent regulatory changes.</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td></tr>
<tr><td>Food & drink, tobacco (combustion)</td><td>Biogas</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td></tr>
<tr><td>Pulp, Paper and Print (combustion)</td><td>Biogas</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td></tr>
<tr><td>Agriculture - stationary combustion</td><td>Biogas</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td></tr>
</table>

[35] The Tier 1/Tier 2 SO_x EF from 2023 Guidebook are not appropriate as very limited sulphur in liquid bio-fuels, so propose to adopt 2023 Guidebook Tier 1 EFs for (solid) biomass.

[36] No Tier 2 EF nor Tier 1 EF for liquid fuel from the 2023 Guidebook, so propose to adopt 2023 Guidebook Tier 1 EFs for (solid) biomass.

[37] Biogas activity data are currently reported as zero for the following NAEI sources: Mineral products (other): combustion, Chemicals (combustion), Construction (combustion), Electrical engineering (combustion), Iron and steel - combustion plant, Mechanical Engineering (combustion), Non-Ferrous Metal (combustion), Textiles and leather (combustion), Road transport - all vehicles biofuels use, Miscellaneous industrial/commercial combustion, Public sector combustion.

Source Name	**Activity Name**	**NO_x**	**PM**	**SO_x**	**NMVOC**	**NH_3**	**As**	**Cd**	**Hg**	**B[a]P**	**BC**	**Dioxin**	**HCB**
Other Industrial Combustion	Plant Biomass [38]	Apply current biomass EF – UK specific (see footnote [39])		Apply current biomass EF from 2019 Guidebook, chapter 1A2, Table 3-5 (which remain the same in 2023 version)	Apply current biomass EF – UK specific (see footnote [40])	Adopt 2023 Guidebook EF (Chapter 1A4, Table 3.48)[41].	Apply current biomass EF from 2019 Guidebook, chapter 1A2, Table 3-5 (which remain the same in 2023 version). The Guidebook EFs are high compared to values reported by other countries but sources of these alternative EFs are unclear.			-	Apply current biomass EF – UK specific (see footnote for PM); alternative EFs from other countries are primarily for residential appliances	Apply current biomass EF – UK specific[42]	-
Food & drink, tobacco (combustion)	Plant Biomass	See above	-	-	-	-	-	-	-	-	-	See above	-
Mineral products (other): combustion	Plant Biomass	See above	See above	See above	See above	-	-	See above	-	-	See above	See above	-
Pulp, Paper and Print (combustion)	Plant Biomass	See above	See above	See above	See above	-	-	See above	-	-	See above	See above	-
Chemicals (combustion)	Plant Biomass	See above	-	-	-	-	-	-	-	-	-	See above	-
Agriculture - stationary combustion	Plant Biomass	See above	See above	-	-	-	-	See above	-	-	-	-	-

[38] Plant biomass activity data are currently reported as zero for the following NAEI sources: Construction (combustion), Electrical engineering (combustion), Iron and steel - combustion plant, Mechanical Engineering (combustion), Non-Ferrous Metal (combustion), Textiles and leather (combustion), Road transport - all vehicles biofuels use, Miscellaneous industrial/commercial combustion, and Public sector combustion.

[39] The current NAEI NO_x factor for biomass is generated from reported emissions for large combustion plant and certain types of furnaces, combined with 2019 EMEP/EEA Guidebook factors for other medium and small plant. See Passant, N. & Stewart, R., NO_x & PM_{10} Emissions from Industrial-Scale Combustion in the UK, Ricardo Energy & Environment, October 2020. EFs from other countries IIR are a mix of sources but not offering less uncertain data.

[40] The current NAEI NMVOC factor is generated from derived fuel split large, medium and small combustion plant and certain types of furnaces, combined with 2019 EMEP/EEA Guidebook factors. Alternative EFs from other countries IIR assume large plant or wood pellet combustion; Netherland EFs are lower and may offer improvement and are classified by size (up to 5MW) but original source is unclear and may not reflect wide range of technology and fuels in UK.

[41] Current NAEI EF (originated from 2019 Guidebook) is very similar to 2023 Guidebook EF.

[42] For information, Canada/US EPA EFs are for general wood combustion in sawmills, Finland data is for residential appliances (large plant EF derived from USEPA), Denmark data is larger than the 2019 Guidebook while Norway data for boiler is similar to the Guidebook.

Source Name	Activity Name	NO_x	PM	SO_x	NMVOC	NH_3	As	Cd	Hg	B[a]P	BC	Dioxin	HCB
Other Industrial Combustion[43]	Animal Biomass	New source & activity combination for the NAEI. Adopt EFs from the 2023 Guidebook for automatic biomass boilers (chapter 1A4, Table 3.48). **Priority for further review as little information available.**											
Other Industrial Combustion	Liquid Bio-fuels	Adopt EFs from 2023 Guidebook for liquid fuel boilers (chapter 1A4, Table 3.24). **Priority for further review as little information available.**		Adopt EFs from 2023 EF Guidebook for (solid) biomass (Table 3.10) [44]. **Priority for further review as little information available.**	Adopt EFs from 2023 Guidebook for liquid fuel boilers (chapter 1A4, Table 3.24). **Priority for further review as little information available.**	Adopt EFs from 2023 Guidebook for liquid fuel boilers (chapter 1A4, Table 3.10) [45]. **Priority for further review as little information available.**	Adopt EFs from 2023 Guidebook for liquid fuel boilers (chapter 1A4, Table 3.24). **Priority for further review as little information available.**						
Heat supply	MSW												
Power Stations	MSW	-	-	-	-	-	-	-	-	-	-	-	Retain current EF[46] (as no alternative EF identified)
Power Stations	Landfill gas	Retain current EFs (UK specific data). **Priority for further review to reflect recent regulatory changes.**	Change EFs - align to 2023 Guidebook, chapter 1A4, Table 3.30.	Retain current EFs (UK specific data).	Change EFs - align to Denmark CHP report for biogas engines [47]	-	-	-	-	-	-	-	-

[43] This also applies to animal biomass use for other sectors including: Mineral products (other): combustion and Agriculture - stationary combustion (where activity data are reported).

[44] The 2023 Guidebook Tier 1/Tier 2 EFs for liquid fuel boilers have higher sulphur contents than typical for liquid bio-fuels, therefore recommend to adopt Tier 1 EF for (solid) biomass.

[45] The 2023 Guidebook Tier 1/Tier 2 EFs for liquid fuel boilers (Table 3.24) do not have NH_3 EF, therefore recommend to use Tier 1 EF for (solid) biomass.

[46] Reference from 1997 paper Berdowski, J.J.M., Veldt, C., Baas, J., Bloos, J.P.J & Klein, A.E., 1995: Technical paper to the OSPARCOM-HELCOM-UNECE emission inventory of heavy metals and persistent organic pollutants. Umweltbundesamt, Berlin, Germany. Not available online. Note that this predates controls on EU incineration plant.

[47] Denmark CHP includes biogas factors that should be applicable to the UK.

Source Name	Activity Name	NO_x	PM	SO_x	NMVOC	NH_3	As	Cd	Hg	B[a]P	BC	Dioxin	HCB
Heat supply	Landfill gas	See above	See above	See above	-	-	-	-	-	-	-	-	-
Power Stations	Sewage gas	See above	See above	See above	-	-	-	-	-	-	-	-	-
Heat supply	Sewage gas	See above	See above	See above	-	-	-	-	-	-	-	-	-
Chemicals	Wood	New source & activity combination for the NAEI. Adopt EFs from 2023 Guidebook for automatic biomass boilers (Chapter 1A4, Table 3-48).											
Food & drink	Wood	See above											
Mineral products	Wood	See above											
Paper, pulp & printing	Wood	See above											
Unclassified and other industries	Wood	See above											

T: +44 (0) 1235 75 3000

E: info@ricardo.com

W: www.ricardo.com