Atmospheric Environment 114 (2015) 1–7

Contents lists available at ScienceDirect

Atmospheric Environment

journal homepage: www.elsevier.com/locate/atmosenv

An AIS-based approach to calculate atmospheric emissions from the UK fishing fleet

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HIGHLIGHTS

- An AIS-based emissions calculation methodology for fishing vessels is introduced.
- Fuel- and AIS-activity-based emissions inventories for a fishing fleet are compared.
- Trawling and dredging vessels have complex engine loads that must be simulated.
- Using AIS data allows greater flexibility when aggregating and mapping emissions.
- AIS-based methods produce higher emissions estimates than fuel-based methods.

ARTICLE INFO

Article history:
Received 13 August 2014
Received in revised form
7 May 2015
Accepted 8 May 2015
Available online 14 May 2015

Keywords:
Greenhouse gas emissions
Atmospheric pollution
UK fishing fleet
Automatic Identification Systems (AIS)
Shipping emissions inventory

ABSTRACT

The fishing industry is heavily reliant on the use of fossil fuel and emits large quantities of greenhouse gases and other atmospheric pollutants. Methods used to calculate fishing vessel emissions inventories have traditionally utilised estimates of fuel efficiency per unit of catch. These methods have weaknesses because they do not easily allow temporal and geographical allocation of emissions. A large proportion of fishing and other small commercial vessels are also omitted from global shipping emissions inventories such as the International Maritime Organisation's Greenhouse Gas Studies. This paper demonstrates an activity-based methodology for the production of temporally- and spatially-resolved emissions inventories using data produced by Automatic Identification Systems (AIS). The methodology addresses the issue of how to use AIS data for fleets where not all vessels use AIS technology and how to assign engine load when vessels are towing trawling or dredging gear. The results of this are compared to a fuel-based methodology using publicly available European Commission fisheries data on fuel efficiency and annual catch. The results show relatively good agreement between the two methodologies, with an estimate of 295.7 kilotons of fuel used and 914.4 kilotons of carbon dioxide emitted between May 2012 and May 2013 using the activity-based methodology. Different methods of calculating speed using AIS data are also compared. The results indicate that using the speed data contained directly in the AIS data is preferable to calculating speed from the distance and time interval between consecutive AIS data points.

1. Introduction

Throughout the 20th century fisheries became highly dependent on fossil fuels (Tyedmers et al., 2005), and are a major source of greenhouse gas emissions and other atmospheric pollutants (Driscoll and Tyedmers, 2010). In 2012, the United Kingdom (UK) fishing fleet was made up of 6434 vessels, comprising a significant fraction of the UK shipping fleet (EC, 2013a).

Previous emissions inventories for the fishing industry have been compiled based on fuel use data surveyed from vessel operators (Curtis et al., 2006; Hospido and Tyedmers, 2005; Iribarren et al., 2010; Tyedmers, 2001; Vázquez-Rowe et al., 2010; Whall et al., 2002; Ziegler and Hansson, 2003). Larger fishing vessels have also been included in global shipping emissions inventories using activity-based methods. However, smaller fishing vessels as well as many other small commercial vessels are omitted (Buhaug et al., 2009; Corbett and Köhler, 2003; Endresen et al., 2003; Eyring et al., 2005; Smith et al., 2014).

Activity-based methodologies have been widely accepted as

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http://dx.doi.org/10.1016/j.atmosenv.2015.05.011

more accurate and useful than fuel-based methods for the calculation of shipping emissions inventories (Buhaug et al., 2009; Smith et al., 2014). Approaches using activity data derived from the messages broadcast by vessel's Automatic Identification Systems (AIS) have emerged as the state-of-the-art in recent years, offering the opportunity to produce accurate, vessel-specific spatially and temporally resolved emissions inventories (Jalkanen et al., 2009; MARIN, 2012; Olesen et al., 2009; Perez et al., 2009; Smith et al., 2014). However, complete emissions inventories of fishing fleets continue to rely on fuel-based methods, possibly due to issues associated with modelling fuel consumption of vessels engaged in trawling and dredging activities and because only a subset of fishing vessels currently broadcast AIS data.

This paper presents an emissions inventory of the UK fishing fleet calculated using an AIS activity-based methodology. Significantly, this methodology uses an activity-sampling approach that enables emissions to be calculated for entire fleets for which only a subset of vessels operate AIS technology, such as fishing fleets. It introduces a new way to identify when vessels are engaged in trawling or dredging and adjusts the engine load used in emissions calculation accordingly. As a means of comparison and validation, an emissions inventory is calculated using a bottom-up methodology using fuel consumption rates per unit of catch and total catch landed by the UK fishing fleet.

1.1. Previous emissions inventorying methods

Methods for the quantification of emissions from the fishing industry have generally relied on fuel use data reported by fishing vessel operators that are used to determine fuel consumption per unit of catch landed before being scaled-up using either fleet vessel numbers or records of total landings Such methods are useful for quantifying and comparing the carbon intensity of various seafood products and fishing methods (Tyedmers, 2001; Thrane, 2004a, 2004b; Ziegler and Hansson, 2003; Ziegler and Valentinsson, 2008), as well as changes in carbon and fuel intensity over time due to changes in fish stocks and fishing methods (Schau et al., 2009). However, they are less useful for producing the kind of spatially and temporally resolved emissions inventories typically used as inputs to atmospheric chemical transport and dispersion models.

Fishing vessels of 100 Gross Tonnes (GT) and above have been included in various activity-based emissions inventories. The activity data used has ranged from educated assumptions (Corbett and Köhler, 2003; Endresen et al., 2003; Eyring et al., 2005), port arrivals and departures (Dalsøren et al., 2009), AIS data used to develop average vessel type and size–class activity data (Buhaug et al., 2009) and, most recently, AIS data used for vessel-specific emission calculation (Smith et al., 2014). However, the omission of fishing vessels under 100 GT is likely to result in considerable underestimation of emissions from the sector (Endresen et al., 2007).

Reliable inclusion of fishing vessels in activity-based estimates based on empirical data, such as AIS data and port arrivals and departures, requires modelling of the elevated engine loads of vessels engaged in trawling and dredging operations to avoid potentially significant underestimates. This is an issue that previous activity-based methodologies have not addressed.

2. Materials and methods

2.1. Fuel-based method

The *Scientific Fishery Data* portal, run by the European Commission (EC), provides data on landings (the recorded total weight of seafood caught) by country, fishing vessel size and gear type for 2008, 2009 and 2010 (EC, 2013b). It also provides fuel efficiency data for various European Union (EU) countries for each fishing vessel category.

Fuel efficiency data were not available for all vessel categories for each year and country. Notably, UK fuel efficiency data were only available for 2008 and 2009. Where UK data were available, the data for both years were averaged to give the fuel efficiency figures used in this study. When UK data were unavailable for a vessel category, data from other countries were used based on a ranking of closeness of fit to UK data using the average variance between the UK and other countries' fuel efficiencies. Average variances were calculated separately for vessels using active gear types (e.g. trawling and dredging) and passive gears. Where data necessary for independent comparison of active and passive gears were lacking, averages across all categories were used. The fuel efficiencies from the closest matching country were averaged across all three years to produce the fuel efficiencies used in this study. For certain vessel categories for which no data were available for any countries, the fuel efficiency from the most similar category of vessel was used as a proxy.

Fuel efficiencies and total landings data were used to estimate fuel consumption by the UK fishing fleet (Table 2). It was assumed that all vessels used Marine Diesel Oil, with a density of 1191 L per tonne (Defra/DECC, 2012). Tier 1 emissions factors were taken from the *EMEP/EEA air pollutant emission inventory guidebook 2013* (Trozzi et al., 2013) to calculate emissions.

2.2. Bottom-up activity-based method

Emissions from the fishing industry were calculated using a bottom-up activity-based methodology, using AIS data to derive vessel activity. AIS data broadcast by fishing vessels within the area between latitudes 40°N and 65°N and longitudes 20°W and 12°E between 9th May 2012 and 15th May 2013 and collected by a terrestrial receiver network were provided by MarineTraffic.com (MarineTraffic.com, 2013). The data comprised an archive of over 55.5 million AIS messages associated with 5188 vessels, identified by their unique Marine Mobile Service Identity (MMSI) numbers. Further analysis of the data showed that 1122 of these tracks belonged to vessels for which at least 10% of port visits were at UK ports. This subset of the AIS data was taken as the sample of activity data for the UK fleet.

A methodology and software tool were developed based on the Tier 3 emissions calculation formula and guidance presented in the *EMEP/EEA air pollutant emission inventory guidebook 2013* (Trozzi et al., 2013) to enable the calculation of emissions using AIS data, vessel characteristics and emissions factors. The EC's Europa database of fishing vessels was used to obtain vessel characteristics data for the 6434 vessels licenced under the UK flag from May 2012 to May 2013 (EC, 2013a). These data include vessel size, engine power and fishing gear used, which were used in emissions calculations. However, data on engine and fuel types, which are necessary for selecting appropriate emission factors, were not available. Therefore, fleet level averages for fishing vessels were taken from Trozzi et al. (2013) (Table 1). Emissions for each vessel were calculated as the weighted average of the engine and fuel type combinations in proportion to the fleet-level data.

The AIS data is used to calculate the engine operating time and load factor required as inputs for the activity-based formula. Main engine load is calculated from speed, using an adaptation of formulae used in other shipping emissions calculation studies (Buhaug et al., 2009; MARIN, 2012; Smith et al., 2012) (Eq. (1)).

Table 1
Percentage of installed Main Engine power by engine type/fuel class (2010 fishing fleet) (adapted from Trozzi et al., 2013).

SSD MDO/MGO	SSD BFO	MSD MDO/MGO	MSD BFO	HSD MDO/MGO	HSD BFO	GT MDO/MGO	GT BFO	ST MDO/MGO	ST BFO
0.00	0.00	84.42	3.82	11.76	0.00	0.00	0.00	0.00	0.00

SSD – Slow Speed Diesel, MSD – Medium Speed Diesel, HSD – High Speed Diesel, GT – Gas Turbine, ST – Steam Turbine, MDO – Marine Diesel Oil, MGO – Marine Gas Oil, BFO – Bunker Fuel Oil.

$$LF = L_{max}*\left(\frac{\left(\frac{V}{V_d}\right)^3 + \left(\frac{L_{min}}{L_{max}-L_{min}}\right)}{1+\left(\frac{L_{min}}{L_{max}-L_{min}}\right)}\right) \quad (1)$$

Where the load factor (LF), relative to an engine's maximum continuous rating (%MCR) is calculated from the cube of a vessel's instantaneous speed (V) relative to design speed (V_d), between a minimum load (L_{min}) assumed for main engines that are idling to a maximum load (L_{max}) assumed for vessels operating at design speed. A minimum main engine load of 20% and a maximum of 90% were taken from Trozzi et al. (2013) and Buhaug et al. (2009), respectively.

Two methods are used to calculate speed between chronologically consecutive AIS data points within the AIS data record produced by each vessel. The first averages the speeds contained in the AIS messages, similar to the interpolation method used by Jalkanen et al. (2009). The second uses the great-circle distance, calculated using the Haversine formula (Sinnott, 1984), and time to calculate speed, similar to Olesen et al. (2009).

The speed calculated for the great-circle distance between two points is treated as a theoretical minimum, so the higher of the two speeds is used unless that speed exceeds a threshold value, beyond which it is considered an error. To reduce the effect of uncertainties in the speeds calculated, the AIS data are grouped into packets representing a minimum of 20 min of activity, for which speeds are averaged. A reliable source of fishing vessel design speed data was unavailable and so these were estimated from the data with the assumption that the maximum speed recorded cumulatively for at least two hours for any AIS activity track was a reasonable proxy for a vessel's design speed.

AIS data were used to assist in estimating auxiliary engine loads at all times and main engine load for vessels while in port or at anchor. Vessel speeds were used to categorise vessels as in port or at anchor, manoeuvring or cruising, similar to Smith et al. (2014), and appropriate auxiliary engine loads were applied from Trozzi et al. (2013). When stops were detected in AIS activity tracks, assumptions were made regarding the duration that main and auxiliary engines were in operation after arrival at their stopped location and before departure using advice provided in Trozzi et al. (2013).

Vessels were identified as being stopped at specific ports based on their proximity to the coordinates of 588 ports that were identified in the study area using online mapping, aerial and satellite photography services and an inspection of the locations of stops observed in the AIS data, which proved an effective way of identifying many smaller fishing harbours.

Interruptions to AIS message broadcasting by vessels or receiving by terrestrial or satellite receiver stations occur for a variety of reasons (Buhaug et al., 2009; Smith et al., 2012, 2014) and the resulting gaps in the AIS record must be addressed. For example, calculating speed and engine load between two chronologically adjacent AIS data points that are temporally separated by several hours or more could lead to considerable underestimation. This is particularly true when using terrestrial AIS data, which has a range of around 50 nautical miles (Buhaug et al., 2009) from receiver stations, to determine fishing vessel activity.

Vessels may exit and re-enter AIS network range at geographically similar locations as they travel to and from fisheries, but travel significant distances at varying speeds outside of network range. This was addressed by identifying time intervals of over 60 min between AIS data points and applying the average engine load calculated for the appropriate trip phase from the rest of the AIS data track rather than using the engine load calculated from the AIS data surrounding the time gap. A similar method is used by Smith et al. (2014) to correct activity records for the Third IMO GHG Study 2014.

Fishing vessels such as trawlers and dredgers tow fishing gear, which results in high engine loads at relatively low speeds (Suuronen et al., 2012). Consultation with staff at Seafish, the industry body representing the UK seafood industry, resulted in the generation of *engine load override rules* specifying speed ranges and minimum durations that apply to vessels engaged in trawling and dredging. An engine load of 75% is applied to all vessels while trawling or dredging (Montgomerie, 2013). These rules were associated with the appropriate vessel types and the sections of AIS data tracks fitting these *engine load override rules* were identified whilst processing AIS data.

A significant challenge that had to be overcome was to develop a way of using the 1122 AIS data tracks that were identified as relating to the UK fleet to calculate emissions for the entire fleet of 6434 vessels. Due to a lack of MMSI numbers in the Europa database, reliable matching of vessel characteristics to AIS data tracks was not possible for any of the vessels. Therefore, emissions for all vessels were calculated using a sampling approach. Vessel length is reported in AIS messages and the AIS data tracks that frequently show activity described in the *engine load override rules* could be categories as belonging to trawling and dredging vessels. This gave a basis for sampling based on vessel size and fishing gear type used.

A sample size of 30 tracks was selected based on the *Central Limit Theorem*, which gives the likelihood of the mean of a sample of a specific size falling within a certain margin of error of the population mean for variables that are normally distributed. A sample size of 30 gives a margin of error of less than ±20% with a 95% confidence level (Burt and Barber, 1996). A larger sample size could be selected; however this would potentially reduce the similarity between the vessels making the sampled tracks and the vessel for which emissions are being calculated using those tracks.

Each of the AIS tracks to be sampled for a particular vessel is divided into hour-long time slices and hourly fuel use and emissions for each vessel are calculated as the mean of the emissions calculated for each of the sampled tracks during that hour. In addition, emissions can be mapped to a grid of a specified resolution by distributing the emissions calculated for a vessel to the grid squares crossed by each of the tracks sampled in proportion to the time spent in each grid square and the intensity of emissions from each AIS track in relation to the other tracks sampled.

3. Results

The fuel consumption calculated using the fuel-based method is presented by vessel category and year in Table 2. Total fuel consumption and emissions calculated using the fuel-based method are presented in Table 3. The results calculated using the bottom-up activity-based approach are presented in Tables 4–6. Taking the average quantity of fuel consumed as the basis for comparison: the average annual fuel consumption for years 2008–2010, calculated using the fuel-based methodology, is 251,270 tonnes.

Fuel use in both main and auxiliary engines, calculated using the bottom-up activity-based approach developed ranges from 295,710 tonnes using the average speed of the two AIS data points as the speed for the journey between them, to 376,250 tonnes using the Haversine formula to calculate distance and speed. Using a hybrid speed calculation method, the result falls between these at 342,340 tonnes (Table 4). The split between main and auxiliary engines also differs by speed calculation method with 7.3% of fuel used in auxiliary engines, where speed is calculated from distance and time, but 14.0% of fuel used in auxiliary engines when taking speeds from the AIS data (Table 5).

Looking only at the results produced using speeds taken directly from the AIS data as a basis for engine load calculation and viewing emissions aggregated by major vessel type and GT; 6007 vessels under 100 GT consume 50.8% of all fuel used by the fishing fleet, the remaining 427 consume the remaining 49.2% (see Table 6). Trawlers, i.e. vessels using trawling gear as either their main or secondary fishing gear, consume 92.6% of the total fuel used by the fleet (Table 6). This is higher than the proportion suggested by the results of the alternative methodology, which suggest a maximum of 66% of fuel use and emissions are attributed to trawlers (Table 2).

Fig. 1 shows the geographical distribution of CO_2 emissions. The distributions of emissions of other pollutants are also very similar. Areas of high emissions intensity are generally clustered around ports.

4. Discussion

Calculating emissions using a bottom-up activity-based approach produced higher estimates of emissions than those produced using a fuel-based approach. The results from the three speed calculation methods trialled also differ significantly. Emissions calculated using speeds from AIS data are lower than those calculated using the alternative speed calculation method. This is due to higher estimates of design speed deduced from AIS data and therefore lower average relative speeds and engine loads. These differences highlight that selecting the speed calculation methodology is a major decision when using AIS data to produce emissions inventories.

The estimation of vessel design speed from the AIS data represents a significant source of uncertainty in this study, as underestimation of design speed leads to overestimation of emissions and vice-versa. This uncertainty could be reduced if a reliable source of design speeds for the various type and size classes of fishing vessel were identified in future work. Another possible explanation for the discrepancy could be the use of activity sampling in the activity-based method. If AIS devices tend to be fitted to vessels that have higher than average levels of activity then this would lead to an overestimate of emissions and fuel use by less active vessels in the fleet using the activity-based methodology presented.

The results of the fuel-based approach used in this study are close to an estimate produced using vessel operator surveys by Seafish, the UK fishing industry body, of 252 kilotons of fuel consumed annually by the UK fishing fleet (Curtis et al., 2006). This goes some way to validate the fuel-based methodology employed in this study and could suggest that the activity-based approach has produced an overestimate.

The activity-based results that are closest to those produced using the fuel-based methodology are calculated using speeds directly taken from the AIS data rather than those calculated from the distance and time interval between consecutive AIS points. This suggests that using speeds taken from the AIS data is the more reliable method. This is based on the assumption that the fuel-based results are close to the real values. There is, however, significant variation in the fuel efficiency figures used in the fuel-based approach, indicating that significant uncertainty exists in fuel-based approaches as well. Indeed, much of the research in the field of shipping emissions inventorying methodologies has concluded that fuel-based methods tend to underestimate atmospheric pollution emissions (Buhaug et al., 2009; Smith et al., 2014). However, whether the same issues of underreporting and misallocation that lead to these underestimates specifically apply fishing activities is unknown.

Nevertheless, the fact that the results produced using independent fuel-based and activity-based methods are somewhat similar indicates that both methods are viable and that activity-based methods should be considered for the other advantages that they offer. Although significant effort is involved in developing the software necessary to model shipping emissions using AIS data, once the modelling framework is in place, the time and effort involved in producing emissions inventories is minimal and does not rely on the cooperation of vessel operators. For example, the software produced for this study could be reused to produce future emissions inventories for fishing vessels or other shipping sectors with minimal additional work provided that AIS data were available. Also, unlike fuel-based estimates, the use of an AIS activity-based methodology enables the production of spatially and temporally resolved emission inventories that can easily be aggregated for any desired sub-group of vessels.

For example, emissions can be aggregated for vessels falling within defined categories of length, GT or engine power, and for different vessel types (e.g. Table 6). The aggregation of emissions by

Table 2
Fuel use by vessel category 2008–2010 calculated from European Commission fisheries statistics (fuel-based approach) (kilotons).

Vessel category	Fuel use 2008	Fuel use 2009	Fuel use 2010
Beam trawlers	29.51	29.78	34.96
Demersal trawlers and/or demersal seiners	131.31	134.89	133.01
Dredgers	16.74	16.53	13.56
Drift and/or fixed netters	4.75	4.87	4.98
Pelagic trawlers	3.98	0.00	0.01
Purse seiners	29.97	31.16	32.27
Vessels using active and passive gears	0.01	0.00	0.01
Vessels using hooks	5.66	6.31	5.81
Vessels using polyvalent active gears	0.37	1.18	1.52
Vessels using polyvalent passive gears	0.01	0.01	0.01
Vessels using pots and/or traps	27.31	25.91	27.44
Total	249.62	250.62	253.58

Table 3
Fuel use and emissions from UK fishing activities 2008–2010 using a fuel-based approach (kilotons).

Fuel use/emissions	2008	2009	2010	Average
Fuel use	249.62	250.62	253.58	251.27
CO_2	796.29	799.47	808.92	801.56
NO_X	19.60	19.67	19.91	19.73
CO	1.85	1.86	1.88	1.86
NMVOC	0.70	0.70	0.71	0.70
SO_X	4.99	5.01	5.07	5.02
PM	0.37	0.38	0.38	251.27

Table 4
Total atmospheric pollution emissions from the UK fishing fleet from 12 May 2012–12 May 2013 (kilotons) using three different speed calculation methods for a bottom-up activity-based approach.

Speed calculation method	CO_2 (main + aux)	NO_x (main + aux)	SO_2 (main + aux)	NMVOC (main + aux)	CO (main + aux)	TSP (main + aux)	Fuel Cons. (main + aux)
Haversine distance/time	1158.69	16.79	0.73	2.04	2.69	1.43	376.25
AIS average	914.38	13.65	0.57	1.49	2.12	1.05	295.71
Hybrid	1057.92	15.74	0.66	1.75	2.45	1.23	342.34

Table 5
Percentage of total atmospheric pollution from the UK fishing fleet emitted from auxiliary engines using a three different speed calculation methods for a bottom-up activity-based approach (12 May 2012–12 May 2013).

Speed calculation method	CO_2 (% aux)	NO_x (% aux)	SO_2 (% aux)	NMVOC (% aux)	CO (% aux)	TSP (% aux)	Fuel Cons. (% aux)
Haversine distance/time	7.6%	9.6%	7.6%	2.4%	7.6%	2.9%	7.3%
AIS average	14.4%	17.6%	14.4%	5.0%	14.4%	5.9%	14.0%
Hybrid	11.1%	13.5%	11.1%	3.8%	11.1%	4.4%	10.7%

Table 6
Atmospheric pollution emissions from the UK fishing fleet by vessel type and Gross Tonnage (GT) calculated using a bottom-up activity-based approach using AIS speed data (12 May 2012–12 May 2013) (tonnes).

	CO_2 (main + aux)	NO_x (main + aux)	SO_2 (main + aux)	NMVOC (main + aux)	CO (main + aux)	TSP (main + aux)	Fuel Cons. (main + aux)
Seiners (<100 GT)	1423.13	21.37	0.89	2.56	3.30	1.78	462.59
Seiners (100 GT+)	15,338.88	219.46	9.61	22.67	35.57	16.14	4938.37
Trawlers (<100 GT)	428,927.67	6320.89	268.83	753.65	994.68	526.03	139,234.97
Trawlers (100 GT+)	440,731.03	6692.94	276.23	659.63	1022.05	469.10	141,979.93
Dredgers (<100 GT)	23,678.58	333.27	14.84	44.04	54.91	30.71	7713.45
Dredgers (100 GT+)	7812.93	125.72	4.90	11.87	18.12	8.43	2518.79
Passive gear (<100 GT)	20,979.21	299.70	13.15	36.73	48.65	25.63	6808.47
Passive gear (100 GT+)	0.00	0.00	0.00	0.00	0.00	0.00	0.00

vessel category shows some degree of disagreement between the activity-based and fuel-based methodologies used. Both show trawlers to be responsible for the majority of fuel use and emissions. However, the activity-based method shows a much larger majority. This may, in part, be due to all vessels with secondary trawling gear being defined as trawlers in the activity-based methodology so that appropriate engine load override rules could be assigned.

The ability to produce temporally and spatially resolved emissions inventories is a significant advantage of the activity-based approach as it makes the results viable for use in chemical transport models to assess the impacts of pollution upon human health and the environment (Corbett et al., 2007; Dalsøren et al., 2009; Lauer et al., 2007; Winebrake et al., 2009). The mapped results (Fig. 1) appear to show a realistic spatial distribution of emissions that would improve with any increase in the proportion of vessels within the fleet using AIS technology.

The major sources of uncertainty in this study, namely the lack of reliable vessel design speed data and the relatively small sample of activity data used are issues of data availability that can be expected to improve in the future. A survey of vessel manufactures or operators could yield the design speed data necessary and a larger proportion of fishing vessel operators can be expected to voluntarily adopt AIS technology for the safety benefits is offers, leading to an increased sample size of activity data. Engine load may also be calculated using a more sophisticated and accurate methodology through prediction of required power at a particular speed in calm water and in waves, provided that sufficient vessel parameters are known (Dedes et al., 2014). The Third International Maritime Organisation (IMO) GHG Study 2014 uses an example of a more advanced yet still reasonably simple engine load calculation methodology (Smith et al., 2014).

The use of satellite AIS data may also improve the coverage of the data captured for vessels operating outside of terrestrial AIS network range. However, the lower signal strength of messages broadcast by the Class-B AIS devices used by small commercial and recreational vessels may not be powerful enough for reliable detection by AIS satellites (Taylor-Branco, 2013).

Ideally, it would be possible to compare the results produced during this study with other activity-based emissions inventories for the UK fishing fleet. However, the only example does not present the results in a disaggregated format, meaning that emissions from fishing vessels alone cannot be interpreted (Whall et al., 2010). The Third IMO GHG Study 2014 (Smith et al., 2014) only considers fishing vessels of 100 GT or more, calculating emissions of 22 million tonnes of CO_2 produced by 22130 vessels globally in 2012, equating to 994 tonnes of CO_2 per vessel. The average emissions calculated for the 427 vessels of 100 GT or more in this study were 1086 tonnes of CO_2, 9.3% higher than the IMO average. This may imply a degree of overestimation in the activity-based results of this study. However, it may also be attributable to the detection of trawling and dredging activities and application of an adjusted engine load in this study.

The results of this study indicate that including only vessels over 100 GT would result in the omission of around 50% of atmospheric pollution emissions from the UK fishing fleet. This supports the estimate of emissions of fishing vessels omitted from shipping emissions inventories by Endresen et al. (2007).

Ultimately, this study builds upon previous work that has used AIS data for the calculation of emissions inventories and specifically addresses some of the issues that must be tackled when calculating emissions from small commercial and recreational vessels. The

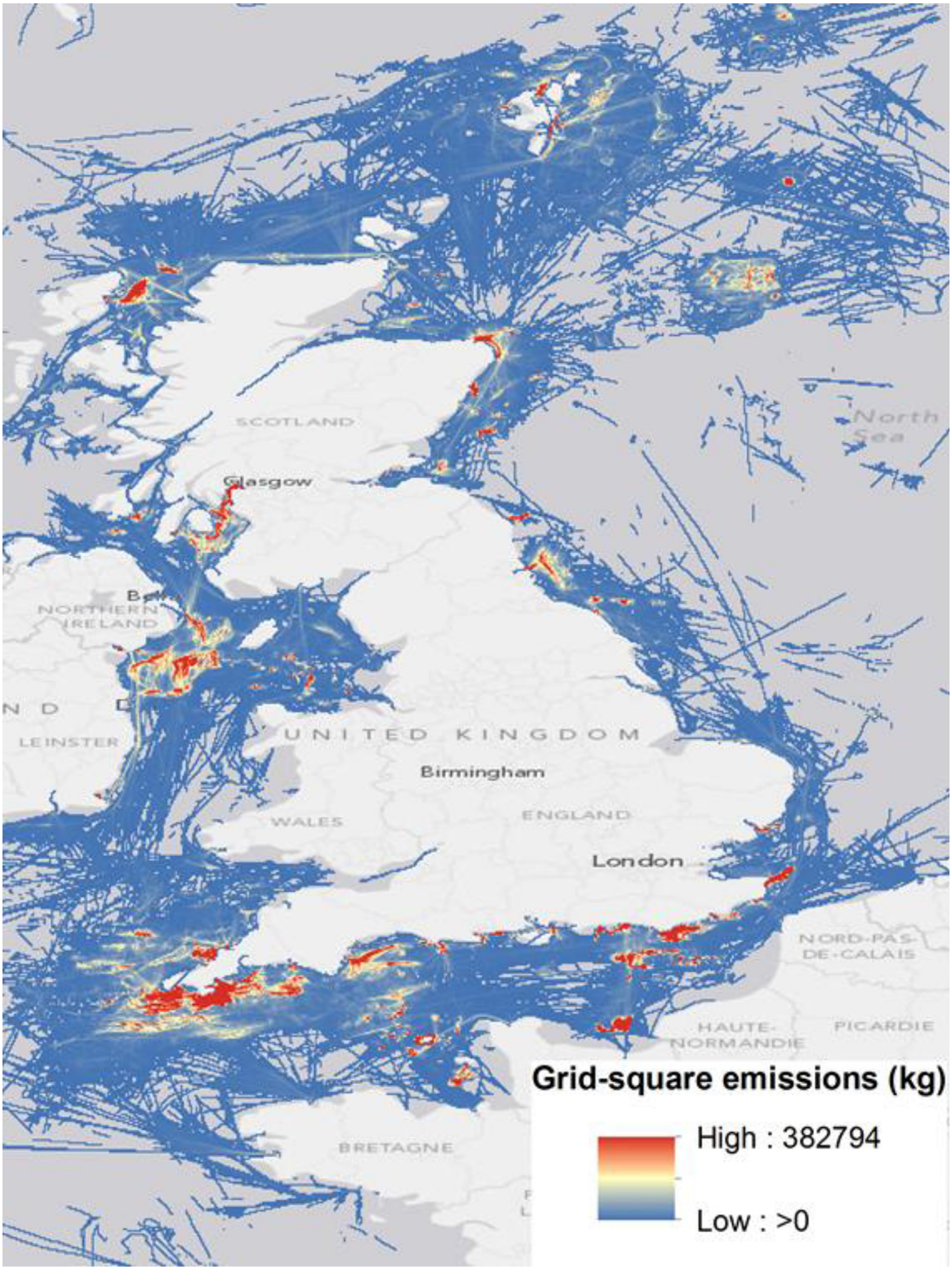

Fig. 1. CO_2 emissions from the UK fishing fleet May 2012–May 2013 mapped in 0.2° x 0.2° grid-squares calculated using a bottom-up AIS activity-based methodology.

challenges of sampling activity for fleets with less than 100% AIS technology uptake in a way that allows emissions to be spatially allocated without the use of supplementary data, uncertainty of engine and fuel type used and the requirement to detect and correct special engine load conditions for vessels engaged in towing and pushing operations will also apply to other types of small commercial and recreational vessel.

5. Conclusions

A new bottom-up activity-based atmospheric emissions modelling approach has been successfully trialled using the UK fishing industry. It is clear that effort is still needed to validate the methodology presented more thoroughly. However, the use of a bottom-up activity-based methodology that makes use of AIS data offers numerous advantages over commonly used fuel-based methods. This methodology is the first that can accommodate special engine load override conditions, which is a necessity when modelling emissions from fishing vessels. It also offers a solution for modelling emissions for fleets of vessels that do not have full uptake of AIS technology that appears to produce reasonable, spatially resolved results.

Given that small commercial, recreational and fishing vessels under 100GT tend to be omitted from shipping emissions inventories, the methodology outlined here could be used to complement the existing highly sophisticated AIS activity-based approaches used for emissions modelling for the larger commercial shipping fleet for the inclusion of emissions from vessels under 100 GT in emissions inventories.

Acknowledgements

We would like to thank MarineTraffic.com for the kind contribution of data to support this study. MarineTraffic.com is a leading provider of AIS data services that supports an active researcher community. We would also like to thank Seafish for their advice on developing engine load override rules for the various classes of fishing vessel in this study.

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