Carbon factors of biofuels

Final Report

Prepared by Ricardo Energy & Environment for the Department for Business, Energy and Industrial Strategy

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NAEI in Confidence

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1 Introduction

Carbon dioxide emissions originating from the combustion of biofuels are reported to the United Nations Framework Convention on Climate Change (UNFCCC) as part of the UK's Greenhouse Gas Inventory (GHGI) submission, but do not contribute to the national total. Currently, emissions are calculated using fuel combustion statistics, predominantly from the Digest of UK Energy Statistics (DUKES), and a suitable emission factor. The carbon emission factors currently in use are largely taken from the 2006 Intergovernmental Panel on Climate Change (IPCC) Guidelines, the Joint Research Centre (JRC) and Concawe's "Well to Wheels" report (2014), or derived from industrial regulator inventories (e.g. the Environment Agency's Pollution Inventory). Estimated emissions of CO_2 from biofuels have increased from around 3 Mt CO_2 in 1990, to around 38 Mt in 2016. The relative contribution of sources has also changed significantly, with wood combustion in power stations now accounting for approximately 34% of bio-carbon emissions, and biofuels in road transport accounting for approximately 8%. There were no emissions from these sources in 1990.

Determining more accurate data on bio-carbon emissions is important for the national and sub-national inventories, company reporting factors outputs for corporate reporting and to improve the underpinning evidence-base for Government policy development such as the imminent Bioenergy Strategy and the Climate Change Committee's review of advice to Government on bioenergy.

1.1 Summary of Current Understanding

Carbon dioxide of biogenic origin is not mandatory to report in national greenhouse gas inventories, hence, estimating these emissions have been a low priority and the UK National Atmospheric Emission Inventory (NAEI) estimates of biogenic carbon are less complete and robust than the rest of the inventory.

Table 1 presents the current emission factors for carbon of biogenic origin used in the NAEI. The biofuels are grouped alphabetically in the first column, by source. The contribution to total biogenic Greenhouse Gas (GHG) emissions is presented, to allow the relative importance of the biogenic carbon factor to be identified. Uncertainties associated with the biogenic Carbon Emission Factors (CEFs) have been made by expert judgement. Biogenic CEFs with a large relative contribution and a large uncertainty have been prioritised in this study.

Table 1 Current Emission factors for carbon of biogenic origin used in the NAEI

Biofuel	Source	Biogenic C contribution[1]	Biogenic CEF uncertainty[2]	Biogenic CEF	Units	Reference[3]
Biodiesel[4]	Road transport	6%	Low	772	kt/Mt	JRC and Concawe "Well to wheels report" version 4a (2014), Appendix 1, table 2.2
Bioethanol	Road transport	2.6%	Low	521	kt/Mt	JRC and Concawe "Well to wheels report" version 4a (2014), Appendix 1, table 2.2
Biogas[5]	Autogenerators	1.4%	Medium	1.41	kt/Mth	Table 2.2, Volume 2, 2006 IPCC Guidelines
Biogas[6]	Domestic combustion	Low	High	IE	N/A	N/A
Biomass	Other industrial combustion	8%	High	401	kt/Mt	Table 2.2, Volume 2, 2006 IPCC Guidelines
Charcoal	Domestic combustion	1.6%	Medium	901	kt/Mt	Table 2.5, Volume 2, 2006 IPCC Guidelines
Landfill gas	Miscellaneous industrial/commercial combustion	0.3%	Medium	1.41	kt/Mth	Table 2.2, Volume 2, 2006 IPCC Guidelines
Landfill gas	Power stations	15%	Medium	1.41	kt/Mth	Table 2.2, Volume 2, 2006 IPCC Guidelines
Liquid bio-fuels	Power stations	0.5%	Medium	772	kt/Mt	JRC and Concawe "Well to wheels report" version 4a (2014), Appendix 1, table 2.2
Municipal Solid Waste (MSW)	Miscellaneous industrial/commercial combustion	Medium	High	NE	N/A	N/A
MSW	Power stations	High	High	NE	N/A	N/A
Poultry litter	Power stations	4%	Medium	272	kt/Mt	Bio-carbon emission factor based on Pollution Inventory data, Environment Agency and Scottish Pollutant Release Inventory (SPRI) data from the Scottish Environment Protection Agency (SEPA) (both 2017)

[1] The is of total bio-carbon emissions between 1990 and 2016, where biogenic emissions are not estimated, a qualitative assessment is made
[2] Qualitative expert judgement; sources which are currently not estimated are automatically assigned a 'high'
[3] References are for the 2016 factor, in most cases this will be the same for earlier years. Note that many of the factors will have been converted from the original units presented in the reference, in particular the IPCC guidance factors.
[4] Currently used for all biofuels blended with diesel, e.g. hydro treated vegetable oil, fatty acid methyl ester
[5] Derived from anaerobic digesters
[6] This is biogas injected into the natural gas distribution network, included in the DUKES natural gas commodity balance for the first-time in DUKES 2017. The UK GHGI 2018 submission does not account for this yet. Therefore the current UK GHGI estimates of natural gas emissions include a small amount of biogas that are reported as fossil carbon.

Biofuel	Source	Biogenic C contribution[1]	Biogenic CEF uncertainty[2]	Biogenic CEF	Units	Reference[3]
Scrap tyres	Cement production - combustion	Low	High	NE	N/A	N/A
Scrap tyres	Other industrial combustion	Low	High	NE	N/A	N/A
Scrap tyres	Power stations	Low	High	NE	N/A	N/A
Sewage gas	Power stations	2.6%	Medium	1.41	kt/Mth	Table 2.2, Volume 2, 2006 IPCC Guidelines
Sewage gas	Public sector combustion	0.8%	Medium	1.41	kt/Mth	Table 2.2, Volume 2, 2006 IPCC Guidelines
Smokeless Solid Fuel (SSF)	Domestic combustion	Low	High	NE	N/A	N/A
SSF	Other industrial combustion	Low	High	NE	N/A	N/A
Straw	Agriculture-stationary combustion	3.0%	Medium	365	kt/Mt	Table 2.2, Volume 2, 2006 IPCC Guidelines
Straw	Power stations	1.5%	Medium	384	kt/Mt	Bio-carbon emission factor based on Pollution Inventory data, Environment Agency and SPRI data from SEPA (both 2017)
Waste	Cement production - combustion	Medium	High	NE	N/A	N/A
Wood	Domestic combustion	24%	Medium	401	kt/Mt	Table 2.2, Volume 2, 2006 IPCC Guidelines
Wood	Other industrial combustion	11%	Medium	518	kt/Mt	Table 2.2, Volume 2, 2006 IPCC Guidelines
Wood	Power stations	17%	Medium	401	kt/Mt	Table 2.2, Volume 2, 2006 IPCC Guidelines

Key:

IE - 'Included elsewhere', means that emissions are expected to be included in the inventory, but is included in a different reporting category

NE - 'Not Estimated', means that emissions do occur in the UK, but are not currently estimated. This is allowed under IPCC guidelines for very insignificant emission sources. Note that biogenic carbon is non-mandatory for reporting in national emission inventories.

Mth - Megatherms, an imperial unit of energy used in the NAEI

MSW - Municipal Solid Waste

SSF - Solid Smokeless Fuel

1.2 Literature Review and References

A review of the scientific literature was conducted to try and identify if there were any recent reviews of the carbon emission factors for biofuels. Over 100 papers were identified, and examined. The review was extended to include biomethane also. The review revealed a surprising lack of relevant scientific literature, and no review papers were identified. The search revealed a number of papers that reported studies on air quality emissions from the combustion of biomass and biofuels, but essentially nothing about bio-carbon emissions was identified. This lack of evidence probably reflects the fact that in recent years the focus of research has mainly been into emissions of the direct and indirect GHGs, and, the air quality pollutants.

Table 2 Summary of literature sources of value to this project

Title	Date	Organisation	Lead Author	Relevant information
Review of landfill methane emissions modelling	2014	Golder Associates	Robert Gregory et al.	Landfill gas composition data
Well-to-wheels analysis of future automotive Fuels and powertrains in the European context	2014	JRC	Robert Edwards et al	Road transport biofuel and blending agent parameters
Determination of the Biomass Content of End-of-Life Tyres	2017	InTech	Muñoz, Adrien Zambon et al.	C^{14} analysis of carbon in scrap tyres
Phyliss2 Data	Various	ECN Biomass & Energy Efficiency	Various	Carbon and other compositional analysis for various solid biomass and waste-derived products
Renewable Transport Fuel Obligation (RTFO) statistics	Annual	Department for Transport (DfT)	N/A	Annual statistics on UK use of road transport biofuels.

1.3 Stakeholder Consultation

Table 3 Summary of stakeholder consultation

Stakeholder	Key input
Department for Business, Energy and Industrial Strategy (BEIS) biofuels team	No new key information for this project.
DUKES team (BEIS)	Clarifications on DUKES, and flagged other biofuel reporting mechanisms
DfT Environmental statistics for transport team	Flagged publications on RTFO data
Environment Agency (EA) European Union Emissions Trading Scheme (EU ETS) team	Clarifications on EU ETS reporting of biogenic carbon and biofuels
Environmental manager for a group of power stations burning biofuels	No new key information for this project.
Carbon Accounting Workbook (CAW, used by water sector to report emissions to regulators) team	General discussion of waste water biogas processes
Clean Air Act and Smoke Control Area consultant	Provided background on SSF
Renewable Energy STATisticS (RESTATS)	Provided background on RESTATS' data sources and assumptions.
Biofuels consultant	General discussion and contacts around biofuels. Flagged the Phyllis2 database.
Anaerobic digestion consultant	Provided background on anaerobic digestion biogas processes, data and potential methods of estimating emissions.

1.4 Summary of study recommendations

Table 4 Summary of study recommendations

Fuel	Recommendation
MSW and Solid Recovered Fuel (SRF)	Apply IPCC default to biogenic fraction of MSW; consider using landfill compositional data to generate a more refined and year-dependent factor.
SSF	Low priority for consideration of looking into the market shares of SSF products and analysing the ingredients to determine a bio-carbon content of individual SSF products.
Scrap Tyres	Apply bio-carbon factor for cement kilns to other users of scrap tyres. Consider further analysis of EU ETS data.

Fuel	Recommendation
Biodiesels	The factor currently applied is sufficient. Consider using a separate factor for an emerging type of bio-diesel.
Bioethanol	No further work required.
Bio-MTBE and biomethanol	Consider separately estimating these products' activity and apply product-specific factors.
Biogases (landfill gas, sewage gas, other biogases)	Apply an IPCC default factor to biogas injected into the national natural gas network. Revise the landfill gas and other biogas factors. Consider improving other biogas factors by modelling national biogas generation and composition or collecting data from sites.
Charcoal	No further work required.
Liquid biofuels (for stationary combustion)	No further work required.
Other biomass used in power stations (poultry litter, straw)	Review again when DUKES reflects ongoing work on resolution of biofuels data.
Wood/solid biomass	Review sectoral resolution of activity data, the types of wood used for domestic appliances. Make greater use of ETS data.

2 Project findings by mixed fuel

There are several fuels known to contain carbon of both fossil and biogenic origin. Where these fuels are derived from either mixed fossil-biogenic waste streams or are manufactured fuels that may have variable raw material recipes in their composition, the fossil-biogenic split of carbon will also differ over time and between installations. For these fuels the UK GHG inventory approach must seek to determine the origin of the carbon (fossil or biogenic) as far as practicable, in order that emissions can be correctly allocated in the UK inventory submission, i.e. within the national total for emissions derived from fossil carbon, and in the memo items for emissions from biogenic carbon.

Inventory good practice is to aim to report fossil carbon emissions that are neither over- nor under-estimated as far as can reasonably be judged, and to minimise uncertainties in the national (fossil carbon) inventory. In some instances, the current UK inventory agency practice is to err on the side of conservative estimates – i.e. where there is a large range of fossil-biogenic % split in the data and high uncertainty, we assume higher fossil carbon emissions (within national totals) and lower biogenic emissions (within memo items).

2.1 Municipal Solid Waste and Solid Recovered Fuel

2.1.1 Current understanding and known challenges

MSW, by its nature, has a highly varied composition of composite materials of both fossil and biogenic origin. Policy changes also mean that the composition is likely to vary in the UK's devolved administrations and with time. Some wastes are processed to generate a product that burns more efficiently, for example, cement kilns tend to use SRF derived from MSW. These products typically have a much higher carbon content than unprocessed MSW.

The UK currently only estimates emissions from the fossil component of burning wastes for energy. There are activity data and bio-carbon emission factors available from the Mineral Products Association on biofuels and mixed (bio- and fossil) fuels, which reflects the utilisation of these fuels across all UK cement manufacturers in recent years. The EU ETS dataset also includes operator reporting of fuel activity and (in some cases) bio-carbon emission factors and Net Calorific Values (NCVs) from across a wide range of industries using waste-derived fuels, but these data are somewhat incomplete and inconsistent. Based on currently available datasets it is therefore not practicable to access regular, representative data on mixed fuel compositions for most UK source categories.

2.1.2 Findings in this project

Consultation with the RESTATS team, which collects data on renewables to feed into UK energy statistics, has clarified that DUKES reporting of waste-derived fuels now includes estimates of MSW of biogenic origin in a separate line from total MSW. These activity data estimates are based on periodic compositional analysis of MSW, and while there may be steps in the fossil-bio split in the time-series when these analyses are updated, the trends in analysis outputs are considered by the RESTATs team to be representative of real trends in UK MSW composition. Even in the absence of any UK-specific CEFs, it is therefore possible to estimate biogenic carbon dioxide emissions from MSW by applying the IPCC default factor for the biogenic component of MSW to the fraction of MSW identified as biogenic in DUKES. We propose that future inventory submissions should include such estimates (or estimates derived from UK-specific CEFs if available) in order to address the current gap in the UK GHGI bio-carbon inventory for MSW.

Consultation with the NAEI waste expert confirms that it is reasonable to assume that the composition of MSW sent to landfill is comparable to MSW sent to incinerators, as these are both disposal streams for residual wastes that have already had potential recyclables removed. This means that the compositional data presented by the UK's environment agency and devolved agencies on waste sent to landfill should be applicable for use in estimating the composition of incinerated MSW.

Analysis of the data reported in the EU ETS Phase III (2013-2016 data) and also from the Mineral Products Association (MPA) has identified a number of findings for waste-derived mixed fuels:

- Typically, over 300,000 tonnes per year of waste-derived fuels are used in UK cement kilns, and through EU ETS a very high proportion of these wastes are analysed for their carbon composition and to determine the fossil-bio split. EU ETS provides CEFs and NCVs for a range of fuels, with the weighted average values ranging across the 4 years from 251 to 283 t bio-C per kt waste-derived fuel. These data are closely consistent to the MPA data.
- There are insufficient data in the EU ETS for any other sector currently, to provide mixed fossil-bio waste analysis to inform bio-CEFs. The reported levels of activity are relatively low except for a small number of sites, and there are therefore only limited CEF data from compositional analysis by EU ETS operators. These may not be representative, and we propose that IPCC defaults would be the more defensible option to generate UK estimates currently**.**

2.1.3 Suggestions for future work

We recommend that the IPCC default could be applied to the biogenic fraction of MSW to improve the completeness of the UK bio-carbon inventory. If a more robust estimate of MSW carbon content is required, we recommend a methodology based on the composition of MSW as set out below.

The composition of waste sent to incinerators is likely to be similar to waste sent to landfill, as both are residual wastes after recyclable materials have been removed. This means that the composition data presented in the EA waste interrogator – and similar from Natural Resources Wales (NRW), SEPA and the Department of Agriculture, Environment and Rural Affairs (DAERA) – for waste sent to landfill could be used to estimate incinerator waste composition. This could be combined with waste-category specific carbon factors, for example from Phyllis2, a database for biomass and waste data[7].

For the cement sector there are EU ETS and MPA data that could be readily used to add new estimates to the UK inventory. This could be implemented as part of an update to NAEI renewable and waste fuel models, and would improve the completeness of both the GHG and Air Quality (AQ) inventories.

2.2 Smokeless Solid Fuel

2.2.1 Current understanding and known challenges

SSF is a derived solid fuel, designed to be suitable for burning in smoke control areas, typically composed of hard, anthracitic coals. There are a large number of SSF brands available in the UK, and these are typically generated either via a heat-treatment to drive off volatiles from fossil materials, or through a cold-pressed manufacturing method to combine fossil or bio-fuel components using a binder. Recent consultation by the NAEI team with the Coal Merchants Federation (CMF) has indicated that the share of the market for each brand and the precise composition of each type of SSF is uncertain. Therefore, the current UK inventory estimates are regarded as uncertain.

2.2.2 Findings in this project

Consultation with the Smokeless Control Areas Team in Ricardo that provides support to applications for smokeless fuels and appliances on behalf of Defra has indicated that:

- Defra's smoke control website[8], provides all authorised fuels' (i.e. smokeless fuels) documentation, including ingredients;
- Typically, these fuels primarily comprise of anthracite, petroleum coke or other hard coals, mixed with other petroleum products like petroleum wax;
- Many SSFs include some biological content, and, particularly recently, there have been a handful of primarily biogenic SSFs, often using petroleum products as a binder; and,
- Data are not readily available on the market share of these products, but likely sources of useful data are the CMF and leading fuel distributors such as CPL.

2.2.3 Suggestions for future work

If an estimate of the biogenic carbon emissions, and potentially an improvement to the fossil carbon estimate, is required, we recommend that BEIS consider further periodic consultation with organisations

[7] A spreadsheet table with a selection of collated Phyllis2 emission factors is presented alongside this report
[8] https://smokecontrol.defra.gov.uk/fuels.php?country=all

such as CMF and CPL to estimate the market shares of the various SSF products and seek market intelligence on annual UK sales of SSF, to derive an estimated breakdown of SSF use by type. This could then be combined with an estimated biogenic and fossil carbon content for each product type to determine an improved estimate of fossil and bio-carbon emissions. Note that we do not consider it likely that this is a major source of bio-carbon emissions missing from the inventory.

Noting the impact that SSF combustion has on AQ emissions (such as metals), such research may be considered in conjunction with the Department for Environment, Food & Rural Affairs (Defra). Even if more accurate activity estimates cannot be obtained, it would still be useful to seek industry insights into the trends of SSF composition, for recent years and to help inform projections.

2.3 Scrap Tyres

2.3.1 Current understanding and known challenges

Due to the high carbon content, scrap tyres have a high energy content, comparable to a hard coal. In the UK, the main use of scrap tyres as a fuel is in the cement sector.

Data provided annually to the inventory agency by the MPA includes cement sector estimates for scrap tyre activity data, fossil carbon emissions and bio-carbon emissions, with the fossil-bio split derived from a standard industry assumption that 27.8% of all carbon in tyres is bio-carbon, the rest fossil. The UK inventory currently includes the fossil carbon emissions, but no estimate is made for the bio-carbon emissions and this is therefore a gap in the UK inventory memo items.

No other sector-specific estimates of scrap tyre use are readily available, and no other estimates are included in the inventory.

2.3.2 Findings in this project

Consultation with the UK regulators for EU ETS (Walker, personal communication 2018) regarding the biogenic content of tyres has sourced a reference for C^{14} testing of scrap tyres[9] that indicates the biomass content to be in the range of 18–22% for passenger car tyres and 29–34% for truck tyres.

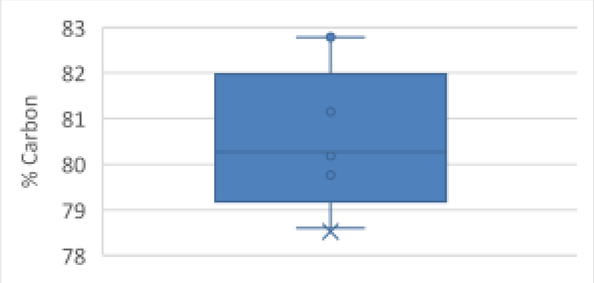
Analysis of installation-level EU ETS data and comparison of the findings against the sector-wide MPA data indicates a closely consistent dataset of activity data and carbon emission factors for fossil and bio-carbon across the 2013-2016 data. This provides reassurance that the scrap tyre activity data used in the inventory are accurate and complete for the sector. However, the derivation of the CEF by all operators is not based on annual compositional analysis but rather all operators use the industry protocol of 27.8% bio-carbon content and a national default factor for total scrap tyre carbon content, instead of any compositional analysis. EU ETS and MPA fuel compositional data show close consistency, and the range of bio-CEFs across 2013-2016 is: 172 – 179 t bio-C per kt scrap tyres.

EU ETS data for other source categories indicates scrap tyre use within a number of other industrial sectors such as lime kilns and electric arc furnaces. While these are very small users of tyres in comparison to the cement sector, these are nevertheless small gaps in the UK GHG inventory memo items. These data are also very useful as they include a high proportion of Tier 3 analysis for the CEF, NCV and the bio-carbon share of the total CEF. These data indicate that the CEF applied in the cement sector is conservative (i.e. higher than that from the analysis by other industry operators) and also that the biogenic share applied in the cement sector is lower than that derived for other sectors (30-37%). These two parameter comparisons indicate therefore that the UK inventory may slightly over-estimate fossil emissions from scrap tyre use, and under-estimate the bio-carbon emissions in the memo items.

Combining the above industry standard assumption with the reported fossil carbon emission factor based on reported data in ETS, derives a total carbon content of approximately 650 kt per Mt fuel consumed. This is notably lower than the Phyllis2 data presented in **Figure 1** suggests.

[9] https://www.intechopen.com/books/biomass-volume-estimation-and-valorization-for-energy/determination-of-the-biomass-content-of-end-of-life-tyres

Figure 1 Scrap tyres carbon contents on a dry matter basis extracted from Phyllis2[10]



2.3.3 Suggestions for future work

In the absence of UK-specific CEFs based on compositional analysis, we recommend applying the bio-CEFs from MPA and EU ETS data for cement kilns to all scrap tyre AD.

To ensure completeness of inventory reporting, we recommend that BEIS considers the EU ETS estimates for other industrial combustion sectors in future DUKES compilation. This will ensure complete activity data in DUKES and the inventory, with memo item estimates added for the bio-carbon component of those tyres also.

Given the minor significance of bio-carbon emissions from scrap tyres in the UK context, we do not consider it a high priority to progress sampling and analysis of scrap tyre composition, nor to seek additional data on the breakdown of car and truck tyre combustion to enable derivation of emissions at a greater level of resolution. This should be periodically reviewed, and new sampling and analysis progressed in the event that tyre composition alters notably in future. We would, however, suggest that the discrepancy between the Phyllis2 dataset and those presented by the MPA and in EU ETS warrants further investigation.

3 Project findings by biogenic fuel

3.1 Biodiesels

3.1.1 Current understanding and known challenges

Biodiesels are fuels that can be blended with (or completely substitute) diesel. Total use of biodiesels is reported in DUKES. It's known that there are several products that can be described as biodiesel and these products can have significantly different properties, for example Hydro treated Vegetable Oil (HVO), Fatty Acid Methyl Ester (FAME).

3.1.2 Findings in this project

Statistics published as part of the RTFO confirm that FAME is by far the most used biodiesel in the UK, making up at least 98.9% of all use in the UK for each year since 2011. However, we believe that HVO, which according to RTFO statistics currently makes up most of the remaining biodiesel, will make an increasingly significant share of biodiesel use in future.

The current factor used in the NAEI is a FAME-specific factor. The same report from which we get the FAME factor (JRC and Concawe, 2014), also presents a factor of 850 kt per Mt fuel for HVO, which is 10% higher than FAME.

3.1.3 Suggestions for future work

We consider it reasonable to assume all biodiesel is FAME for the historic inventory to date. However, it may be worth considering separating HVO using the RTFO statistics and applying an HVO-specific factor to future-proof the NAEI methodologies and periodically reviewing whether other biodiesels should be estimated separately.

3.2 Bioethanol

3.2.1 Current understanding and known challenges

Bioethanol is a fuel primarily used for blending with road petrol, and total use in the UK is reported in DUKES. Bioethanol has a very specific chemical composition, which means carbon content can be determinable by stoichiometric analysis and should not vary.

[10] Note that these data are total carbon, rather than fossil only. Also, there was an outlier of 60.9% C which can't be seen in the graph as displaying a range to include this would be difficult to make out the area of interest

3.2.2 Findings in this project

Statistics published as part of the RTFO confirm that bioethanol is by far the most used biogenic petrol blending agent in the UK, making up at least 92% of all use in the UK for each year since 2011. However, it was noted that Methyl Tert-Butyl Ether (MTBE) of biogenic origin and biomethanol are non-trivial components (which are discussed in more detail in **Section 3.3**), making up to 7% and 4% respectively since 2011.

The current UK factor is specific to ethanol, and we have confirmed that this is consistent with the chemical composition of ethanol.

3.2.3 Suggestions for future work

Given the specific chemical composition of this product we do not believe that any further work is required as the carbon content will not change in future.

3.3 Bio-MTBE and biomethanol

3.3.1 Current understanding and known challenges

MTBE and methanol are oxygenates blended with petrol, which can be derived from fossil or biogenic sources. Similar to bio-ethanol, MTBE and methanol have specific chemical compositions, so carbon content can be determinable by stoichiometric analysis and should not vary. As mentioned in **Section 3.2.2**, the RTFO suggests that MTBE and biomethanol of biogenic origin are small, but non-trivial shares of petrol blending agent use in the UK, these are also not currently included in the NAEI.

3.3.2 Findings in this project

Stoichiometric analysis derives factors of 682 and 375 kt C per kt fuel used for bio-MTBE and biomethanol respectively.

Activity data are available from the RTFO for 2011 onwards, which could be integrated into DUKES and inventory models. Note that estimates of biofuels used for road transport are currently based on HM Revenue & Customs (HMRC) data, which may have differences in scope to the RTFO data (although our analysis suggests that HMRC data likely excludes bio-MTBE and biomethanol) and that carbon emissions from these fuels make up less than 140 kt CO_2 in any given year, compared to up to 1250 kt CO_2 for bio-ethanol.

3.3.3 Suggestions for future work

Whilst these fuels are minor sources in the UK context currently, there is the possibility that their use will increase in significance in future. We therefore recommend that BEIS considers integration of these data into DUKES and to add these activities into an upgraded inventory waste and renewable model, for completeness and to aid future tracking of uptake of biofuels (primarily in the transport and off-road mobile machinery sectors).

3.4 Biogases (landfill gas, sewage gas, other biogases)

3.4.1 Current understanding and known challenges

Biogases are gases generated by bacteria breaking down biological material in an oxygen-free environment. They primarily comprise carbon dioxide and methane, of which methane makes the product an effective fuel. The key challenge for biogas is understanding the CO_2-CH_4 split, as determining this allows you to understand the result of combusting it.

Biogases are derived from capturing landfill gas, from anaerobic treatment of sewage sludge, and more recently at dedicated anaerobic digesters using biological waste or purpose-grown crops as a feedstock. Recently, some biogases have been enriched and injected into the UK natural gas network. UK biogas production and use are reported in DUKES, presented as landfill gas, sewage gas and other biogas. Whilst the activity is very small currently, DUKES also presents annual activity data on the injection of biogas into the UK natural gas network, which is anticipated to increase in future.

The generation, use and reporting of biogas as a fuel (and to generate electricity) has been tracked and reported consistently for landfill gas and sewage gas in the UK for many years. Discrete, regulated industry sectors are responsible for managing and reporting activities, with financial mechanisms established to incentivise and aid tracking of biogas generation and utilisation, and with established data reporting mechanisms in place. The same cannot be said for many of the emerging sources of biogas across a wide range of industries, which often may be smaller scale, with technologies less widely utilised across a given sector. There is a higher level of uncertainty that all UK activity is captured and reported for these emerging sources of other biogas. The EU ETS provides some limited insights into the types of industries and installations generating and using biogases, and the trends across the UK, but the data quality is limited and the scope of reporting somewhat uncertain.

For example, where an industrial process (e.g. food and drink production fermentation processes) generate a CO_2 stream, it is unclear whether vented emissions are routinely reported through regulatory mechanisms. Most such sites will also include a boiler and therefore there will also be fuel combustion CO_2 emissions, and from installation-wide reporting under the Industrial Emissions Directive (IED)/ Pollutant Release and Transfer Register (PRTR) there is no way to determine the split of emissions from fuel combustion and process sources.

Furthermore, where an organic biogas is combusted, it may typically contain (pre-combustion) 50-60% methane, traces of other hydrocarbons and a high percentage of CO_2. Any data on biogas use on an energy basis will only account for the methane content of the fuel, as there is a comparatively negligible energy to be gained from combusting the other components of biogas.

In estimating total CO_2 emissions through IED/PRTR or EU ETS reporting mechanisms, it is unclear whether a consistent method is used by all operators to account for (i) the emissions derived from methane combustion, (ii) emissions from the combustion of other Hydrocarbons (HCs), and (iii) the venting of the CO_2 in the fuel gas at the point of combustion.

3.4.2 Findings in this project

The Golder Associates report, 'Review of Landfill Methane Emissions Modelling' analysed thousands of samples of landfill gas. In Table 8 of the Golder Associates report a methane:carbon dioxide ratio of 57:43 is presented, with a very high confidence of only 3% standard deviation. It is believed that this is a higher methane ratio than would be expected from anaerobic digestion of the same waste because CO_2 is absorbed my other material in the landfill before the gas escapes. With the assumption that the methane has a similar calorific content to natural gas, this yields a CEF of 2.8 kt/Mth, when you include the CO_2 vented at the point of combustion. This is approximately double that of the IPCC default, which was found to be consistent with an assumption of nearly 100% methane; an assumption of 100% methane is would be suitable for enriched biogas injected into the national grid.

Consultation with sewage carbon reporting and anaerobic digestion experts has confirmed that biogas generation and composition are dependent on what feedstocks are used, with sewage sludge generating a high methane content (approaching or perhaps exceeding 60% methane), and general food wastes generating a lower methane content (closer to 50%). Biogas generation and composition is also sensitive to temperature, and can be influenced by the technology used. It's believed that almost all anaerobic digestion will have meters recording the gas generation and composition, but these data are not collated and reported in a publicly accessible source. There is industry literature which is designed to allow the approximation of biogas generation and composition based on feedstock, which could be used in conjunction with national data on feedstocks used for anaerobic digestion to generate a modelled estimate of biogas composition.

Examples of industry literature includes:

- A collation of feedstock parameters prepared by the NNFCC at http://www.biogas-info.co.uk/about/feedstocks/ (database download link is http://www.cropgen.soton.ac.uk/deliverables/CROPGEN_D4_WU-Soton_Methane_Database%20230511.zip)
- Examples of biogas generation factors dependent on feedstock presented at http://www.biogas-info.co.uk/about/feedstocks/
- A summary of biogas composition analysis presented by Naskeo Environnement at http://www.biogas-renewable-energy.info/biogas_composition.html

Analysis of the Phase III (2013-2016) EU ETS data provides useful data on the generation of biogas in several industries, such as brewing, distillation, sugar manufacture, animal feed manufacture, other food and drink manufacture and paper and pulp manufacture. All of the data entries are noted as "combustion" or "flaring", and in most cases very limited data on bio-CEF or NCVs are provided, and no Tier 3 bio-CEF data are evident at all, with only three sites reporting Tier 3 NCV data. Therefore, none of the EU ETS data are considered useful to inform UK GHG inventory bio-CEFs at this stage. It is considered likely that some of the EU ETS data submissions reflect generation of process CO_2 as an off-gas for venting, rather than a combustion of a process off-gas (e.g. from fermentation), but further analysis and consultation is needed here.

3.4.3 Suggestions for future work

For the immediate future we recommend that:

- A factor of 2.8 kt/Mth is used for landfill gas;
- The IPCC default factor is used for biogas injected into the national natural gas network; and,

- A factor of 3.2 kt/Mth is used for other biogas, which is based on the conservative assumption that there is a 1:1 ratio of CH_4:CO_2 in biogas.

The estimate for other biogases could be further improved by either:

1. Using industry literature on biogas generation and composition in conjunction with national data on feedstocks used for anaerobic digestion to generate a modelled estimate of biogas composition; or,
2. Contacting regulatory bodies and/or trade associations for the anaerobic digestion sector to organise for metered data on biogas generation and composition to be collated and delivered to the NAEI team.

The first option would be possible with relatively limited investment and there are no barriers to conduct this analysis, whereas the second option would offer a much more accurate estimate, accounting for other factors than just the feedstock.

We also recommend that BEIS considers further consultation to clarify the types of biogas reported in mechanisms such as EU ETS and to understand better the scope of reporting. This may be achievable through engagement with a relatively small number of operators in the brewing, distilling and food and drink sectors, e.g. to estimate the emissions of process and combustion CO_2 separately. These estimates could then be added to the UK GHGI.

3.5 Charcoal

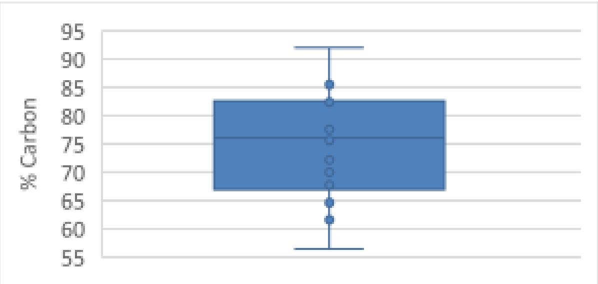
3.5.1 Current understanding and known challenges

Charcoal is a derived fuel from wood created by baking off the volatile component, leaving a high carbon fuel. This is a similar process and result as transforming coals into coke. Charcoal is typically only used for small-scale residential use. Charcoal consumption data are not included in DUKES, but instead obtained from FAOstat for the UK inventory.

3.5.2 Findings in this project

The current NAEI assumption for charcoal is that 90.1% of charcoal is carbon. When compared to the data presented in Phyllis2, as presented in **Figure 2**, we found only one case where a higher carbon content was found and 17 analyses which suggested varying levels of lower carbon contents. While data were presented in Phyllis2 for charcoal on an as received basis, there were much fewer data, so those are not presented, however, moisture content of charcoal is expected to be low. The charcoals analysed were for a variety of different biomass (and in some cases, do not specify the biomass), but we do not have data on the relative share of woods used for charcoal upon which to base a robust weighting of these factors.

Figure 2 Charcoal carbon contents on a dry matter basis extracted from Phyllis2



3.5.3 Suggestions for future work

Given the relatively low contribution of charcoal use, that the current NAEI factors is conservatively high and that there is no robust data to determine a weighted factor, we recommend that the NAEI factor is retained, and that unless there is a market shift towards charcoal use, no further work is required.

3.6 Liquid biofuels (for stationary combustion)

3.6.1 Current understanding and known challenges

There is very little data available on use of liquid biofuels for source categories other than in transport fuels (see above), and no clear resolution of this activity in DUKES. Currently in the UK GHG inventory estimates are included for a small amount of liquid biofuel use noted in power generation, but this is not a very significant source in the UK context.

3.6.2 Findings in this project

Other than for power stations, the Phase III (2013-2016) EU ETS data provides a very small dataset on the use of liquid biofuels across a number of sectors including: food and drink, public sector and commercial. There is a very small dataset across all 4 years (only 19 records across all non-power sectors) and the level of activity and emissions is trivial, with no Tier 3 CEF or NCV data. There is insufficient data from EU ETS reporting to be used in the UK GHGI. No other consultees have provided any additional insights into the use and quality of liquid biofuels.

3.6.3 Suggestions for future work

Given the low level of significance of this fuel type and scarce UK data, we recommend that the current bio-carbon factor is sufficient.

3.7 Other biomass used in power stations (poultry litter, straw)

3.7.1 Current understanding and known challenges

Biomass-only power stations are not included in the scope of reporting to EU ETS, but the UK GHGI does include estimates of emissions based on data reported directly by operators of these installations and from annual returns under IED/PRTR to the Pollution Inventory and SPRI. Data are readily available on fuel GCVs and also on the fossil emissions from support fuels such as natural gas and gas oil (sometimes used at start-up), which can be used together with IED/PRTR data to estimate the bio-carbon emissions.

The data on fuel Gross Calorific Values (GCVs) of individual fuel streams indicates some slight variability in fuel composition between installations and within the year (as monthly data are available for several stations), which may reflect small variations in moisture content, but the routine fuel quality monitoring and low level of variability indicates overall a low level of uncertainty in the emission estimates by operators.

3.7.2 Findings in this project

There are no readily available data on fuel composition and bio-CEF.

3.7.3 Suggestions for future work

Our current understanding is that installation-level reporting is assumed to be underpinned by fuel-specific bio-carbon factors, derived by UK operators, but it is not currently possible to derive CEFs from these data for application to UK-wide activity data. We recommend that BEIS considers further work and consultation as DUKES data resolution continues to evolve, to aim to develop an inventory model that will enable emission estimates to be derived at a greater level of resolution, fuel by fuel, once those activity data become available and as the uptake of these types of fuels continues to increase (as they are projected to do so). The use of IED/PRTR data is defensible to continue in the meantime, and/or to use IPCC defaults or UK-specific factors (if they become available from operators) as the AD are developed.

3.8 Wood/solid biomass

3.8.1 Current understanding and known challenges

Wood, short rotation coppice and other similar solid biomass are fuels used for a wide range of applications, from domestic appliances to large power stations. The difference in emission factor in the current NAEI estimates are driven by differing calorific values for each end use of wood presented in DUKES.

The EU ETS dataset includes wood and solid biomass use by a range of industries, dominated by power generation, but also with high annual consumption recorded across installations in a number of other sectors such as: wood products manufacture, cement kilns, paper and pulp manufacture. The UK energy statistics currently presents wood use only for the residential sector and waste wood use in unclassified industry, commercial and agriculture. The NCVs for these different types of wood reflects the different assumed water content for virgin wood (residential: 14.7 GJ net/t) compared to (drier) waste wood (industry: 19.0 GJ net/t).

3.8.2 Findings in this project

Consultation with the RESTATS team confirmed that the differing calorific values of different solid biomass presented in DUKES is driven by assumptions about the moisture content, with the base assumption that wood and other solid plant-based biomass is well approximated by the chemical composition of cellulose. For example, industrial wood use is assumed to be from waste wood products, which are therefore considered to be dry, whereas it’s expected that freshly cut wood for domestic use would have a much higher moisture content. The significance of moisture content to carbon content is illustrated by the clear inverse correlation presented in **Figure 3** and **Figure 4**.

Analysis of the Phase III (2013-2016) EU ETS dataset provided a detailed and comprehensive activity dataset for the power sector, and highlights also that several other sectors are high users of wood, waste wood or other biomass such as: wood products manufacture (>400,000 t/yr.), paper and pulp manufacture (also >400,000 t/yr.), food and drink (>15,000 t/yr.) and cement (15-40,000 t/yr.).

However, for power generation a surprisingly low level of compositional analysis is evident from the EU ETS data, and the overall annual average bio-CEF range across the 4 years is 360-450 t bio-C per kt.

The cement sector bio-CEF from EU ETS and MPA data shows close consistency (between the two data sources) but the data are from only a handful of sites and are not presented here to prevent data disclosure. The annual bio-CEFs are all lower than the range presented above for power generation.

The wood products manufacture bio-CEF from EU ETS is derived from around 25% of Tier 3 (compositional analysis) by operators in each year, from 6 of the largest sector installations in the UK, and across the 4 years (2013-2016) range from 367-426 t bio-C per kt, which is similar to the power sector spread of data.

There was an insufficiently large dataset for wood/biomass use (in terms of numbers of installations and therefore likely representativeness of the CEFs derived) for sectors such as paper and pulp, food and drink and cement, as noted above.

In comparison to the carbon analysis of samples on an as received basis in the Phyllis2 dataset, presented in **Figure 3**, the NAEI factors are within the range of observations, but the factor for power stations and domestic use (401 kt/Mt) relatively low and the NAEI factor for other industrial combustion (518 kt/Mt) is relatively high. **Figure 3** also illustrates the side range of carbon contents possible in wood, and the variability by wood type. It should be noted that we would expect industrial wood combustion to be higher than typical woods, because this is typically waste wood, which would have almost no moisture content. We haven't presented waste wood data from Phyllis2 in **Figure 3** because the data for this fuel was more challenging to extract.

At the moment we do not have sufficient data on the types of wood used in the UK to make use of these wood type-specific data, and we would expect it to be very challenging to get representative data on moisture content of wood for the domestic sector.

Figure 3 Wood carbon contents on an 'as received' basis extracted from Phyllis2[11]

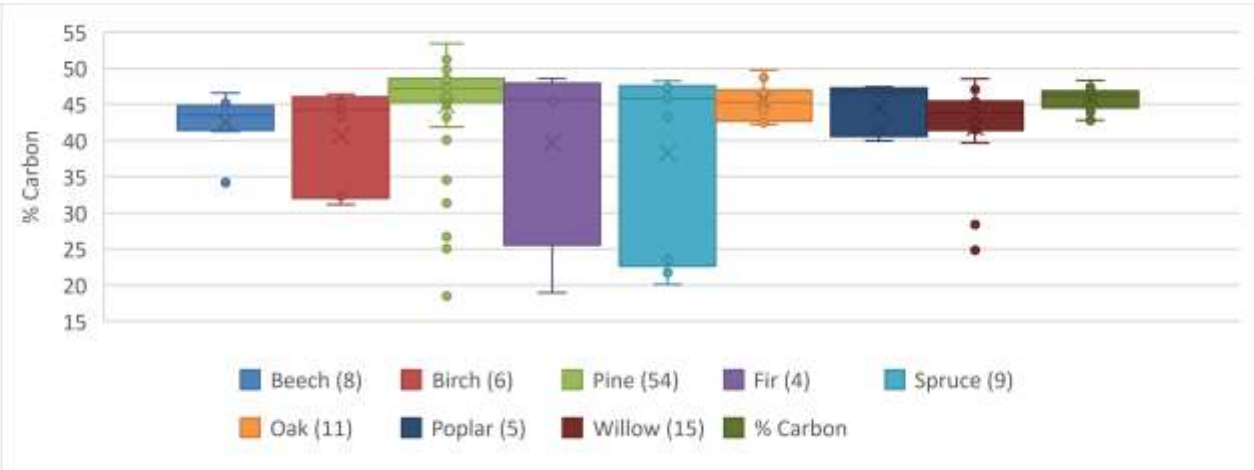
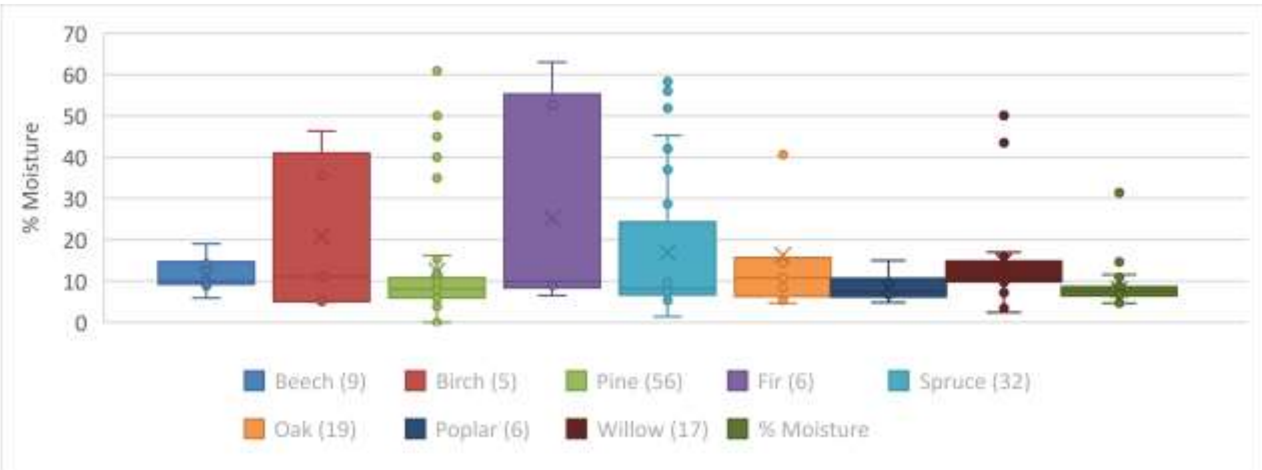


Figure 4 Wood moisture contents on an 'as received' basis extracted from Phyllis2[11]



[11] Numbers in brackets in the legend indicate the number of samples

3.8.3 Suggestions for future work

The highest priority is to seek to improve the dataset for power station wood/biomass use, as this is by far the highest single emission source of bio-carbon in the UK inventory, and the lack of detailed operator reporting in EU ETS and consistency of the derived bio-CEFs warrants further work. The findings indicate that further research is needed into the type of fuels used, their quantities, moisture levels and carbon content, and this information may be available via EU ETS or IED permits, or through other reporting mechanisms in to RESTATs and DUKES. Consultation with operators and regulators may be the best route to access such information.

In addition, we recommend that BEIS considers:

- A review of the sector resolution of wood/biomass use within DUKES (we understand that such work is ongoing via the RESTATs team); and,
- A review of the types of wood in use in the UK for the domestic sector, which could be combined with the Phyllis2 data on carbon contents of each wood type.

We also recommend that BEIS considers integration of the EU ETS activity data for wood products manufacture, paper and pulp, cement and food and drink in future DUKES, and considers use of the bio-CEFs for each sector to be used to derive estimates for the UK GHG inventory memo items, to improve accuracy, completeness and sector resolution, and to aid tracking of renewable fuel trends across industry sectors.

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