

## Response to reviewers

### PRIMAP-crf: UNFCCC CRF data in IPCC 2006 categories

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### Overview

We thank the editor and four anonymous reviewers for their time and constructive comments on the manuscript and data. In response to these comments we have made some edits to the manuscript and added some additional supporting material. A tracked changes version of the manuscript can be found at the end of this document.

In addition to the changes made in response to reviewer comments we have

- (1) updated figure 3 because the EU was missing in the original version of the paper. Some re-formatting was required to include the legend but the figure is otherwise unchanged.
- (2) Updated the data description in response to feedback from collaborators and in anticipation of releasing updated versions of the dataset (Page 2, Line 29 and Section 5)

Below are specific responses to the reviewers comments, with reviewer comments in black and [author responses in blue](#).

## Anonymous Referee #1

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Excellent overall! Good description, good links to supplements and graphics, much needed step in the overall emissions quantification and validation process. Easy to access and use the source data files. Strong recommendation for publication in ESSD.

Thank you for your positive feedback.

A few comments, mostly by way of suggestion:

Page 2 line 29 - Until this point the manuscript has carefully addressed only Annex I countries with a few explicit additions. Here, apparently, we switch to CRF data for “all” countries? Because most Annex II countries do not report CRF, this sentence must still refer only to Annex I? Worthy of clarification or, earlier in the text, emphasis that all subsequent discussion refers only to Annex I?

You are correct, here ‘all’ refers to all Annex I countries and Kazakhstan. We have reworded the text here and elsewhere to say ‘all reporting countries’.  
(Page 3 | Line 3 ; Page 5 | Line 25 ; Page 9 | Line 26 ; Page 11 | Line 8)

We assume that here you mean “non-Annex I” countries, that do not have the same reporting requirements under the Kyoto Protocol or Convention as the Annex I countries. All Annex II countries are also members of Annex I, but additionally have support obligations under Articles 2.3-2.5 of the Convention.

Page 3 line 6 - Here the reader confronts the short-hand acronym IPC4 which we understand if we have read the legend for Table 2 but otherwise we have not had explanation in the text?

Thank you for pointing this out, we have added (Page 3 | Line 10) a brief explanation that ‘IPC’ indicates the categorisation system used. ‘IPC’ and the difference to ‘CAT’ are then further explained later in the text (Page 10| Line 19-21) and in the caption for Table 2.

Page 5 line 21 - Not until later in this paragraph do the authors clarify that the expert review occurs at the UNFCCC level. At the start of the paragraph a reader does not know whether expert review happens at the country level or the international level.

We have reworded the first sentence of the paragraph to indicate that the Expert Review occurs under the UNFCCC. It now reads:

*“Reported country data undergoes mandatory review under the UNFCCC by an Expert Review Team according to the Guidelines for review under Article 8 of the Kyoto Protocol (most recently updated in Decision 13/CP.20).”* (Page 5 | Line 29)

For those interested, further information on the Expert Review Process can be found on the UNFCCC website - <https://unfccc.int/index.php/process/transparency-and-reporting/reporting-and-review-under-the-convention/greenhouse-gas-inventories-annex-i-parties/review-process>

.csv tables work well, with clear organisation and good explanations. For some categories, e.g. the rarer HFCs, the table includes a strange mixture of formats, e.g. 0.000503 in one row but 1.2E-06 two rows below. Do these differences arise from the CFRs (because each type of format tends to occur consistently across a row) or from PRIMAP? Do we need a more consistent data formatting for these very small numbers? In terms of GWP, not worth the effort?

We have fixed the data formatting for the current version of PRIMAP-crf (2017-v1) and all data points are now formatted in scientific notation with data provided to 3 significant figures.

Kyoto bucket data (e.g. KYOTOGHGAR4) occur mixed in with the individual gas data? Although presentation of all data in one table with uniform formatting may prove necessary, the present organisation presents a substantial challenge to users (countries?) who might like to check specific PRIMAP outcomes e.g. where bucket total differs from sum of individual concentrations. Even if duplicative, should we have the bucket to individual components comparison as a separate table? Or the authors could build in a summary line before or after each bucket group, showing cumulative individual concentrations for comparison? We read about these discrepancies in the text e.g. in Section 3 but nowhere do we see a figure, which suggests to this reader that these discrepancies remain obscure except to the authors? Not worth the effort if the discrepancies remain minor but some countries will want to see?

Many of the discrepancies are not visible at the top categories for Kyoto-GHG because the absolute magnitudes of emissions involved are very small. Rather, they occur in the summing of lower level categories that we do not publish as part of PRIMAP-crf. The discrepancies are also, generally, still very small (<1%). To provide more transparency and explanation, we have added an additional table (CRF17-paper-data-discrepancy-table) to the supplementary material that contains the relevant category and sub-category data for three of the country-specific issues described in section 3. The tables show the absolute and percent difference in emissions for the category and the summed sub-categories. During the data reading and preparation process, we found that it was necessary to go to the original data tables for each country to identify the cause of these discrepancies. The other issues described are either structural issues with the CRF tables, or are clear, specific errors (e.g. incorrect units).

We agree that the Kyoto-GHG data may be more widely used than the full dataset, and propose to make that data more readily available on our website ([Paris-Reality-Check](#)), but prefer to keep the main data repository as a single file. With many data processing tools, it should be relatively easy to filter the data for the categories and gases of interest.

In Figure 4, left panel LULUCF appears on rough estimate about cumulative sink of 20% or so. From global carbon budget also in ESSD, for decade 2007 to 2016, fossil fuel emission roughly 10 GtC with a net land impact (sink minus sources) of very roughly 2 GtC, so again roughly 20%. Thinking about validation, for which these authors address only the PRIMAP product vs the original CFRs. But they could perhaps validate their PRIMAP outcomes against carbon budget because the latter uses several sources in addition to the UNFCCC reports used here? Even a brief mention of validation in text would strengthen reader confidence in their PRIMAP outcomes?

As we understand it, you are here suggesting that we should cross-check the country-reported data against an independent estimate for further verification. Our goal with

this study was not to verify that the country reported data is correct, but to make the dataset itself more accessible. In doing so, we want to ensure that we have not made mistakes in the processing and therefore make checks for internal consistency as this is an indicator that the data is correctly processed.

A possible use of this dataset is to further verify country reported data. Verification against the GCB is difficult as the data sources are slightly different, as are the categories of emissions. In the PRIMAP-hist dataset (Gütschow et al., 2016) we utilise several different emissions data sources (including CRF data) and in future work intend to include a comparison of these different sources.

We therefore consider the suggestion here out of the scope of this particular paper but will consider it for other analysis.

Also in Figure 4, right hand panel about bunkers, we should interpret this more as who reports and who doesn't rather than as actual emission numbers?

We don't think it's possible to interpret completeness of reporting from the data as shown. The wide spread in data results more from the fact that the share of emissions from each country is shown, thereby reflecting the geographic location and main industries of the countries, some of whom have a higher share of international shipping and aviation activities in their economies. Reporting of emissions from international bunkers is, however, somewhat complicated.

As with most activities, the IPCC Guidelines describe three options for estimating emissions from aviation and marine bunkers with increasing complexity (See Ch 3.6 and 3.X of IPCC 2006 Reporting Guidelines). The lower tiers for aviation are based on fuel sales data only, whereas the upper tier (3) is based on activity data (e.g. how many flights with which type of aircraft between which airport). Both tiers for shipping (water-borne navigation) are based on fuel sales, with the upper tier incorporating country specific emissions factors and ship movement data where available.

The second challenge with reporting bunker emissions is in separating international and domestic activities, particularly when basing the reporting on fuel sales. The difference between domestic and international is based on the departure and arrival destinations (and not airline, ship ownership, or flag state).

The IPCC suggest a few methods for distinguishing between the two; taxation data where "fuel sold for domestic use is subject to taxation, but that for international use is not", or bottom-up data from airlines that may know the fuel consumption for domestic and international flights. The definition of 'international' and 'domestic' can lead to data discrepancies between country reported data and other sources.

## **Anonymous Referee #2**

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Thanks for the excellent paper and data. I have only minor comments, as the paper presents a well done analysis, including quite some technical details. The transparency of the results is very good.

Minor comments: 1/ I would also present the impact of the new reporting guidelines on the emissions relative to 1990 levels (of BY emissions), including and excluding LULUCF, in a table. The %-changes are presented on page 5, the second paragraph, but I would also present an overview in a Table.

Thank you for the suggestion, we think that it is a great idea of a use for this dataset and is a reason we produced it. However, this paper is about describing the data and how it was prepared and we prefer not to include analysis of the data. In section 3.2 of the manuscript we describe the change in average emissions over the full reporting time-period, rather than changes in emissions relative to the base year, that is change in trends when using alternate guidelines. The exercise you suggest is non-trivial (e.g. which year to plot relative to 1990, base year emissions for targets are not always the same as total reported emissions, etc.).

We will consider doing such analysis with this data in the future.

2/ Now the results of three countries are highlighted. I would also recommend to include a few additional other countries, as the current figure brings these countries on the spotlight.

The three displayed in this figure were specifically chosen as they are the only three countries that clearly have a shift in total LULUCF emissions associated with the change in guidelines. Reported historic LULUCF emissions change a lot for countries through time and for multiple reasons (e.g. updated activity data, changes in methodology, choice of which tier of reporting guidelines to use) and plots for other countries are therefore much more complicated. We therefore prefer not to add additional countries as they would rather raise issues with reporting in addition to the transition to the new reporting guidelines, which is the focus of this paper and dataset.

**Anonymous Referee #3**

I think that this manuscript is well written and very useful for analyzing the large emission data and check possible errors in the reported data. I recommend this manuscript for publication.

Thank you for your positive feedback, we are glad that you find the dataset useful.

#### **Anonymous Referee #4**

Overall, this is a great study, very detailed and sophisticated. Thanks for such a good work. This data can be used for many advanced research and publications. Recommended to be published in ESDD after few, but not major clarifications.

Thank you for your feedback and constructive comments below. We hope we have sufficiently addressed your points.

In the line 27<sup>th</sup>, it is stated that “Kazakhstan is included in the data set as a member of Annex I countries for the purpose of the Kyoto Protocol”. What does this mean? Kazakhstan is considered as Annex-I because it ratified the Kyoto Protocol? If this is the reason, many other non-Annex I countries ratified Kyoto Protocol as well. Why only including Kazakhstan? Could you please clarify this little bit more?

The UNFCCC website notes on the [download page](#) for national inventory submissions and CRF data that:

*“In accordance with the COP conclusion (FCCC/CP/2001/13/Add.4, section V.C.) and following ratification by Kazakhstan of the Kyoto Protocol on 19 June 2009 and its entry into force on 17 September 2009, Kazakhstan is considered an Annex I Party for the purposes of the Protocol but remains to be a non-Annex I Party for the purposes of the Convention.”*

The relevant COP conclusion states:

*“C. Amendment proposed by Kazakhstan to add its name to the list in Annex I to the Convention<sup>2</sup>*

*1. At its 8 plenary meeting, on 9 November 2001, the Conference of the Parties, acting upon the recommendation of the Subsidiary Body for Implementation, took note that Kazakhstan, in accordance with Article 4, paragraph 2(g), had notified the Depositary on 23 March 2000 that it intended to be bound by Article 4, paragraphs 2(a) and (b) of the Convention. The Conference further noted that the Depositary had informed the other signatories and Parties of that notification, and that, upon ratification of the Kyoto Protocol by Kazakhstan and its entry into force, Kazakhstan becomes a Party included in Annex I for the purposes of this Protocol In accordance with Article 1, paragraph 7 of the Protocol.*

*2. The Conference of the Parties noted the interest expressed by Kazakhstan in engaging in negotiations with a view to defining a quantified emission limitation or reduction commitment for Kazakhstan under Annex B of the Protocol.*

*3. The Conference of the Parties recognized that Kazakhstan will continue to be a Party not included in Annex I for purposes of the Convention.*

<sup>2</sup> *The heading of this item reflects the original request of Kazakhstan of 24 April 1999. The heading has been retained although this conclusion by the Conference of the Parties does not imply any amendment of the lists in the Annexes to the Convention.”*

We have added a reference to the COP decision to the manuscript, and the following additional sentence for further clarification:

*“Kazakhstan voluntarily elected to be considered as an Annex I Party for the Kyoto Protocol, and thereby to have a quantified emissions reduction target and associated reporting obligations.”* (Page 2 | Lines 3-4)

Also, in the following sentence it is stated that Malta and Cyprus are reporting their emissions as members of European Union. Can you provide some reference for this, where do you get such information?

After joining the European Union, Malta and Cyprus agreed to be bound by the EU emissions reduction targets and enter into the EU Emissions Trading Scheme. They also were also officially added to the list of countries in Annex one of the Convention through amendments. The official decisions can be found on the UN website here:

Cyprus - <https://treaties.un.org/doc/Publication/CN/2012/CN.355.2012-Eng.pdf>

Malta - <https://treaties.un.org/doc/Publication/CN/2010/CN.237.2010-Eng.pdf>

We have updated the sentence in the original text to better reference and describe the situation. We also include a reference to additional countries that joined Annex I in the late 1990s. Malta and Cyprus are highlighted as unique because they joined Annex I and began reporting CRF data after the initial years of CRF data submission.

*“Several Parties (Croatia, Cyprus, Czech Republic, Liechtenstein, Malta, Monaco, Slovakia, Slovenia) were not originally listed in Annex I but have subsequently been added through amendments to the Convention. Most recently, Malta (United Nations, 2010) and Cyprus (United Nations, 2012a) requested to be included in Annex I after joining the European Union (EU) and adopting the EU-wide emissions reduction targets under the Doha amendments (United Nations, 2012b).”*

(Page 1| Line 26 to Page 2 | Line 1)

Lastly, at the data description file on page 2, it is stated there are 3 .csv files in the date sets. However, there are only 2 csv files in addition to two other text files. The following file is not there: “PRIMAP-crf-IPCC2006-category-codes.csv” Could you please include this file as well.

We apologise for this omission and now include the file in the data repository. The same file is also available as supplementary material to the paper.

Please also check the correction of the measurements, there are several variables/units, a mistake easily can be made. Since I am not able to go over each calculation in details, I can only suggest you making sure that there is no mistake in the calculations.

Thank you for noting the challenges with ensuring correct units and conversions. The PRIMAP emissions module itself has unit checks built-in to the framework and we further check the unit conversions, particularly to GWP baskets, by cross-checking against the country-reported calculations and also against the National Inventory Reports. This process is described in the Methods section of the paper (2.1).

After these corrections and clarifications, I recommend the study to be published in ESSD.

# PRIMAP-crf: UNFCCC CRF data in IPCC 2006 categories

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**Abstract.** All Annex I Parties to the United Nations Framework Convention on Climate Change (UNFCCC) are required to report domestic emissions on an annual basis in a 'Common Reporting Format' (CRF). In 2015, the CRF data reporting was updated to follow the more recent 2006 guidelines from the IPCC and the structure of the reporting tables was modified accordingly. However, the hierarchical categorisation of data in the IPCC 2006 guidelines is not readily extracted from the reporting tables. In this paper, we present the PRIMAP-crf data as a re-constructed hierarchical dataset according to the IPCC 2006 guidelines. Furthermore, the data is organised in a series of tables containing all available countries and years for each GHG individual gas and category reported. It is therefore readily usable for climate policy assessment, such as the quantification of emissions reduction targets.

In addition to single gases, the Kyoto basket of greenhouse gases (CO<sub>2</sub>, N<sub>2</sub>O, CH<sub>4</sub>, HFCs, PFCs, SF<sub>6</sub>, and NF<sub>3</sub>) is provided according to multiple global warming potentials. The dataset was produced using the PRIMAP emissions module. Key processing steps include; extracting data from submitted CRF Excel spreadsheets, mapping CRF categories to IPCC 2006 categories, constructing missing categories from available data, and aggregating single gases to gas baskets. Finally, we describe key aspects of the data with relevance for climate policy; the contribution of NF<sub>3</sub> to national totals, changes in data reported over subsequent years, and issues or difficulties encountered when processing currently available data. The processed data is available under an Open Data CC BY 4.0 license, and available at <http://doi.org/10.5880/pik.2018.001>.

## 1. Introduction

Under the United Nations Framework Convention on Climate Change (UNFCCC), Annex I countries are required to report detailed GHG emissions inventories to the UNFCCC on an annual basis. All data are reported in the 'Common Reporting Format' (CRF) Excel tables and accompanying National Inventory Reports (NIRs), which are made available on the UNFCCC website (UNFCCC, 2017c). Several Parties (Croatia, Cyprus, Czech Republic, Liechtenstein, Malta, Monaco, Slovakia, Slovenia) were not originally listed in Annex I but have subsequently been added through amendments to the Convention. Most recently, Malta (United Nations, 2010) and Cyprus (United Nations, 2012a) requested to be included in Annex I after joining the European Union (EU) and adopting the EU-wide emissions reduction targets under the Doha amendments (United

Nations, 2012b). In addition to those Parties now listed in Annex I of the Convention (UNFCCC, 1992), Kazakhstan is considered a member of Annex I for the purpose of the Kyoto Protocol (COP7 Decision FCCC/CP/2001/13/Add.4, section V.C.). Kazakhstan voluntarily elected to be considered as an Annex I Party for the Kyoto Protocol, and thereby has quantified emissions reduction targets and associated reporting obligations. Malta and Cyprus also report CRF data as members of the European Union, but are not listed under Annex I of the Convention.

Prior to 2015, CRF data were reported following guidelines published by the IPCC in 1996 (IPCC, 1996), which detail the methodologies that should be used to calculate the inventories. Since 2015, reporting follows revised IPCC guidelines published in 2006 (IPCC, 2006). The methodologies to calculate emissions are primarily based on combining activity levels and emissions factors. For example, how many cows does a country have (activity), and what are the typical methane emissions per cow (emissions factor)? For each source, multiple methods of calculation are possible with increasing complexity from tier 1 to tier 3. In general, tier 1 methods use a basic calculation and default emissions factors, tier 2 incorporates country specific emissions factors, and tier 3 may include advanced modelling approaches alongside country specific emissions factors. Tier 3 approaches are generally considered more accurate but may require more information and are more difficult to calculate. In addition to revisions in methodology and emissions factors, the IPCC 2006 guidelines (IPCC, 2006) and supplementary methods arising from the Kyoto Protocol (IPCC, 2013) updated the range of activities and gases covered, and the hierarchical categorisation of the data. Major changes included (1) Combining categories 2 (Industrial Processes) and 3 (Solvent and Other Product Use) to the new category Industrial Processes and Product Use (IPPU) and (2) combining the Agriculture and Land-Use, Land-Use Change, and Forestry (LULUCF) categories into one Agriculture, Forestry, and Other Land-Use (AFOLU) category.

Although the more up to date methodological guidelines are now followed, the CRF reporting tables still closely resemble the structure of the previous version. For example, Agriculture and LULUCF emissions are still reported separately and top-level tables of fugitive emissions from fuels still reflect IPCC 1996 categories. The legacy effect is primarily a result of the negotiating process.

A consistent and complete hierarchical dataset according to the 2006 guidelines and categories allows (1) checks on data consistency to be made, and (2) comparison with other datasets. For these reasons, we have extracted and processed all reported CRF data and re-organised it to the IPCC 2006 categorisation (Fig. 1). Furthermore, we make the data available in an easily used, machine readable, comma-separated values (CSV) file with aggregate gas baskets according to multiple global warming potentials (GWPs). Each table contains data for all countries and years available, allowing for time series analysis and comparison between countries. The data described and presented in this paper is that published in 2017 and available for download by 15 December, 2017. CRF data is published annually in April and, where possible, that new data will be published in the same format and following the methods presented here.

## 2. Methods

### 2.1. General approach

Annual CRF data for all reporting countries is available from the UNFCCC website (UNFCCC, 2017c). The CRF data for each country consists of one file for every inventory year, currently at least 26 per country (1990 to 2015 in data released in  
5 2017), with some countries reporting additional years to include their Kyoto Protocol base years (1986-1989). Each file contains detailed data for separate categories and summary tables as required by UNFCCC decisions (UNFCCC, 2017a).

To prepare the PRIMAP-crf dataset, the necessary data is read, processed, and prepared using the PRIMAP emissions module (Nabel et al., 2011). The PRIMAP emissions module is a MATLAB (2017) based tool with a custom database structure ('PRIMAPDB') that can handle conversion of GHG emissions data with different units and GWPs. Each table in the database  
10 consists of a country-year matrix and is defined in terms of an entity (e.g. CO<sub>2</sub>), category (e.g. IPC4-IPC1 (Energy, where 'IPC' indicates the categorisation system AFOLU)), class (e.g. TOTAL), type (e.g. NET), scenario (e.g. HISTORY), and source (e.g. CRF2017).

Data in the individual spreadsheets is first mapped to the PRIMAPDB table structure according to a specifications file. As the data is not reported directly against the IPCC 2006 categorisation, we define a set of categories that are specific to the CRF  
15 data and are later used to build the IPCC 2006 categories from sub-categories. Categories in the PRIMAP emissions module but outside the main IPCC 2006 categorisation are denoted as "M" categories in the emissions module and in this paper (e.g. M0EL is "national total excluding LULUCF"). Not all data available in the CRF tables is read in to the PRIMAP database. The level of detail is determined based on two criteria; (1) data that is useful for policy assessment, or (2) data that is required to build complete categories from the bottom up. Upon read-in to the PRIMAPDB, data from individual CRF tables is  
20 aggregated across countries and years to give tables for individual gases, categories, class, and type.

After raw data is read-in, the full IPCC 2006 category hierarchy is constructed by addition of sub-categories. Any directly read data from higher sub-categories is not replaced at this stage, rather the addition of sub-categories is used to fill in any gaps where data is not directly reported.

Next, 'gas baskets' are generated by summing across gases to generate tables with all HFCs (hydrofluorocarbons), PFCs  
25 (perfluorocarbons), F-gases (HFCs, PFCs, SF<sub>6</sub>, and NF<sub>3</sub>), or Kyoto-GHG (CO<sub>2</sub>, N<sub>2</sub>O, CH<sub>4</sub>, HFCs, PFCs, SF<sub>6</sub>, and NF<sub>3</sub>). Each gas basket is created from individual gases according to four different sets of GWPs - Second Assessment Report (SAR), Fourth Assessment Report (AR4), Fifth Assessment Report (AR5), and AR5 with carbon-cycle feedbacks (AR5CCF) (IPCC, 1995, 2007, 2014). Some gas species are included in later IPCC reports but not in earlier ones. Those gases for which a GWP estimate was not available at the time of publication of a particular report are assigned a GWP according to the next report in  
30 which a GWP estimate was given (see Supplementary Material for GWPs used in PRIMAP-crf).

Finally, the data is checked and verified for consistency and accuracy against the original data. First, we verify that the data is internally consistent in that each category in the hierarchy is equal to the sum of its sub-categories. This check is performed

across all gases and countries individually, and both for categories that were generated in post-processing and those that were directly read-in. For example, we verify that category 3, created as the sum of its sub-categories, is also equal to the sum of the directly read Agriculture (MAG) and LULUCF (MLULUCF) categories. If the discrepancy between different category levels exceeds 0.01% for any country or year, that data is flagged and checked. Where possible, discrepancies are fixed and, where not, we note them in the results section below. Second, a manual check is performed against the raw tables and national inventory reports, particularly for the top-level categories (e.g. IPC0). Third, we compare top-level categories with data downloaded directly from the UNFCCC data portal (UNFCCC, 2017b). Fourth, data for main categories and gases is plotted against data from previous years to check for major changes. The source of any major differences between data in different years is verified to ensure that it is a real change in the raw data and not an error in the read-in process.

## 10      **2.2. AFOLU**

The most challenging part of the IPCC 2006 hierarchy to construct from CRF data is the AFOLU category (3). This is because AFOLU data is still reported in two entirely separate sections (CRF Table 3. Agriculture and Table 4. LULUCF), but the IPCC 2006 categorisation integrates emissions from some Agriculture and LULUCF sources into the same categories.

Categories 3A and 3B are exclusively Agriculture and LULUCF respectively, but category 3C combines data from both sectors (Fig. 2). To construct the category 3C sub-categories, multiple PRIMAP 'M' categories were created and data read-in at its most detailed level to these categories. A full description of the mapping from CRF data to PRIMAP-crf categories can be found in the Supplementary Material.

### **2.3. Bunkers and Multi-lateral operations**

Emissions from international aviation and marine bunkers, and multi-lateral operations are included in the IPCC 2006 categorisation and are reported to the UNFCCC. However, emissions from these sectors are not included in the national totals for reporting or accounting purposes under the UNFCCC and are therefore also excluded in the PRIMAP-crf hierarchy and national totals. Instead, data for these sectors is provided in separate 'M' categories (Table 1). Only France, Slovenia, Sweden, and Ukraine currently report emissions from multilateral operations.

## **3. Results**

### 25      **3.1. National totals**

The PRIMAP-crf dataset is intended for multiple uses. Two key examples include (1) comparison of national total emissions between Parties (Fig. 3) and (2) analysis of the share of emissions from each major category within the national total (Fig. 4). In Fig. 4 we also show the additional emissions from international bunkers and how these compare to national totals.

### 3.2. Changes in reported data through time

Annual updates to the data reported by countries in their national inventories do not only extend the time series but also include updates to previous data years according to revisions in source data, updates in methodologies, and updates in reporting guidelines. The extent to which the reported data changes varies by sector; energy emissions have a low uncertainty compared to LULUCF emissions and accordingly do not undergo such significant annual modifications.

We do not identify the reason for all updates to historic time series, but isolate significant changes related to the transition to new reporting guidelines. We find that the 1990 to 2015 reported national total emissions (excluding LULUCF) for Monaco, Croatia, Hungary, and Cyprus all dropped significantly (>5% on average over 1990-2012) between the 2014 and 2017 releases, and that Russia and Malta's reported emissions increased by >5% on average over 1990-2012. Average reported total emissions (excluding LULUCF) for Australia, Bulgaria, France, Lithuania, Portugal, and Kazakhstan all changed by 3-5% over the same period between the 2014 and 2017 versions.

In the LULUCF sector, we identify three countries for which the new guidelines introduced substantially different overall emissions levels - Iceland, Ireland, and the Netherlands (Fig. 5). Updates to emissions factors for drained organic soils and methods for accounting for emissions associated with peat extraction result in much higher reported LULUCF emissions from Iceland and Ireland. LULUCF emissions from the Netherlands are also significantly higher, but the increases are distributed across several land-use categories and not so readily attributable to a single source. The new guidelines also introduced significant changes to the LULUCF time series from many other countries.

### 3.3. Data Issues

The current format of the CRF data allows for some flexibility in reporting for countries. As a result, it was not possible to obtain data for all categories for all reporting countries. In addition, the detailed checks revealed some issues in the raw data where data reported in one table was not consistent with data reported in another table. Here we briefly describe those issues and how it impacts the final dataset. We first describe structural issues with the data tables and then some country specific inconsistencies in the reported data. For three of the country specific inconsistencies, we provide additional data in the supporting information.

Reported cCountry data ~~reported to the UNFCCC~~ undergoes mandatory review under the UNFCCC by an Expert Review Team according to the Guidelines for review under Article 8 of the Kyoto Protocol (most recently updated in Decision 13/CP.20). Expert review reports are made available on the UNFCCC website (UNFCCC, 2016). Many of the country specific issues identified here may be picked up in the UNFCCC Expert Review process and corrected in future updates of the CRF data. If so, future updates of PRIMAP-crf will also incorporate these corrections.

### 3.3.1. Table construction

#### Fugitive emissions from solid fuels

Some sub-categories of emissions from category 1B1A 'Coal mining and handling' are not explicitly and separately reported in the current CRF tables and therefore could not be included as separate categories in PRIMAP-crf. These sub-categories are  
5 1B1B 'Uncontrolled Combustion, and Burning Coal Dumps' and 1B1A14 'Flaring of drained CH<sub>4</sub> or Conversion of CH<sub>4</sub> to CO<sub>2</sub>'.

Category 1B1A is reported in table 1.B.1 of the CRF tables, which includes lines for '1.B.1.b. Solid fuel transformation' and '1.B.1.c. Other (please specify)'. Additional information indicates that fugitive emissions from coke and charcoal production may be included in the 1.B.1.b line, and that the 'Other' category may be used for 'reporting any other solid fuel related activities  
10 resulting in fugitive emissions, such as emissions from waste piles.' If emissions from either IPCC 2006 category 1B1B or 1B1A14 are calculated and reported in either of these lines, then they are included in the national totals (category 0) but cannot be reported explicitly as separate categories in the PRIMAP-crf data.

A further issue with the CRF tables for category 1B1 is that two countries (Australia and United Kingdom) report N<sub>2</sub>O emissions from category 1B1 in the summary tables (e.g. Table 1s2 and Table 10s4) but it's not possible to include the details  
15 on N<sub>2</sub>O emissions from this category in the Table 1.B.1, which only has columns for CO<sub>2</sub> and CH<sub>4</sub>. Because the CRF data for category 1B1 is read from Table 1.B.1 and not the summary tables, a discrepancy occurs when comparing the category 1B total for N<sub>2</sub>O with the sub-categories 1B1, 1B2, and 1B3 for Australia and the United Kingdom. The sub-totals are up to 0.2% too low for the United Kingdom, and 0.9% too low for Australia due to the missing category 1B1 data.

#### IPC1A2 sub-categories for N<sub>2</sub>O, CH<sub>4</sub>, and CO<sub>2</sub>

It is not mandatory to report all sub-categories of category 1A2 (fuel combustion for manufacturing industries and construction) explicitly in CRF tables. Sub-categories of 1A2 are reported in CRF table 1.A(a)s2 with explicit lines for 1A2A through 1A2F  
20 (Fig. 6) and optional reporting under 'Other' for categories 1A2G through 1A2M. Bulgaria, Germany, Estonia, France, Ireland, Italy, and Japan do not fully report these additional sub-categories and the sum of their 1A2 sub-categories in PRIMAP-crf is therefore not equal to the category 1A2 total. However, for category 1A2 and higher levels in the hierarchy, the data is complete  
25 and correct.

### 3.3.2. Country specific

Some data issues are not structural issues with the CRF table set-up but result from the way in which individual countries report the data. Here we describe inconsistencies found for individual countries during the read-in and testing process.

#### Germany

Germany does not report CH<sub>4</sub> emissions from drainage and rewetting of soils on settlements land in table 4(II) or in table 4. The data is listed as 'IE' (Included Elsewhere) but it is not apparent where. The documentation notes suggest that it is included

in table or category 4E. However, CRF Table 4.E is for CO<sub>2</sub> only, so it cannot be reported there. As a result, the PRIMAP-crf tests that compare category 3 and category 3 sub-categories with the directly read-in LULUCF data fail for Germany.

Germany also failed tests that check whether the national totals of HFCs, PFCs, and F-gases are equal to the sum of the main sub-categories, in this case just category 2. The tests only fail for the final year (2015) and for AR4 GWPs. This indicates a discrepancy in the original data. Inspection of Table 10s5 shows that the value reported for 2015 for the HFC and PFC baskets is approximately 1000 times higher than that reported in 2014, suggesting a units error in reporting. We expect this error to be corrected in future submissions. The spurious data points are corrected in post-processing and not present in the PRIMAP-crf source.

### **Kazakhstan**

10 In the raw Excel file (dated 17-11-2017) for 1993, the CO<sub>2</sub> emissions factor for gas/diesel oil for domestic navigation is too high by a factor of 10<sup>6</sup>, resulting in emissions for the category 1A3D2 that are too high by the same magnitude for that year. In the PRIMAP-crf dataset we manually replace this data point and use the corrected data to recalculate the higher-level categories. The emissions factor was corrected from 74.1x10<sup>6</sup> to 74.1 (t/TJ), resulting in 40.502 kt CO<sub>2</sub> for category 1A3D2 from Kazakhstan in 1993, which fits with the full time-series. This correction is applied to all affected higher level categories  
15 and gas baskets in the final PRIMAP-crf dataset.

### **Lithuania**

N<sub>2</sub>O emissions in category 3 (AFOLU) for Lithuania do not equal the sum of reported emissions under Agriculture and LULUCF. This discrepancy occurs because total category 3 emissions are calculated from the sum of sub-categories (Fig. 2) and N<sub>2</sub>O data is not completely reported in LULUCF sub-categories for Lithuania. The issue occurs with sub-category 3C4  
20 (Other land), which is partially reported in CRF table 4(III) and read-in under PRIMAP category M3C4LUBOTH. However, the total N<sub>2</sub>O LULUCF emissions from Other Land reported in summary table 4 are higher than those reported in table 4(III). Table 4 is also not internally consistent and it is not clear from the CRF tables what the source of the additional emissions is. As a result, the PRIMAP-crf data fails tests for N<sub>2</sub>O that compare category 3 with LULUCF. The LULUCF and national total (category 0) values are correct. The error propagates to the Kyoto-GHG basket, which includes N<sub>2</sub>O.

### **Luxembourg**

N<sub>2</sub>O emissions data for category 3 (AFOLU) are also incorrect for Luxembourg for similar reasons to Lithuania. Data is reported under 'Other land' in CRF Table 4 that is not reported in any other table, including Table 4(III) where it would be expected. As the data is not read-in to a sub-category, the resulting aggregated category 3 is not consistent with the directly read-in LULUCF category. As with Lithuania, category 3 is incorrect, but the LULUCF and national total categories are  
30 correct. The error propagates to the Kyoto-GHG basket for category 3, which includes N<sub>2</sub>O.

## Norway

Norway fails a test for N<sub>2</sub>O emissions that compares the directly read-in LULUCF total to the sum of its components. The error averaged over all years is 0.017%. The source of the discrepancy is unclear but CRF Table 4 is internally inconsistent suggesting some missing data in sub-categories. Because the error is small, tests on higher level categories and aggregate gas baskets are all passed.

## Sweden

For the year 2015, Sweden reports fugitive emissions from Oil production in Table 1.B.2, item 1.B.2.a.Oil. However, for CH<sub>4</sub> and CO<sub>2</sub>, no data is reported in the subsectors. For N<sub>2</sub>O, no data is reported at all in Table 1.B.2, but data is reported in Table 1s2, item "2. Oil and natural gas and other emissions from energy production".

A further problem in Sweden's CRF reporting is an inconsistency between tables. In Table 1.s.2, item "c. Other (as specified in table 1.B.1)" N<sub>2</sub>O emissions are reported. However, Table 1.B.1 does not allow reporting of N<sub>2</sub>O emissions and thus the sum obtained from Tables 1.B.1 and 1.B.2 does not coincide with the data read from Table 1.s.2.

In category 2 (Industrial processes and product use), 0.36 kt of methane emissions are reported for 2015 while the data available for subsectors only sums to 0.01 kt. There are discrepancies in subcategories: the category 2B10 (chemical industry - other) has no data reported for CH<sub>4</sub> in Tables 2(I)s1 and 2(I).A-Hs1 but a subcategory (other inorganic chemical products) contains data. But probably most important is that nothing is reported in Table 2(I).A-Hs1, item "2.H.1 Pulp and paper" where the majority of CH<sub>4</sub> emissions for category 2 was reported for 2014.

Consequently, CRF data for Sweden fails tests that compare category 1.B to its subcategories for CO<sub>2</sub>, CH<sub>4</sub>, N<sub>2</sub>O and the Kyoto-GHG basket, as well as tests that compare category 2 to its subcategories for CH<sub>4</sub>. The errors propagate to the Kyoto-GHG basket.

### 3.4. NF<sub>3</sub>

For the second period of the Kyoto Protocol (2013-2020), NF<sub>3</sub> emissions must be reported and accounted in all historical data. Emissions of NF<sub>3</sub> are primarily from the chemical and electronics industries (CRF Tables 2(I)s1 and 2(I)s2). Despite its relatively high 100-year GWP of 16,100 (Myhre et al., 2013), the share of emissions from NF<sub>3</sub> is low; the average annual contribution of NF<sub>3</sub> to total Kyoto-GHG (AR4 GWPs) since 1990 ranges between 0.000032% for Canada and 0.053% for Japan (only 13 countries report NF<sub>3</sub> emissions). Japan and the USA are the two major emitters of this gas-, but NF<sub>3</sub> emissions from Japan reduced by more than half between 2013 and 2015.

### 3.5. Indirect N<sub>2</sub>O and CO<sub>2</sub> emissions

Another addition for the second commitment period of the Kyoto Protocol is that countries may now also report indirect N<sub>2</sub>O and CO<sub>2</sub> emissions from additional sectors, whereas previously only indirect N<sub>2</sub>O from agriculture was explicitly listed in the reporting tables. Indirect emissions are greenhouse gases that result from secondary chemical reactions of precursor substances.

5 Indirect CO<sub>2</sub> emissions are the result of oxidation of carbon containing non-CO<sub>2</sub> gases, such as CH<sub>4</sub>, CO, and non-methane volatile organic compounds (NMVOC). Indirect N<sub>2</sub>O emissions have two primary sources; (1) volatilisation and subsequent atmospheric deposition of NH<sub>3</sub> and NO<sub>x</sub>, and (2) leaching and runoff of added N to water systems, such as from the use of nitrogen fertilisers in agriculture (IPCC, 2006).

10 The UNFCCC COP Decision 24/CP.19 states that: "29. In addition, Annex I Parties should provide information on the following precursor gases: carbon monoxide (CO), nitrogen oxides (NO<sub>x</sub>) and non-methane volatile organic compounds (NMVOCs), as well as sulphur oxides (SO<sub>x</sub>). Annex I Parties may report indirect CO<sub>2</sub> from the atmospheric oxidation of CH<sub>4</sub>, CO and NMVOCs. Annex I Parties may report as a memo item indirect N<sub>2</sub>O emissions from other than the Agriculture and LULUCF sources. These estimates of indirect N<sub>2</sub>O should not be included in national totals. For Parties that decide to report indirect CO<sub>2</sub> the national totals shall be presented with and without indirect CO<sub>2</sub>." (UNFCCC, 2017a)

15 Indirect N<sub>2</sub>O emissions from the AFOLU sector are therefore included in the national totals (category 0), but indirect emissions from other sectors are not. In PRIMAP-crf, category 0 'national total' also excludes indirect CO<sub>2</sub> emissions. In PRIMAP-crf, national totals including indirect CO<sub>2</sub> are included as category 'M0INDRCT', and separate indirect N<sub>2</sub>O and CO<sub>2</sub> emissions are contained as categories M0N2OIND and M0CO2IND respectively.

20 As reporting of indirect emissions is optional, data is not available for all [reporting](#) countries. Countries currently reporting indirect N<sub>2</sub>O emissions from non-AFOLU sectors are Belarus, Bulgaria, Czech Republic, Denmark, Finland, Italy, Norway, Romania, Sweden, Switzerland, and the United Kingdom. Countries currently reporting indirect CO<sub>2</sub> emissions are Canada, Czech Republic, Denmark, Finland, Japan, Latvia, Netherlands, Portugal, and Switzerland.

25 Note that it is necessary to distinguish between different usages of the term 'indirect emissions'. The indirect emissions referred to here are emissions resulting from subsequent reactions of GHG precursors. However, businesses, industry and the IPCC also use indirect emissions to refer to emissions that result from the activities of that entity, but that are not under their direct control (GHG Protocol, 2017). For example, a business may include the emissions associated with heating its offices as indirect emissions.

### 4. IPCC 1996 categories

30 The 1996 categories are still useful for comparison and combination with older data sources. We therefore created a mapping of higher level 2006 categories to 1996 categories to enable the use of the PRIMAP-crf dataset in such cases, especially for

the forthcoming v1.2 of the PRIMAP-hist historical time-series dataset (Gütschow et al., 2016). As the new CRF tables are very similar to the old IPCC 1996 CRF tables, building the 1996 categories can be achieved with reading a few additional items from the tables. Table 2 shows which IPCC2006 categories are used to create each IPCC1996 category. Some additional items from the CRF tables are needed and read into “M” categories. The categorical detail is selected according to those required for the PRIMAP-hist dataset (Gütschow et al., 2016). Consequently, we create the main categories (1–7) for all gases and additionally the subcategories of categories 1 and 2 for CO<sub>2</sub>. National totals under the two sets of guidelines differ for two primary reasons: (1) the IPCC1996 guidelines do not include all sources covered by the 2006 guidelines. At the level of detail we employ for the conversion, this only affects the carbon capture and storage (CCS) related emissions reported in the new category 1C, which are not included in 1996 categories. (2) For the creation of IPCC 1996 categories 1 and 2 we need detailed subcategories which are not reported in full detail by all countries. In other cases, emissions are not reported consistently across the different tables. This means that sometimes we cannot perfectly create the IPCC 1996 categories. Both effects are very small.

In the PRIMAP emissions module and in the published PRIMAP-crf data, we distinguish between the two sets of guidelines using separate sets of category codes. Data following the hierarchy of the IPCC2006 guidelines have category codes prefixed with ‘IPC’, and data following the 1996 categories have category codes with the prefixed ‘CAT’.

## 5. Data Availability

The dataset is available from the GFZ Data Services under doi:10.5880/PIK.2018.001 (Jeffery et al., 2018). When using this dataset, or one of its updates, please cite this paper and the precise version of the dataset used. Please also consider citing the original UNFCCC source (UNFCCC, 2017c) when using this dataset. The data presented in this paper was released in 2017 and includes all data revisions until 15 December 2017.

New versions of the UNFCCC CRF data are released annually with an additional year of data. Some countries also submit revised versions of their data through the year. Where possible, the PRIMAP-crf data will be updated accordingly and a revised dataset released.

Data releases with an additional year of data are indicated in the naming of the data - the year of data publication is indicated by the dataset name, e.g. PRIMAP-crf 2017-v1 data includes data first released by countries in 2017. Inclusion of subsequent data revisions from the same year are indicated by the version number, for example PRIMAP-crf 2017-v2 includes all CRF2017 data published by 1 June 2018.

## 6. Conclusions

We provide a processed dataset of the CRF data reported to the UNFCCC in an easily used format (PRIMAP-crf) and accompanied by a detailed description of its derivation. Two key facets of the processed data are that (1) data for all reporting

countries and years is readily accessed for a given gas and category, and (2) the data is categorised in a consistent hierarchy according to the IPCC 2006 guidelines. In addition, we also provide data in top-level categories under the IPCC1996 categorisation.

PRIMAP-crf data (Jeffery et al., 2018) is provided under an open CC BY 4.0 licence and can be accessed at  
5 <http://doi.org/10.5880/pik.2018.00>. The data is provided in a machine-readable format (CSV) for bulk download. As such it can be used easily and flexibly, and is not tied to any specific software or operating system.

Some structural issues with the current table format have been identified and country specific issues with reported data have been highlighted.

## 10 7. Author Contributions

L.J. wrote the manuscript with contributions from J.G. and R. Gieseke. L.J., J.G., and R. Gebel processed and prepared the dataset. L.J. and J.G. maintain the PRIMAP emissions module.

## 8. Acknowledgements

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The development of this dataset and the paper made use of several open source software tools; we acknowledge and thank the developers of colorbrewer2.org and MacDown. The tree diagram figures were constructed based on D3 code by Mike Bostock.

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## 10. Figures

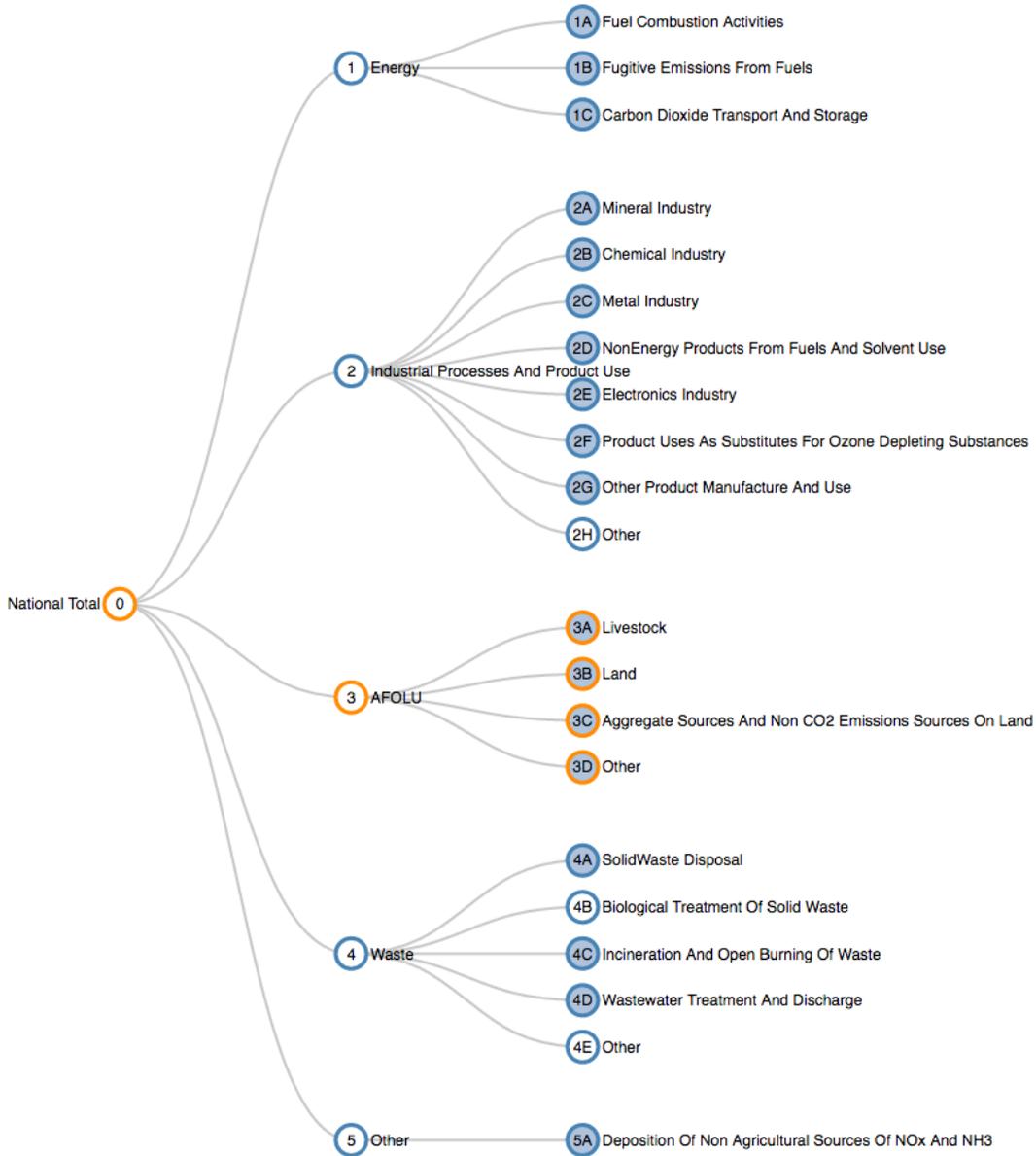


Figure 1: Top three levels of the IPCC 2006 categorisation. Filled circles indicate that further sub-categories exist. Orange circles indicate that the category is generated by aggregation of sub-categories in PRIMAP-crf. A fully expandable and explorable version of this graphic is available at <https://www.pik-potsdam.de/paris-reality-check/primap-crf/>.

○ Combined ○ LULUCF ○ Agriculture

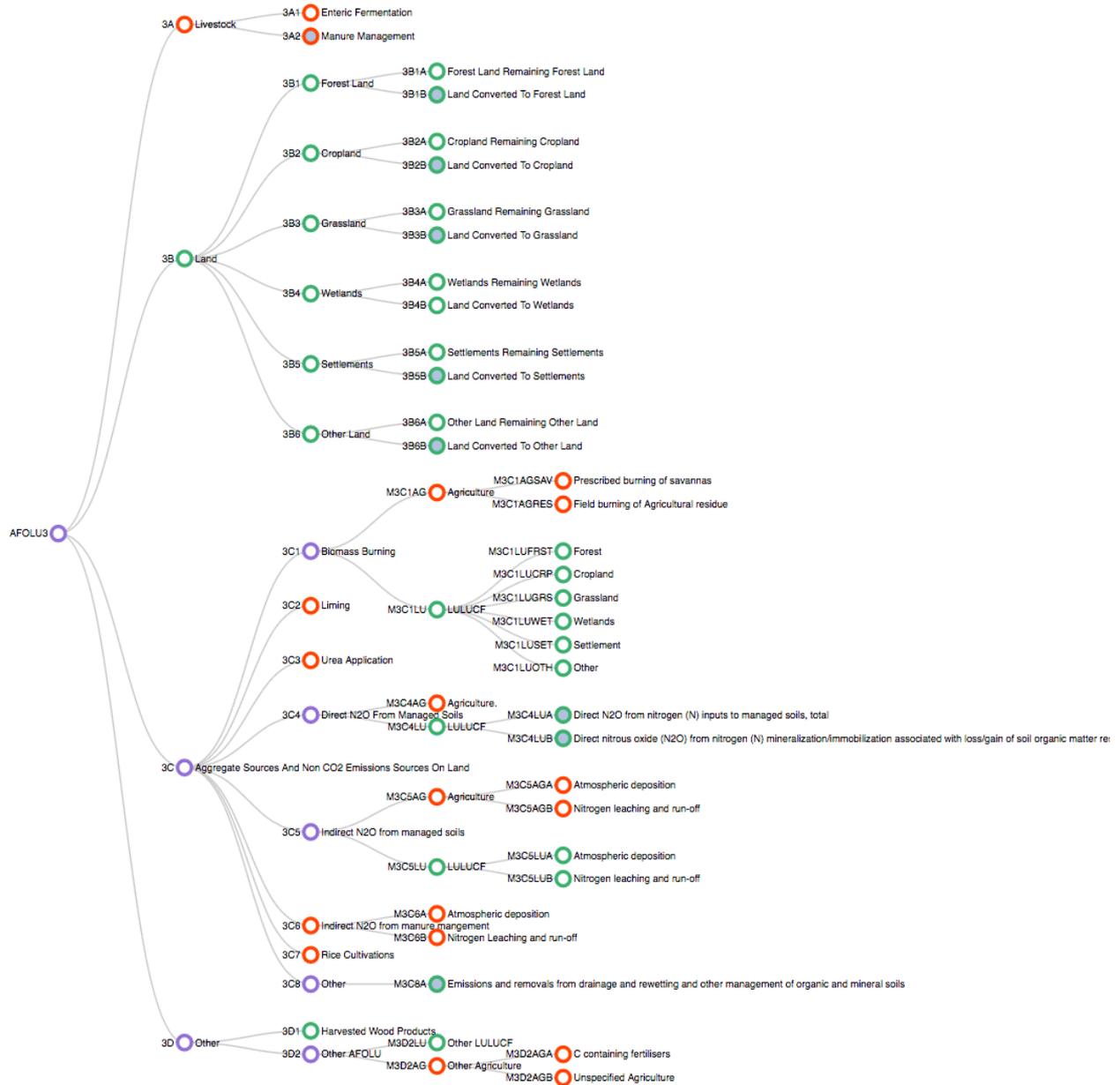


Figure 2: AFOLU categorisation. Agriculture only (red) and LULUCF only (green) categories are aggregated to give combined categories (purple). Some of the data that is provided as Agriculture or LULUCF only does not map directly to an IPCC 2006 category. Additional PRIMAP 'M' categories are therefore created for this data and integrated into the hierarchy. Filled circles indicate categories for which further sub-categories are available in the full dataset. An interactive version of this figure is available at <https://www.pik-potsdam.de/paris-reality-check/primap-crf/>.

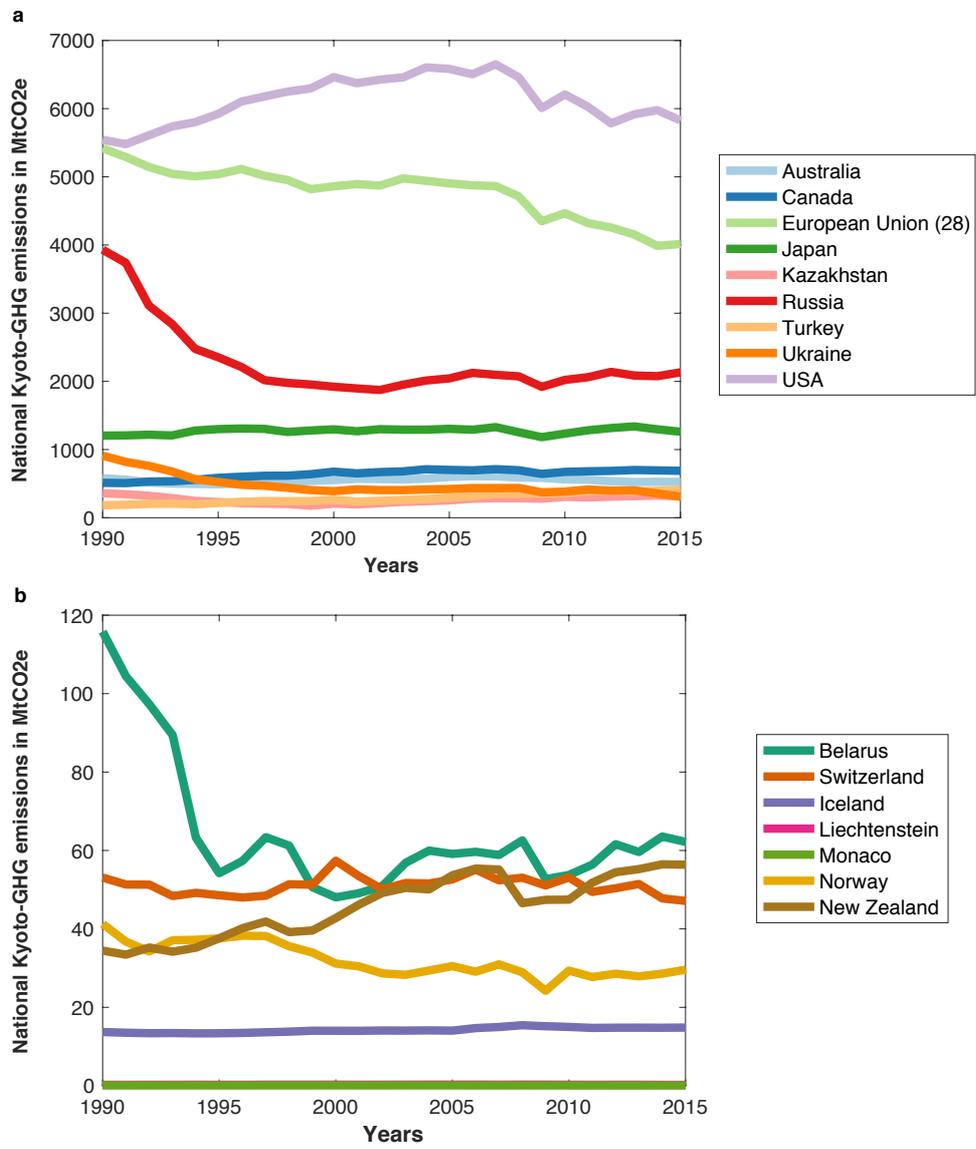
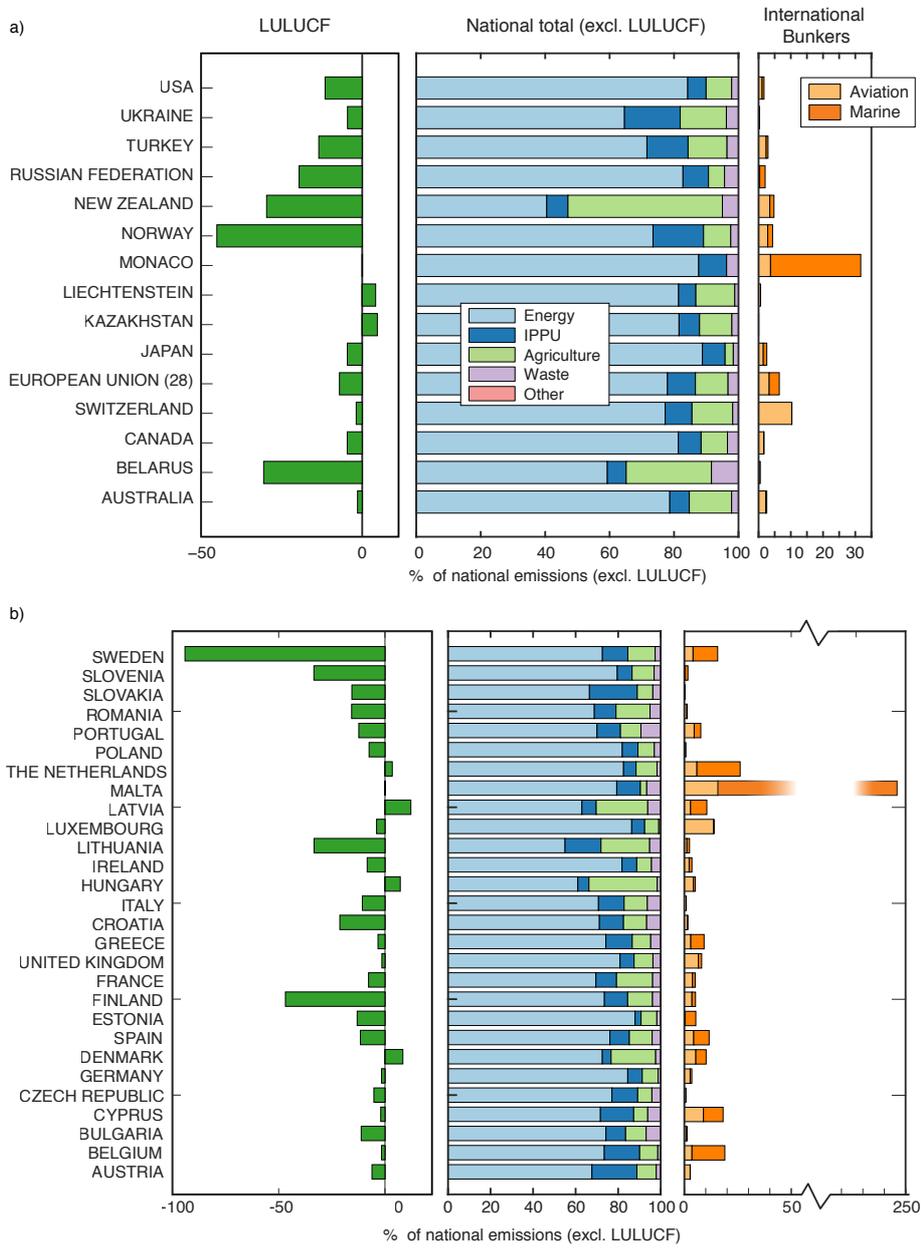
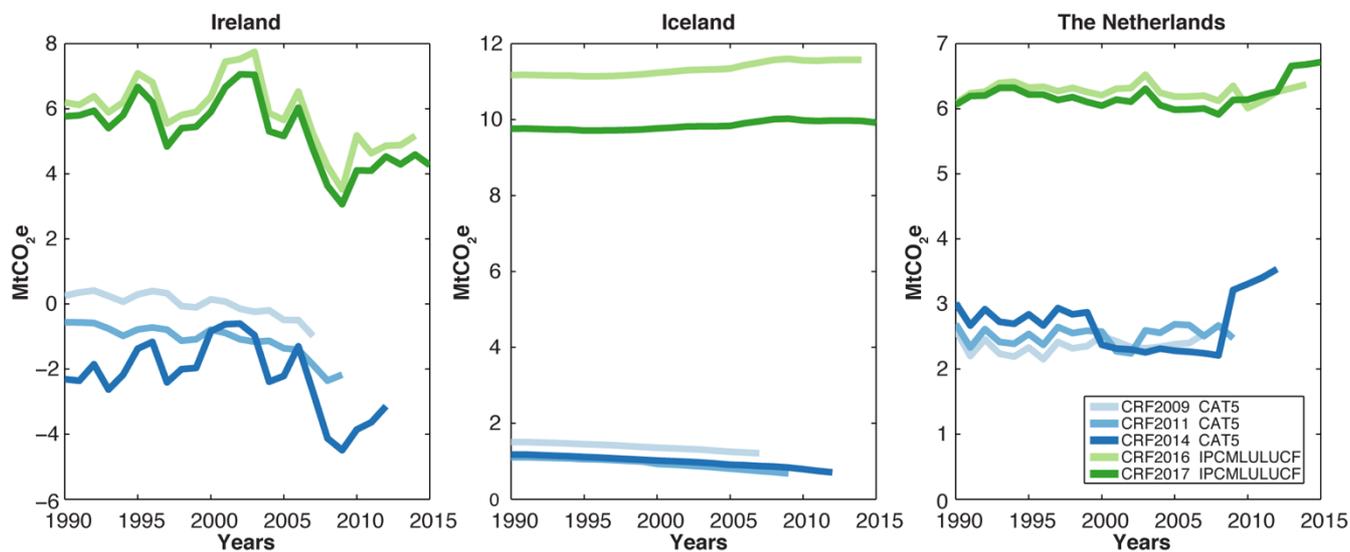


Figure 3: Time series of national total emissions (including LULUCF) as reported in CRF tables for larger emitters (a) and smaller emitters (b).

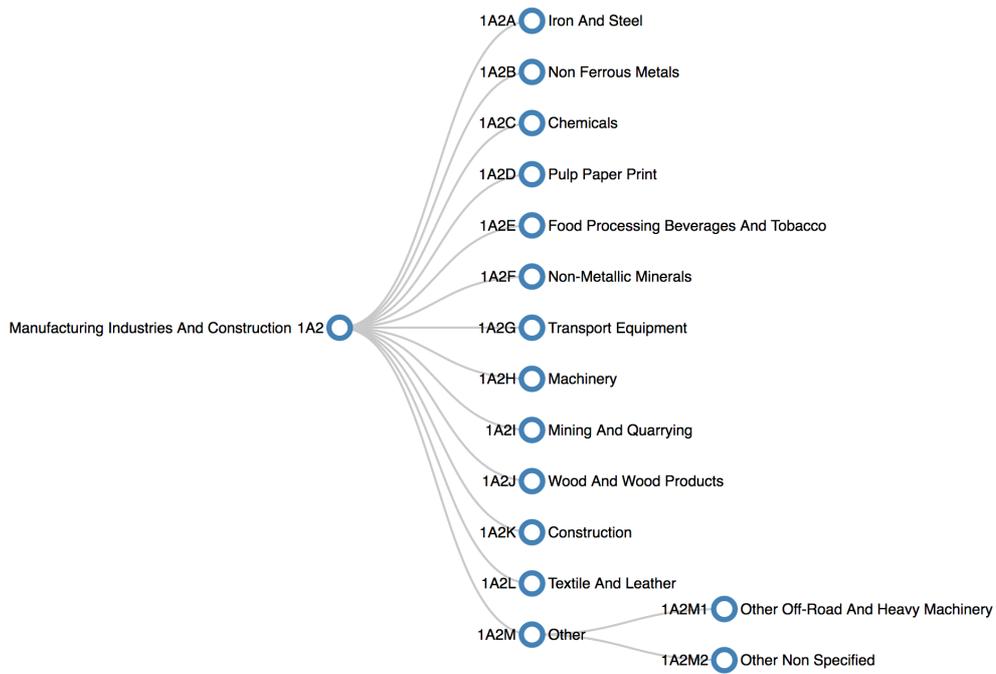


**Figure 4: Shares of sectors in the national total emissions, excluding LULUCF and international bunkers. For comparison, reported emissions from LULUCF are shown as % of national total (green, LHS) and reported emissions for international bunkers (orange, RHS). (a) Annex I countries and Kazakhstan, with the European Union presented as a group. (b) Same as (a) but for individual EU countries. Note the break in scale for international bunker emissions from Malta.**



**Figure 5: Impact of new reporting guidelines (used from 2015 onwards) on reported Kyoto-GHG emissions in the LULUCF sector from Ireland, Iceland, and the Netherlands. Due to historic reporting conventions, Kyoto-GHG emissions in this figure are calculated using GWPs from the IPCC SAR (IPCC, 1995).**

5



**Figure 6: Full category 1A2 sub-categories. For some countries, only sub-categories 1A2A to 1A2F are reported as sub-categories and categories 1A2G to 1A2M are reported together as 'other'. PRIMAP-crf contains the detailed categories where available.**

## 11. Tables

<b>Emissions source</b>	<b>'M' category code</b>
International Bunkers	MBK
International Aviation	MBKA
International Marine	MBKM
Multilateral Operations	MMULTIOP

**Table 1: PRIMAP-crf category codes for emissions from international bunkers and multi-lateral operations. These codes are used in the data repository.**

5

<b>Gas</b>	<b>IPCC 1996 Category</b>	<b>Built from</b>
<b>CO<sub>2</sub></b>	CAT1	CAT1A + CAT1B
	CAT1A	IPC1A
	CAT1B	CAT1B1 + CAT1B2
	CAT1B1	IPC1B1 + IPC1B3
	CAT1B2	IPC1B2
	CAT2	CAT2A + CAT2B + CAT2C + CAT2D + CAT2G
	CAT2A	IPC2A + IPC2B7 + IPC2D4
	CAT2B	IPC2B – IPC2B7
	CAT2C	IPC2C
	CAT2D	IPC2H1 + IPC2H2
	CAT2G	IPC2H3 + IPC2H4
	CAT3	IPC2D1 + IPC2D2 + IPC2D3
	CAT4	IPCMAG
	CAT5	IPCMLULUCF
	CAT6	IPC4
CAT7	IPC5	
<b>CH<sub>4</sub> and N<sub>2</sub>O</b>	CAT1	IPC1 – IPC1C
	CAT2	IPC2 – CAT3
	CAT3	IPC2D1 + IPC2D2 + IPC2D3 + IPC2G3
	CAT4	IPCMAG
	CAT5	IPCMLULUCF
	CAT6	IPC4
	CAT7	IPC5
<b>HFCs, PFCs, SF<sub>6</sub></b>	CAT2	IPC2

**Table 2: Creation of IPCC1996 categories from IPCC2006 categories and additional items from the CRF tables. ‘CAT’ is used to indicate IPCC1996 categories, and ‘IPC’ is used for IPCC2006 categories, both here and in the PRIMAP emissions module.**

## 12. Appendix

The following items can be found in the supplementary material to this paper.

- 5 1. **PRIMAP-crf-IPCC2006-category-codes.csv** A full documentation of the IPCC category codes used in PRIMAP and their meaning. Also include the PRIMAP ‘M’ categories used for reading CRF data and building categories.
- 10 2. **PRIMAP-crf\_2018v1.0\_categories.json** This JSON file shows which CRF table was used to build each category in the IPCC 2006 hierarchy. This file also provides the basis for figure 1.
- 15 3. **CRF\_tables\_key\_IPCC2006.xls and CRF\_tables\_key\_IPCC2006.csv** Similar to above, this file outlines the mapping from CRF tables to IPCC 2006 categories for the PRIMAP-crf source. The two files are identical except that the Excel version is formatted for easy reading, the CSV is unformatted.
- 20 4. **PRIMAP-crf\_figure\_codes\_and\_data** This folder contains the data (JSON) and code (HTML) underlying figures 1 and 2 of the main manuscript. Opening the HTML code in your browser (Firefox recommended) should enable you to explore the full hierarchy. An internet connection is required to retrieve the D3 library.
- 25 **5. PRIMAP\_EMMOD\_GWPs.xls and PRIMAP\_EMMOD\_GWPs.csv** These two files contain the 100-year global warming potentials of individual gases used to generate the greenhouse gas baskets in the PRIMAP-crf dataset. The Excel file contains additional information about which IPCC Report each GWP value was derived in for those gases that were not included in the earlier reports.
- 30 **5.6. PRIMAP-crf-data-discrepancy-details.csv** This file contains additional data on the reported N<sub>2</sub>O and CH<sub>4</sub> emissions for sub-categories of the LULUCF sector for Luxembourg, Liechtenstein, and Germany. Here we demonstrate the inconsistency between available sub-category data and the higher level LULUCF category. The absolute and % differences are also provided.