Global anthropogenic CO$_2$ emissions and uncertainties as prior for Earth system modelling and data assimilation

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Supplementary Information

S.1 Power industry emissions

Uncertainties calculated in this study are being used in the CO$_2$ Human Emissions (CHE) project to produce an ensemble of simulation with perturbed emissions for emission sensitivity studies (McNorton et al 2020), and also as prior uncertainties in the future carbon dioxide (CO$_2$) Monitoring and Verification Support (MVS) system (CHE, 2020; Janssens-Maenhout et al., 2020). In order to get most of the perturbation (e.g. using random noise) and inverse system techniques correct allocation of emission activity is needed. Main source of CO$_2$ emission information in this study is Emission Database for Global Atmospheric Research (EDGAR) version 4.3.2_FT2015 (Olivier et al., 2016b; Janssens-Maenhout et al., 2019). Based on the comparison with regional data from the Netherlands Organisation for Applied Scientific Research (TNO) first version of their greenhouse gas (GHG) and co-emitted species emission database (TNO_GHGco_v1.1) EDGARv4.3.2_FT2015 energy sector (ENE) emissions were divided into autoproducers (energy generated specially for industry) and the rest using percentage value reported by each country (IEA, 2016), prior implementation percentage values were limited to 30.0 % maximum. Then the autoproducer emissions were added to the industry sector (IND), in order to have better sectoral allocation of CO$_2$ emissions.

According to the Intergovernmental Panel on Climate Change (IPCC) 2006 Guidelines for National Greenhouse Gas Inventories and revised information from its 2019 Refinements (IPCC-TFI, 2019) ENE emission factors (EFs) are quite well known, and even after taking all the assumptions and activity data (AD) uncertainty into account overall emission uncertainty grows up only till about ±10.0 %. However, huge power plants operate based on their yearly plan – their construction and maintenance are quite expensive, so normally they are operating at full capacity and this upper bound of uncertainty is too high for them. According to the expert knowledge the upper bound of uncertainty for big power plants
can’t be more than +3.0%. In contrast, small plants operate based on day-to-day needs and their upper bound of uncertainty can reach up to +15.0%. Baring this in mind it was decided to separate modified ENE (after relocation of autoproducer emissions) into two sub-sectors: (i) energy generated by the super power plants – most emitting single located plant or average emitting and close located (fall into one grid-cell in the gridded ENE field) multiple plants (in total 30 grid-cells), and (ii) energy generated by the remaining (non-super) power plants – average emitting single or few close located plants. First, all grid-cells of yearly ENE gridded field were ranked according to the energy flux from the highest to the lowest flux value. Next, all values higher than 7.9·10^{-6} kg·m^{-2}·s^{-1} were treated as fluxes generated by super power plants, all the rest as fluxes generated by average power plants. Finally, two new energy gridded fields were generated, ENE-SUP and ENE-OTH respectively. Currently 30 grid-cells from 13 different geographical entities (i.e. 12 countries) of the initial ENE sector were moved to ENE-SUP, representing 7.1% (896.7 Mton) of the total ENE sector (12705.5 Mton). Top 3 countries that produce energy using super power plants are China, Russia and India. Usually the share of energy generated by super power plants for a country is ~15.0%, exceptions are China where this share is 4.0%, and Kuwait where this share is 72.4%. Table S1 shows 30 grid-cell flux values, their ranks and geographical locations. Figure S1 shows graphical representation of these ranked 30 grid-cell fluxes, it also shows possible extension of grid-cell number used based on the step change in the grid-cell values.

Table S1: List of 30 grid-cells with 2015 CO₂ flux values where energy is generated by super power plants (new ENE-SUP field), grid-cell ranks, locations and budgets per country

| Rank | Latitude, ° | Longitude, ° | CO₂ flux, ·10^{-6} kg·m^{-2}·s^{-1} | Country / Emission budget, Mton |
|------|-------------|-------------|-----------------------------------|-------------------------------|
| 14   | -32.25      | 150.95      | 10.18                             | Australia [AUS] / 33.6       |
| 8    | 31.25       | 120.55      | 10.89                             |                               |
| 16   | 48.55       | 119.75      | 9.62                              |                               |
| 17   | 38.15       | 106.35      | 9.54                              |                               |
| 23   | 40.25       | 111.35      | 8.57                              |                               |
| 28   | 31.35       | 121.65      | 8.18                              |                               |
| 30   | 30.65       | 121.05      | 7.92                              |                               |
| 10   | 51.05       | 6.55        | 10.53                             |                               |
| 21   | 51.85       | 14.45       | 8.65                              | Germany [DEU] / 46.6         |
| 24   | 53.75       | 359.15      | 8.56                              | United Kingdom [GBR] / 19.7  |
| 12   | 24.15       | 82.75       | 10.42                             | India [IND] / 133.5          |
| 18   | 24.05       | 82.65       | 9.17                              |                               |
| 19   | 11.55       | 79.45       | 8.81                              |                               |
| 26   | 21.95       | 83.45       | 8.32                              |                               |
| 11   | 35.45       | 139.65      | 10.47                             | Japan [JPN] / 59.4           |
| 27   | 35.65       | 140.15      | 8.23                              |                               |
| 15   | 51.85       | 73.35       | 9.87                              | Kazakhstan [KAZ] / 23.8      |
| 7    | 36.75       | 126.25      | 11.37                             |                               |
| 13   | 36.85       | 126.65      | 10.27                             | Korea South [KOR] / 94.3     |
| 20   | 37.75       | 128.15      | 8.67                              |                               |
| 9    | 29.45       | 48.25       | 10.71                             | Kuwait [KWT] / 36.4          |
| 25   | 51.25       | 19.35       | 8.43                              | Poland [POL] / 20.6          |
| 1    | 55.95       | 37.75       | 17.74                             | Russian Federation [RUS] / 168.4 |
| 2    | 60.35       | 28.65       | 17.19                             |                               |
### S.2 Coal production emissions

Generation of electricity and heat worldwide relies heavily on coal, the most carbon-intensive fossil fuel. In IPCC (2006) it is suggested to neglect CO$_2$ emissions from coal production if prescribed EFs and AD (Tier 1 approach) are used, because during this process is mainly emitted methane (CH$_4$). IPCC-TFI (2019) suggests to take CO$_2$ emissions from underground mines into account, as they are already known from the mine filtering equipment. In order to use prescribed EF and AD uncertainties we had to generate a coal production emission map (COL). Global grid-maps at 0.1°x0.1° horizontal resolution of CH$_4$ emissions from hard coal and brown coal 2012 production provided by Joint Research Centre of the European
Commission (JRC) are used for this purpose. Greet Janssens-Maenhout suggested the possible way of transforming CH$_4$ into CO$_2$ emissions. Main assumption (based on IPCC-TFI (2019)) is that CO$_2$ is emitted only during underground mining; CO$_2$ emissions from surface mining are neglected.

First, hard and brown coal CH$_4$ emission global fields had to be separated into underground and surface mining emissions. Surface mines are usually represented by the large area (several touching grid-cells on a grid-map), underground mines – only by the mine entrance (one or maximum two touching grid-cells on a grid-map). For underground mining only values from grid-cells with 6 and more (up to 8) empty neighbouring grid-cells were used. Next, values from hard and brown coal fields are summed together and finally, translated from CH$_4$ into CO$_2$ emissions by multiplication by (5.9/18.0) value, result in kg·m$^{-2}$·s$^{-1}$.

According to the newly generated CO$_2$ emissions from COL map (Figure S2) 105 geographical entities (i.e. 102 countries) have CO$_2$ emissions from underground coal mining. Total emissions globally are 7.0 Mton: 50 geographical entities with less than 1.0 kton, 29 geographical entities with 1.0 up to 10.0 kton, 11 geographical entities with 10.0 up to 50.0 kton, and 15 geographical entities with emissions of 50.0 or more kton. Table S2 shows the 15 most emitting countries based on coal production emissions. 95.0 % of all CO$_2$ emissions from coal production globally is emitted by these 15 countries.

According to the geographical entity type (see Section S.4 below), i.e. countries with well- (WDS) and less well- (LDS) developed statistical systems: 24 WDS geographical entities emit 70.2 % (4.9 Mton) of global CO$_2$ emissions from coal production versus 81 LDS geographical entities that emit only 29.8 % (2.1 Mton) of the global value.

**Table S2: List of 15 most emitting geographical entities based on the CO$_2$ emissions from underground mining coal production map, ranks and budgets per country**

| Rank | ISO Code | Geographical name                                      | Emission budget, kton |
|------|----------|--------------------------------------------------------|-----------------------|
| 1    | CHN      | China                                                  | 3044.9                |
| 2    | IDN      | Indonesia                                              | 786.5                 |
| 3    | USA      | United States Of America                               | 645.7                 |
| 4    | IND      | India                                                  | 512.1                 |
| 5    | RUS      | Russian Federation                                     | 356.4                 |
| 6    | UKR      | Ukraine                                                | 202.7                 |
| 7    | AUS      | Australia                                              | 196.6                 |
| 8    | VNM      | VietNam                                                | 185.2                 |
| 9    | KAZ      | Kazakhstan                                              | 158.1                 |
| 10   | ZAF      | South Africa                                           | 139.6                 |
| 11   | MNG      | Mongolia                                                | 120.4                 |
| 12   | PRK      | Democratic People's Republic Of Korea (North Korea)    | 103.9                 |
| 13   | COL      | Colombia                                                | 62.4                  |
| 14   | DEU      | Germany                                                | 61.1                  |
| 15   | POL      | Poland                                                 | 50.8                  |
|      | **TOTAL**|                                                        | **6626.3**            |
Figure S2: Global distribution of the CO₂ emission sources from coal production based on 2012 CH₄ emissions data for brown and hard coal, locations of underground mines are marked with blue dots

Main source of emission data in CHE_EDGAR-ECMWF_2015 is EDGARv4.3.2_FT2015, Table S3 shows the full list of differences between EDGARv4.3.2_FT2015 and CHE_EDGAR-ECMWF_2015.

Table S3: List of differences between EDGARv4.3.2_FT2015 and CHE_EDGAR-ECMWF_2015

| № | EDGARv4.3.2_FT2015 | CHE_EDGAR-ECMWF_2015 |
|---|------------------|----------------------|
| 1 | Power industry [ENE] and solid waste incineration [SWD-INC] sectors | (i) Power industry [ENE] emissions are divided between autoproducers and remaining; (ii) Remaining energy is divided between super emitting power plants and average emitting power plants; (iii) Emissions from super power plants form group ENERGY_S; emissions from average emitting power plants combined with solid waste incineration [SWD-INC] emissions form group ENERGY_A |
| 2 | Combustion for manufacturing [IND], iron and steel production [IRO], non-ferrous metals production [NFE], non energy use of fuels [NEU], non-metallic minerals production [NMM] and chemical processes [CHE] sectors | (i) Autoproducers are combined with combustion for manufacturing [IND] emissions; (ii) Non energy use of fuels [NEU] and chemical processes [CHE] emissions are replaced by the ones from EDGARv4.3.2; (iii) Emissions above combined with iron and steel production [IRO], non-ferrous metals production [NFE] and non-metallic minerals production [NMM] emissions form group MANUFACTURING |
| 3 | Residential heating (energy for buildings) [RCO] sector | (i) Emissions from residential heating [RCO] form group SETTLEMENTS |
| 4 | Aviation cruise [1.A.3.a_CRS], aviation climbing & descent [1.A.3.a_CDS] and aviation landing & take off [1.A.3.a_LTO] sectors | (i) Emissions from aviation cruise [1.A.3.a_CRS], aviation climbing & descent [1.A.3.a_CDS] and aviation landing & take off [1.A.3.a_LTO] form group AVIATION |
| 5 | Road transportation [TRO], shipping [TNR-Ship] and railways, pipelines, off-road transport [TNR-Other] sectors | (i) Emissions from road transportation [TRO], shipping [TNR-Ship] and railways, pipelines, off-road transport [TNR-Other] |
### S.3 Details on the parameterisation of the lognormal distribution

A lognormal distribution is typically an accurate assumption for the model output form, where the uncertainty range is not symmetric with respect to the mean, even though the variance for the total inventory may be correctly estimated from Approach 1. IPCC (2006) guidelines provide a practical methodology based on Frey (2003) for approximate asymmetric uncertainty range calculations based on the error propagation method. This methodology was applied if corrected lower half-range uncertainty estimated from error propagation method was $\geq 50.0\%$. IPCC (2006) suggests to define parameters of the lognormal distribution in terms of the geometric mean $\mu_g$ (which can be estimated based upon the arithmetic mean and the arithmetic standard deviation) following Eq. (1) and geometric standard deviation $\sigma_g$ following Eq. (2):

\[
\mu_{g_{EDGARj}} = \exp \left\{ \ln(E_{EDGARj}) - \frac{1}{2} \cdot \ln \left( 1 + \left[ \frac{(UC_{EDGARj})_{corr}}{200} \right]^2 \right) \right\},
\]

\[
\sigma_{g_{EDGARj}} = \exp \left\{ \ln \left( 1 + \left[ \frac{(UC_{EDGARj})_{corr}}{200} \right]^2 \right) \right\},
\]

where $E_{EDGARj}$ – anthropogenic CO$_2$ emissions per sector $j$; $corr$ corresponds to the corrected uncertainty (i.e. corrected for the systematic underestimation of uncertainty calculated by the error propagation approach used in this study comparing to uncertainties calculated by using the Monte Carlo approach); $UC_{EDGARj}$ is in %.

In this study all calculations were performed for upper and lower uncertainty limits separately to preserve as much information provided by IPCC (2006) and IPCC-TFI (2019) as possible, even though it is not required for Tier 1 approach (error propagation method) that we are applying. Because calculations were performed for upper and lower uncertainty limits separately, there are two values of $(UC_{EDGARj})_{corr}$: $(UC_{EDGARj})_{corr}^{low}$ – the absolute value of the lower uncertainty limit of sector $j$, and $(UC_{EDGARj})_{corr}^{high}$ – the absolute value of the upper uncertainty limit of sector $j$. 

| 6 | Oil refineries and Transformation industry [REF-TRF], fuel exploitation [PRO], agricultural soils [AGS] and solvents and products use [PRU-SOL] sectors | (i) Coal mining CO$_2$ emissions from underground mines [COL] are generated based on CH$_4$ emissions from hard and brown coal production of EDGARv4.3.2; (ii) Coal mining CO$_2$ emissions from underground mines [COL] combined with oil refineries and transformation industry [REF-TRF], fuel exploitation [PRO], agricultural soils [AGS] and solvents and products use [PRU-SOL] emissions form group OTHER |
|---|---|---|
| 7 | Monthly emissions for 2010 | (i) Monthly scaling factor grid-maps derived from monthly EDGARv4.3.2; (ii) Monthly scaling factor applied to yearly CHE_EDGAR-ECMWF_2015 emissions |
As it is preferred to preserve as much accuracy (extra knowledge) as possible in our calculations and not to inflate uncertainty upper or lower bounds artificially, lower \( \{ \left[ \left( U_{E D G A R} \right)_{c o r r} \right]_{l o w} \} \) and upper \( \{ \left[ \left( U_{E D G A R} \right)_{c o r r} \right]_{h i g h} \} \) uncertainty half-range from the error propagation method were calculated with a logarithmic transformation using \( \left[ \mu_{E D G A R} \right]_{l o w} \), \( \left[ \mu_{E D G A R} \right]_{h i g h} \) and \( \left[ \sigma_{E D G A R} \right]_{l o w} \), \( \left[ \sigma_{E D G A R} \right]_{h i g h} \) respectively according to the following Eq. (3) and Eq. (4) (see Figure S3 for visual representation of these equations):

\[
\begin{align*}
\{ \left[ \left( U_{E D G A R} \right)_{c o r r} \right]_{l o w} \} &= \left( \exp \left( \ln \left( \left[ \mu_{E D G A R} \right]_{l o w} \right) - 1.96 \cdot \ln \left( \left[ \sigma_{E D G A R} \right]_{l o w} \right) - E_{E D G A R} \right) \right) \times 100, \\
\{ \left[ \left( U_{E D G A R} \right)_{c o r r} \right]_{h i g h} \} &= \left( \exp \left( \ln \left( \left[ \mu_{E D G A R} \right]_{h i g h} \right) + 1.96 \cdot \ln \left( \left[ \sigma_{E D G A R} \right]_{h i g h} \right) - E_{E D G A R} \right) \right) \times 100,
\end{align*}
\]

where \( \ln \) corresponds to logarithmic transformation of the distribution; resulting values are not absolute – they have signs!

**Figure S3:** Visual representation of an empirical logarithmic transformation formula for upper and lower uncertainty bounds according IPCC (2006)

It should be noted that according to this methodology (with constants for 2.5\(^{th}\) and 97.5\(^{th}\) percentiles, +1.96 and -1.96 respectively, from the Z-table\(^1\)) the lower uncertainty half-range \( \{ \left[ \left( U_{E D G A R} \right)_{c o r r} \right]_{l o w} \} \) will always be less than 100.0 %.

Upper uncertainty half-range \( \{ \left[ \left( U_{E D G A R} \right)_{c o r r} \right]_{h i g h} \} \) is approximately symmetric relative to the 0 (Gaussian distribution) up to ~20.0 %, then has rather rapid growth till ~500.0 % (which with logarithmic transformation results in ~486.0 %), maxima at ~1350.0 % (which with logarithmic transformation results in ~582.6 %) and further gradual decrease. Next, these calculated uncertainty bounds were combined into 7 ECMWF groups.

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\(^1\) The Z-table is a mathematical table for the values of the cumulative distribution function of the normal distribution.
The whole world in this study is presented in 242 geographical entities (i.e. 232 countries) over the land and 1 residual entity over the ocean (including seas). Each geographical entity represents part of the country (e.g. Isle of Man, Bermuda and Cayman Islands are different parts of the United Kingdom) or several countries merged together (e.g. Sudan and South Sudan or Netherlands Antilles and Bonaire, Sint Eustatius, Saba and Curacao).

Each entity reports its annual GHG inventory with anthropogenic emission budgets, uncertainties and trends. Residual entity emissions are calculated from any activity (e.g. aviation, shipping, etc.) that took place over the ocean based on global country mask (international aviation and international shipping are explicitly taken into account in the residual entity emissions, not any specific country). Accuracy of these reported values strongly depend on statistical system development level of the entity. According to IPCC (2006) suggestions all entities are divided into two groups – with well-developed statistical systems (WDS) and with less well-developed statistical systems (LDS), and can be related to Annex I and Non-Annex I countries respectively, see Figure S4 for schematic representation of all world countries grouping.

Annex I countries must report their GHG inventories annually and consist of the 24 countries of the Organisation for Economic Co-operation and Development of 1990 (24OECD90) and the 16 countries with Economies in Transition (mainly the Commonwealth of Independent States, 16EIT90). The 24OECD90 countries are assumed to be economically stable and to have good statistical infrastructure and thus to have the lowest uncertainties in their inventories. The 16EIT90 countries experienced more economical instability and flaws in the statistical reporting during the early 1990’s but are nowadays assumed to have a good statistical infrastructure. As such, they have slightly higher uncertainties in their inventories than the...
OECD90 countries but are still quite certain. Non-Annex I countries consist of the United Nations Framework Convention on Climate Change (UNFCCC) developing countries (Janssens-Maenhout et al., 2019).

We made certain exceptions to this grouping: (i) far away territories of Annex I countries are treated as LDS countries (e.g. the United Kingdom is Annex I country meaning WDS, Bermuda is its part yet treated as LDS country because of its far away geographical location from the main part of the United Kingdom); (ii) China is treated as WDS country, because quality of its GHG inventories has recently increased; (iii) India is treated as WDS country, because of its well-developed statistical infrastructure; (iv) Russian Federation is currently treated as LDS country, because completion of its GHG inventory has recently decreased. Table S3 shows all geographical entities involved in this study with their statistical system development level and countries main part.

Table S3: Full list of geographical entities, their statistical infrastructure development level and main country of dependence

| ISO Code | Geographical name          | Type | Main country (dependency) | Full information                      |
|----------|----------------------------|------|---------------------------|----------------------------------------|
| AFG      | Afghanistan                | LDS  | Afghanistan               | Afghanistan                            |
| ALA      | Aland Islands              | LDS  | Finland                   | Aland Islands                          |
| ALB      | Albania                    | LDS  | Albania                   | Albania                                |
| DZA      | Algeria                    | LDS  | Algeria                   | Algeria                                |
| ASM      | American Samoa             | LDS  | United States of America  | American Samoa                         |
| AND      | Andorra                    | WDS  | Andorra                   | Andorra                                |
| AGO      | Angola                     | LDS  | Angola                    | Angola                                 |
| AIA      | Anguilla                   | LDS  | United Kingdom            | Anguilla                               |
| ATA      | Antarctica                 | LDS  | Antarctica                | Antarctica                             |
| ATG      | Antigua and Barbuda        | LDS  | Antigua and Barbuda       | Antigua and Barbuda                    |
| ARG      | Argentina                  | LDS  | Argentina                 | Argentina                              |
| ARM      | Armenia                    | LDS  | Armenia                   | Armenia                                |
| ABW      | Aruba                      | LDS  | Netherlands               | Aruba                                  |
| AUS      | Australia                  | WDS  | Australia                 | Australia                              |
| AUT      | Austria                    | WDS  | Austria                   | Austria                                |
| AZE      | Azerbaijan                 | LDS  | Azerbaijan                | Azerbaijan                             |
| BHS      | Bahamas                    | LDS  | Bahamas                   | Bahamas                                |
| BHR      | Bahrain                    | LDS  | Bahrain                   | Bahrain                                |
| BGD      | Bangladesh                 | LDS  | Bangladesh                | Bangladesh                             |
| BRB      | Barbados                   | LDS  | Barbados                  | Barbados                               |
| BLR      | Belarus                    | WDS  | Belarus                   | Belarus                                |
| BEL      | Belgium                    | WDS  | Belgium                   | Belgium                                |
| BLZ      | Belize                     | LDS  | Belize                    | Belize                                 |
| BEN      | Benin                      | LDS  | Benin                     | Benin                                  |
| BMU      | Bermuda                    | LDS  | United Kingdom            | Bermuda                                |
| BTN      | Bhutan                     | LDS  | Bhutan                    | Bhutan                                 |
| BOL      | Bolivia                    | LDS  | Bolivia                   | Bolivia, Plurinational State of        |
| BIH      | Bosnia and Herzegovina     | LDS  | Bosnia and Herzegovina    | Bosnia and Herzegovina                 |
| BWA      | Botswana                   | LDS  | Botswana                  | Botswana                               |
| BVT      | Bouvet Islands             | LDS  | Norway                    | Bouvet Islands                         |
| BRA      | Brazil                     | LDS  | Brazil                    | Brazil                                 |
| IOT      | British Indian Ocean Territory | LDS | United Kingdom           | British Indian Ocean Territory          |
| BRN      | Brunei Darussalam          | LDS  | Brunei Darussalam         | Brunei Darussalam                      |
| BGR      | Bulgaria                   | WDS  | Bulgaria                  | Bulgaria                               |
| ISO Code | Geographical name                  | Type | Main country (dependency)                  | Full information                                      |
|----------|-----------------------------------|------|-------------------------------------------|-------------------------------------------------------|
| BFA      | Burkina Faso                      | LDS  | Burkina Faso                              | Burkina Faso                                          |
| BDI      | Burundi                           | LDS  | Burundi                                   | Burundi                                               |
| CPV      | Cabo Verde                        | LDS  | Cabo Verde                                | Cabo (or Cape) Verde                                   |
| KHM      | Cambodia                          | LDS  | Cambodia                                  | Cambodia                                              |
| CMR      | Cameroon                          | LDS  | Cameroon                                  | Cameroon                                              |
| CAN      | Canada                            | WDS  | Canada                                    | Canada                                                |
| CYM      | Cayman Islands                    | LDS  | United Kingdom                            | Cayman Islands                                         |
| CAF      | Central African Republic          | LDS  | Central African Republic                  | Central African Republic                                |
| TCD      | Chad                              | LDS  | Chad                                      | Chad                                                  |
| CHL      | Chile                             | LDS  | Chile                                     | Chile                                                 |
| CHN      | China                             | WDS  | China                                     | China                                                 |
| CXR      | Christmas Islands                 | LDS  | Australia                                 | Christmas Islands                                      |
| CCK      | Cocos Islands                     | LDS  | Australia                                 | Cocos (or Keeling) Islands                             |
| COL      | Colombia                          | LDS  | Colombia                                  | Colombia                                               |
| COM      | Comoros                           | LDS  | Comoros                                   | Comoros                                               |
| COG      | Congo                             | LDS  | Congo                                     | Congo                                                 |
| COD      | Congo, Democratic Republic of     | LDS  | Congo, Democratic Republic of             | Congo, Democratic Republic of                         |
| COK      | Cook Islands                      | LDS  | New Zealand                               | Cook Islands                                           |
| CRI      | Costa Rica                        | LDS  | Costa Rica                                | Costa Rica                                            |
| CIV      | Cote D'Ivoire                     | LDS  | Cote D'Ivoire                             | Cote D'Ivoire                                          |
| HRV      | Croatia                           | WDS  | Croatia                                   | Croatia                                               |
| CUB      | Cuba                              | LDS  | Cuba                                      | Cuba                                                  |
| CYP      | Cyprus                            | WDS  | Cyprus                                    | Cyprus                                                |
| CZE      | Czechia                           | WDS  | Czechia                                   | Czechia                                               |
| DNK      | Denmark                           | WDS  | Denmark                                   | Denmark                                               |
| DJI      | Djibouti                          | LDS  | Djibouti                                  | Djibouti                                              |
| DMA      | Dominica                          | LDS  | Dominica                                  | Dominica                                              |
| DOM      | Dominican Republic                | LDS  | Dominican Republic                        | Dominican Republic                                     |
| ECU      | Ecuador                           | LDS  | Ecuador                                   | Ecuador                                               |
| EGY      | Egypt                             | LDS  | Egypt                                     | Egypt                                                 |
| SLV      | El Salvador                       | LDS  | El Salvador                               | El Salvador                                            |
| GNQ      | Equatorial Guinea                 | LDS  | Equatorial Guinea                         | Equatorial Guinea                                      |
| ERI      | Eritrea                           | LDS  | Eritrea                                   | Eritrea                                               |
| EST      | Estonia                           | WDS  | Estonia                                   | Estonia                                               |
| SWZ      | Eswatini                          | LDS  | Eswatini                                  | Eswatini                                              |
| ETH      | Ethiopia                          | LDS  | Ethiopia                                  | Ethiopia                                               |
| FRO      | Faeroe Islands                    | WDS  | Denmark                                   | Faeroe Islands                                         |
| FLK      | Falkland Islands                  | LDS  | United Kingdom                            | Falkland Islands                                       |
| FJI      | Fiji                              | LDS  | Fiji                                      | Fiji                                                  |
| FIN      | Finland                           | WDS  | Finland                                   | Finland                                               |
| FRA      | France                            | WDS  | France                                    | France, merged with: Monaco [MCO]                      |
| GUF      | French Guiana                     | LDS  | France                                    | French Guiana                                          |
| PYF      | French Polynesia                  | LDS  | France                                    | French Polynesia                                       |
| MAF      | French Saint Martin               | LDS  | France                                    | French Saint Martin, merged with: Sint Maarten [SXM]   |
| ATF      | French Southern Territories       | LDS  | France                                    | French Southern Territories                            |
| GAB      | Gabon                             | LDS  | Gabon                                     | Gabon                                                 |
| GMB      | Gambia                            | LDS  | Gambia                                    | Gambia                                                |
| GEO      | Georgia                           | LDS  | Georgia                                   | Georgia                                                |
| DEU      | Germany                           | WDS  | Germany                                   | Germany                                                |
| GHA      | Ghana                             | LDS  | Ghana                                     | Ghana                                                 |
| ISO Code | Geographical name                        | Type | Main country (dependency)              | Full information                                      |
|---------|------------------------------------------|------|----------------------------------------|-------------------------------------------------------|
| GRC     | Greece                                   | WDS  | Greece                                 | Greece                                                |
| GRL     | Greenland                                | WDS  | Denmark                                | Greenland                                             |
| GRD     | Grenada                                  | LDS  | Grenada                                | Grenada                                               |
| GLP     | Guadeloupe                               | LDS  | France                                 | Guadeloupe                                            |
| GUM     | Guam                                     | LDS  | United States of America               | Guam                                                  |
| GTM     | Guatemala                                | LDS  | Guatemala                              | Guatemala                                             |
| GGY     | Guernsey                                 | WDS  | United Kingdom                         | Guernsey                                              |
| GIN     | Guinea                                   | LDS  | Guinea                                 | Guinea                                                |
| GNB     | Guinea-Bissau                            | LDS  | Guinea-Bissau                          | Guinea-Bissau                                         |
| GUY     | Guyana                                   | LDS  | Guyana                                 | Guyana                                                |
| HTI     | Haiti                                    | LDS  | Haiti                                  | Haiti                                                 |
| HMD     | Heard Island and McDonald Island         | LDS  | Australia                              | Heard Island and McDonald Island                      |
| HND     | Honduras                                 | LDS  | Honduras                               | Honduras                                              |
| HKG     | Hong Kong                                | LDS  | China                                  | Hong Kong                                             |
| HUN     | Hungary                                  | WDS  | Hungary                                | Hungary                                               |
| ISL     | Iceland                                  | WDS  | Iceland                                | Iceland                                               |
| IND     | India                                    | WDS  | India                                  | India                                                 |
| IDN     | Indonesia                                | LDS  | Indonesia                              | Indonesia                                             |
| IRN     | Iran                                     | LDS  | Iran                                   | Iran, Islamic Republic of                            |
| IRQ     | Iraq                                     | LDS  | Iraq                                   | Iraq                                                  |
| IRL     | Ireland                                  | WDS  | Ireland                                | Ireland                                               |
| IMN     | Isle of Man                              | WDS  | United Kingdom                         | Isle of Man                                           |
| ISR     | Israel                                   | LDS  | Israel                                 | Israel                                                |
| ITA     | Italy                                    | WDS  | Italy                                  | Italy, merged with: Holy See [VAT]                    |
| JAM     | Jamaica                                  | LDS  | Jamaica                                | Jamaica                                               |
| JPN     | Japan                                    | WDS  | Japan                                  | Japan                                                 |
| JEY     | Jersey                                   | WDS  | United Kingdom                         | Jersey                                                |
| JOR     | Jordan                                   | LDS  | Jordan                                 | Jordan                                                |
| KAZ     | Kazakhstan                               | LDS  | Kazakhstan                             | Kazakhstan                                            |
| KEN     | Kenya                                    | LDS  | Kenya                                  | Kenya                                                 |
| KIR     | Kiribati                                 | LDS  | Kiribati                               | Kiribati                                              |
| PRK     | Korea, Democratic People's Republic of   | LDS  | Korea, Democratic People's Republic of | Korea, Democratic People's Republic of (North Korea) |
| KOR     | Korea, Republic of                       | LDS  | Korea, Republic of                     | Korea, Republic of (South Korea)                      |
| KWT     | Kuwait                                   | LDS  | Kuwait                                 | Kuwait                                                |
| KGZ     | Kyrgyzstan                               | LDS  | Kyrgyzstan                             | Kyrgyzstan                                            |
| LAO     | Lao People's Democratic Republic         | LDS  | Lao People's Democratic Republic       | Lao People's Democratic Republic                       |
| LVA     | Latvia                                   | WDS  | Latvia                                 | Latvia                                                |
| LBN     | Lebanon                                  | LDS  | Lebanon                                | Lebanon                                               |
| LSO     | Lesotho                                  | LDS  | Lesotho                                | Lesotho                                               |
| LBR     | Liberia                                  | LDS  | Liberia                                | Liberia                                               |
| LBY     | Libya                                    | LDS  | Libya                                  | Libya                                                 |
| LIE     | Liechtenstein                            | WDS  | Liechtenstein                          | Liechtenstein                                         |
| LTU     | Lithuania                                | WDS  | Lithuania                              | Lithuania                                             |
| LUX     | Luxembourg                               | WDS  | Luxembourg                             | Luxembourg                                            |
| MAC     | Macao                                    | LDS  | China                                  | Macao                                                 |
| MKD     | Macedonia                                | LDS  | Macedonia                              | Macedonia                                             |
| MDG     | Madagascar                               | LDS  | Madagascar                             | Madagascar                                            |
| MWI     | Malawi                                   | LDS  | Malawi                                 | Malawi                                                |
| MYS     | Malaysia                                 | LDS  | Malaysia                               | Malaysia                                              |
| ISO Code | Geographical name                  | Type | Main country (dependency)     | Full information                                                                 |
|---------|------------------------------------|------|-------------------------------|----------------------------------------------------------------------------------|
| MDV     | Maldives                           | LDS  | Maldives                      | Maldives                                                                         |
| MLI     | Mali                               | LDS  | Mali                          | Mali                                                                             |
| MLT     | Malta                              | WDS  | Malta                         | Malta                                                                            |
| MHL     | Marshall Islands                   | LDS  | Marshall Islands              | Marshall Islands                                                                 |
| MTQ     | Martinique                         | LDS  | France                        | Martinique                                                                       |
| MRT     | Mauritania                         | LDS  | Mauritania                    | Mauritania                                                                       |
| MUS     | Mauritius                          | LDS  | Mauritius                     | Mauritius                                                                        |
| MYT     | Mayotte                            | LDS  | France                        | Mayotte                                                                          |
| MEX     | Mexico                             | LDS  | Mexico                        | Mexico                                                                           |
| FSM     | Micronesia                          | LDS  | Micronesia                    | Micronesia, Federated State of                                                  |
| MDA     | Moldova                            | LDS  | Moldova                       | Moldova, Republic of                                                            |
| MNG     | Mongolia                           | LDS  | Mongolia                      | Mongolia                                                                         |
| MNE     | Montenegro                         | LDS  | Montenegro                    | Montenegro                                                                       |
| MSR     | Montserrat                         | LDS  | United Kingdom                | Montserrat                                                                       |
| MAR     | Morocco                            | LDS  | Morocco                       | Morocco                                                                          |
| MOZ     | Mozambique                         | LDS  | Mozambique                    | Mozambique                                                                       |
| MMR     | Myanmar                            | LDS  | Myanmar                       | Myanmar                                                                          |
| NAM     | Namibia                            | LDS  | Namibia                        | Namibia                                                                          |
| NPL     | Nepal                              | LDS  | Nepal                         | Nepal                                                                            |
| NLD     | Netherlands                        | WDS  | Netherlands                   | Netherlands, merged with: Bonaire, Sint Eustatius, Saba [BES], Curacao [CUW]     |
| ANT     | Netherlands Antilles               | LDS  | Netherlands                   | Netherlands                                                                      |
| NCL     | New Caledonia                      | LDS  | France                        | New Caledonia                                                                   |
| NZL     | New Zealand                        | WDS  | New Zealand                   | New Zealand                                                                     |
| NIC     | Nicaragua                          | LDS  | Nicaragua                     | Nicaragua                                                                       |
| NER     | Niger                              | LDS  | Niger                         | Niger                                                                            |
| NGA     | Nigeria                            | LDS  | Nigeria                       | Nigeria                                                                          |
| NIU     | Niue                               | LDS  | New Zealand                   | Niue                                                                            |
| NFK     | Norfolk Island                     | LDS  | Australia                     | Norfolk Island                                                                   |
| MNP     | Northern Mariana Islands           | LDS  | United States of America      | Northern Mariana Islands                                                        |
| NOR     | Norway                             | WDS  | Norway                        | Norway                                                                          |
| OMN     | Oman                               | LDS  | Oman                          | Oman                                                                            |
| PAK     | Pakistan                           | LDS  | Pakistan                      | Pakistan                                                                         |
| PLW     | Palau                              | LDS  | Palau                         | Palau                                                                           |
| PSE     | Palestine                          | LDS  | Palestine                     | Palestine, State of                                                            |
| PAN     | Panama                             | LDS  | Panama                        | Panama                                                                          |
| PNG     | Papua New Guinea                   | LDS  | Papua New Guinea              | Papua New Guinea                                                                |
| PRY     | Paraguay                           | LDS  | Paraguay                       | Paraguay                                                                         |
| PER     | Peru                               | LDS  | Peru                          | Peru                                                                            |
| PHL     | Philippines                        | LDS  | Philippines                   | Philippines                                                                      |
| PCN     | Pitcairn                           | LDS  | United Kingdom                | Pitcairn                                                                        |
| POL     | Poland                             | WDS  | Poland                        | Poland                                                                          |
| PRT     | Portugal                           | WDS  | Portugal                      | Portugal                                                                         |
| PRI     | Puerto Rico                        | LDS  | United States of America      | Puerto Rico                                                                     |
| QAT     | Qatar                              | LDS  | Qatar                         | Qatar                                                                           |
| REU     | Reunion                            | LDS  | France                        | Reunion                                                                          |
| ROU     | Romania                            | WDS  | Romania                        | Romania                                                                          |
| RUS     | Russian Federation                 | LDS  | Russian Federation            | Russian Federation                                                              |
| RWA     | Rwanda                             | LDS  | Rwanda                         | Rwanda                                                                           |
| BLM     | Saint Barthelemy                   | LDS  | France                        | Saint Barthelemy                                                                |
| SHN     | Saint Helena, Ascension and Tristan Da Cunha | LDS  | United Kingdom                | Saint Helena, Ascension and Tristan Da Cunha                                    |
| ISO Code | Geographical name                              | Type | Main country (dependency)                  | Full information                                                                 |
|----------|-----------------------------------------------|------|--------------------------------------------|----------------------------------------------------------------------------------|
| KNA      | Saint Kitts and Nevis                         | LDS  | Saint Kitts and Nevis                      | Saint Kitts and Nevis                                                            |
| LCA      | Saint Lucia                                   | LDS  | Saint Lucia                                | Saint Lucia                                                                     |
| SPM      | Saint Pierre and Miquelon                     | LDS  | France                                     | Saint Pierre and Miquelon                                                       |
| VCT      | Saint Vincent and The Grenadines              | LDS  | Saint Vincent and The Grenadines           | Saint Vincent and The Grenadines                                                 |
| WSM      | Samoa                                         | LDS  | Samoa                                      | Samoa                                                                           |
| SMR      | San Marino                                    | WDS  | San Marino                                 | San Marino                                                                      |
| STP      | Sao Tome and Principe                         | LDS  | Sao Tome and Principe                      | Sao Tome and Principe                                                           |
| SAU      | Saudi Arabia                                  | LDS  | Saudi Arabia                               | Saudi Arabia                                                                    |
| SEN      | Senegal                                       | LDS  | Senegal                                    | Senegal                                                                         |
| SRB      | Serbia                                        | LDS  | Serbia                                     | Serbia (including Kosovo)                                                       |
| SYC      | Seychelles                                    | LDS  | Seychelles                                 | Seychelles                                                                      |
| SLE      | Sierra Leone                                  | LDS  | Sierra Leone                               | Sierra Leone                                                                    |
| SGP      | Singapore                                     | LDS  | Singapore                                  | Singapore                                                                       |
| SVK      | Slovakia                                      | WDS  | Slovakia                                   | Slovakia                                                                        |
| SVN      | Slovenia                                      | WDS  | Slovenia                                   | Slovenia                                                                        |
| SLB      | Solomon Islands                               | LDS  | Solomon Islands                            | Solomon Islands                                                                 |
| SOM      | Somalia                                       | LDS  | Somalia                                    | Somalia                                                                         |
| ZAF      | South Africa                                  | LDS  | South Africa                               | South Africa                                                                    |
| SGS      | South Georgia and South Sandwich Islands      | LDS  | United Kingdom                             | South Georgia and The South Sandwich Islands                                    |
| ESP      | Spain                                         | WDS  | Spain                                      | Spain, merged with: Gibraltar [GIB]                                              |
| LKA      | Sri Lanka                                     | LDS  | Sri Lanka                                  | Sri Lanka                                                                       |
| SDN      | Sudan                                         | LDS  | Sudan                                      | Sudan, merged with: South Sudan [SSD]                                            |
| SUR      | Suriname                                      | LDS  | Suriname                                   | Suriname                                                                        |
| SMI      | Svalbard, Jan Mayen                           | LDS  | Norway                                     | Svalbard, Jan Mayen                                                            |
| SWE      | Sweden                                        | WDS  | Sweden                                     | Sweden                                                                          |
| CHE      | Switzerland                                   | WDS  | Switzerland                                | Switzerland                                                                    |
| SYR      | Syrian Arab Republic                          | LDS  | Syrian Arab Republic                       | Syrian Arab Republic                                                            |
| TWN      | Taiwan                                        | LDS  | China                                      | Taiwan, Province of China                                                       |
| TJK      | Tajikistan                                    | LDS  | Tajikistan                                 | Tajikistan                                                                      |
| TZA      | Tanzania                                      | LDS  | Tanzania                                   | Tanzania, United Republic of                                                    |
| THA      | Thailand                                      | LDS  | Thailand                                   | Thailand                                                                        |
| TSL      | Timor-Leste                                   | LDS  | Timor-Leste                                | Timor-Leste                                                                     |
| TGO      | Togo                                          | LDS  | Togo                                       | Togo                                                                            |
| TKL      | Tokelau                                       | LDS  | New Zealand                                | Tokelau                                                                         |
| TON      | Tonga                                         | LDS  | Tonga                                      | Tonga                                                                           |
| TTO      | Trinidad and Tobago                           | LDS  | Trinidad and Tobago                        | Trinidad and Tobago                                                             |
| TUN      | Tunisia                                       | LDS  | Tunisia                                    | Tunisia                                                                         |
| TUR      | Turkey                                        | WDS  | Turkey                                     | Turkey                                                                          |
| TKM      | Turkmenistan                                  | LDS  | Turkmenistan                               | Turkmenistan                                                                    |
| TCA      | Turks and Caicos Islands                      | LDS  | United Kingdom                             | Turks and Caicos Islands                                                        |
| TUV      | Tuvalu                                        | LDS  | Tuvalu                                     | Tuvalu                                                                          |
| UGA      | Uganda                                        | LDS  | Uganda                                     | Uganda                                                                          |
| UKR      | Ukraine                                       | WDS  | Ukraine                                    | Ukraine                                                                         |
| ARE      | United Arab Emirates                          | LDS  | United Arab Emirates                       | United Arab Emirates                                                            |
| GBR      | United Kingdom                                | WDS  | United Kingdom                             | United Kingdom                                                                  |
| UMI      | United States Minor Outlying Islands          | LDS  | United States of America                   | United States Minor Outlying Islands                                            |
| USA      | United States of America                      | WDS  | United States of America                   | United States of America                                                        |
| URY      | Uruguay                                       | LDS  | Uruguay                                    | Uruguay                                                                         |
| UZB      | Uzbekistan                                    | LDS  | Uzbekistan                                 | Uzbekistan                                                                      |
Comparison of geographical entity lists from this study and from EDGARv4.3.2_FT2015 is shown in Table S4. In total EDGARv4.3.2_FT2015 distinguish 228 geographical entities, because of the historical (Serbia [SRB] and Montenegro [MNE] are still treated as one the State Union of Serbia and Montenegro [SCG]) or emission reporting (Switzerland [CHE] and Liechtenstein [LIE] emission budgets are reported together under Switzerland [CHE]) reasons. In this study these restrictions were not relevant, so most of geographical entities could be separated. In addition, for comparison reasons extra two geographical entities were introduced, i.e. Europe (28 members till end 2019) [E28], and all world countries [GLB]. It should be noted, that for several geographical entity uncertainty aggregation (e.g. Europe (28 members till end 2019)) emissions are considered to be fully uncorrelated, following the suggestion from IPCC (2006).

### Table S4: List of geographical entity differences between this study and EDGARv4.3.2_FT2015 dataset

| №  | EDGARv4.3.2_FT2015                              | CHE_EDGAR-ECMWF_2015                          |
|----|-----------------------------------------------|-----------------------------------------------|
| 1  | France (including Monaco and Andorra) [FRA]   | France (including Monaco) [FRA], Andorra [AND]|
| 2  | Israel (including Palestine) [ISR]            | Israel [ISR], Occupied Palestinian Territory [PSE]|
| 3  | Italy (including Vatican, San Marino) [ITA]    | Italy (including Vatican) [ITA], San Marino [SMR]|
| 4  | Norway [NOR]                                  | Norway [NOR], Svalbard (including Jan Mayen) [SIM]|
| 5  | Serbia and Montenegro (including Kosovo) [SCG] | Serbia (including Kosovo) [SRB], Montenegro [MNE]|
| 6  | Spain [ESP], Gibraltar [GIB]                  | Spain (including Gibraltar) [ESP]             |
| 7  | Switzerland (including Liechtenstein) [CHE]   | Switzerland [CHE], Liechtenstein [LIE]        |
| 8  | Ocean [SEA], Nauru [NRU]                      | Ocean (including Nauru) [SEA]                 |
| 9  | French Saint Martin (including Sint Maarten [SXM]) [MAF] |                                |
| 10 | Netherlands Antilles (including Bonaire, Sint Eustatius, Saba [BES], Curacao [CUW]) [ANT] | |
| 11 | Sudan (including South Sudan) [SDN]           |                                               |

### S.5 Fuel specific information

EDGAR dataset with incorporated fuel-specific AD and EF uncertainties and Tier 1 approach for uncertainty calculation from IPCC (2006) hereinafter referred to as EDGAR-JRC. Table S5 shows CO₂ EF uncertainties by process or fuel type (based on Table 3.2.1 of IPCC (2006)) used in EDGAR-JRC. Uncertainties are specified for countries with well developed
(WDS) and less well-developed (LDS) statistical infrastructures. Upper and lower ranges refer to the 95% confidence interval of the mean. No specification means that process or fuel type uncertainty was applied to all sectors.

Table S5: Prior uncertainties (lower L and upper U bounds) per each process or fuel type from EDGAR-JRC dataset and two geographical entity types; * stands for energy for buildings sector (RCO) only

| Fuel type | Specification | Prior uncertainty bounds, % |
|-----------|---------------|-----------------------------|
|           |               | WDS countries | LDS countries |
|           |               | L  | U  | L  | U  |
| Motor Gasoline |                 | 2.6 | 5.3 | 5.3* | 5.3* |
| Aviation Gasoline |             | 3.6 | 4.3 | 4.3* | 4.3* |
| Gas/Diesel Oil |                | 2.0 | 1.0 | 2.0* | 2.0* |
| Liquefied Petroleum Gases (LPG) |        | 2.3 | 4.0 | 4.0* | 4.0* |
| Kerosene |                        | 2.0 | 3.0 | 3.0* | 3.0* |
| Naphtha, Lubricants, Refineries' Soda, Paraffin Waxes, White Spirit, Non-specified Petroleum Products, Other Hydrocarbon | in road transport sector | 1.9 | 2.6 | 2.6 | 2.6 |
|          | in Lubricant and Naphtha in commercial and residential sectors | 1.5 | 1.5 | 1.5 | 1.5 |
|          | in energy, industry, transformation and residential sectors | 3.0 | 3.0 | 3.0 | 3.0 |
| Natural Gas |                     | 3.2 | 3.9 | 3.9* | 3.9* |
| Natural Gas Liquids |                | 9.2 | 9.6 | 9.6 | 9.6 |
| Anthracite |                          | 3.8 | 2.7 | 3.8 | 3.8 |
| Biogasoline, Biodiesel |            | 15.5 | 19.1 | 19.1 | 19.1 |
| Blast Furnace Gas |                    | 15.8 | 18.5 | 18.5 | 18.5 |
| Additives/Blending Components | in residential sector | 1.5 | 1.5 | 1.5 | 1.5 |
|          | in all other sectors | 3.0 | 3.0 | 3.0 | 3.0 |
| Crude Oil |                              | 1.5 | 1.5 | 1.5 | 1.5 |
| Bitumen |                                | 15.5 | 18.1 | 18.1 | 18.1 |
| Sub-Bituminous Coal |                        | 3.4 | 4.0 | 4.0 | 4.0 |
| BKB/Peat Briquettes |                      | 14.5 | 18.0 | 18.0 | 18.0 |
| Brown Coal |                             | 10.0 | 14.0 | 14.0 | 14.0 |
| Other Bituminous Coal |                        | 7.7 | 6.8 | 7.7 | 7.7 |
| Charcoal |                                 | 25.0 | 25.0 | 25.0 | 25.0 |
| Ethane |                                  | 8.3 | 11.3 | 11.3 | 11.3 |
| Biogas |                                      | 50.0 | 50.0 | 50.0 | 50.0 |
| Gas Coke |                                   | 16.0 | 17.0 | 17.0 | 17.0 |
| Gas Works Gas |                               | 16.0 | 22.0 | 22.0 | 22.0 |
| Residual Fuel Oil |                            | 2.4 | 1.8 | 2.4 | 2.4 |
| Municipal Waste (Renew) in Fuel Combustion Petroleum |               | 7.0 | 7.0 | 7.0 | 7.0 |
| Bagasse in Pumped Storage of Electricity |                     | 7.0 | 7.0 | 7.0 | 7.0 |
| Heat Output from Non-specified Manufacture Gases |               | 7.0 | 7.0 | 7.0 | 7.0 |
| Primary Solid Biomass in Fuel Combustion Petroleum |               | 16.0 | 17.0 | 17.0 | 17.0 |
| Shale Oil |                                | 16.0 | 17.0 | 17.0 | 17.0 |
| Petroleum Coke |                       | 15.0 | 18.0 | 18.0 | 18.0 |
| Coke Oven Coke |                         | 10.5 | 11.2 | 11.2 | 11.2 |
| Coke Oven Gas |                          | 16.0 | 22.0 | 22.0 | 22.0 |
| Coking and Hard Coal |                       | 7.7 | 7.0 | 7.7 | 7.7 |
| Coal Tar |                              | 0.1 | 11.4 | 11.4 | 11.4 |
| Crude/NGL/Feedstock |                       | 3.0 | 3.0 | 3.0 | 3.0 |
| Gasoline Jet Fuel |                        | 2.6 | 4.3 | 4.3 | 4.3 |
| Kerosene Jet Fuel |                       | 2.5 | 4.0 | 4.0 | 4.0 |
| Industrial Waste |                      | 23.0 | 28.0 | 28.0 | 28.0 |
| Material/Process                                                                 | EDGAR-JRC | CHE_EDGAR-ECMWF_2015 |
|---------------------------------------------------------------------------------|-----------|---------------------|
| Municipal Waste                                                                 | 20.0 32.0 | 20.0 32.0 32.0 32.0 |
| Oxygen Steel Furnace Gas                                                        | 20.0 11.0 | 20.0 11.0 20.0 20.0 |
| Patent Fuel                                                                     | 15.0 18.0 | 18.0 18.0 18.0 18.0 |
| Peat                                                                            | 5.7 1.9  | 5.7 5.7 5.7 5.7    |
| Refinery Gas                                                                    | 16.3 20.0 | 20.0 20.0 20.0 20.0 |
| Venting and Flaring during Oil and Gas Production, Oil Transmission, Transport by Oil Trucks | 50.0 50.0 | 75.0 75.0 75.0 75.0 |
| Crude Oil, Natural Gas, Gasoline, Diesel, Residual Fuel Oil, LPG, Ethane, Naphta, Bitumen, White Spirit, Anthracite, Other Bituminous Coal, Gas Coke, Gas Works Gas, Blast Furnace Gas, Biodiesel, BKB/Peat Briquettes, Renewables Wastes (1B1c only, Coke Ovens input: Non-specified Combust) | 50.0 50.0 | 50.0 50.0 50.0 50.0 |
| in fuel transformation coke ovens                                               | 50.0 50.0 | 100.0 100.0 100.0 250.0 |
| in fuel transformation of gaseous fuels (non-specified transformation)         | 100.0 100.0 | 100.0 100.0 100.0 250.0 |
| in other non-energy use of fuels in industry                                   | 100.0 100.0 | 100.0 100.0 100.0 100.0 |
| in blast furnaces                                                              | 25.0 25.0 | 25.0 25.0 25.0 25.0 |
| Production                                                                      |           |                     |
| cement                                                                          | 11.0 61.0 | 61.0 61.0 61.0 61.0 |
| lime                                                                            | 2.0 2.0  | 2.0 2.0 2.0 2.0    |
| limestone                                                                       | 3.0 3.0  | 3.0 3.0 3.0 3.0    |
| ammonia                                                                         | 7.0 7.0  | 7.0 7.0 7.0 7.0    |
| titanium                                                                        | 7.0 7.0  | 7.0 7.0 7.0 7.0    |
| silicon, calcium                                                                | 10.0 10.0 | 10.0 10.0 10.0 10.0 |
| ethylene, methanol                                                              | 30.0 30.0 | 30.0 30.0 30.0 30.0 |
| vinyl                                                                           | 50.0 50.0 | 50.0 50.0 50.0 50.0 |
| carbon black, urea                                                              | 15.0 15.0 | 15.0 15.0 15.0 15.0 |
| steel, ferroalloys                                                              | 25.0 25.0 | 25.0 25.0 25.0 25.0 |
| aluminium                                                                       | 10.0 10.0 | 10.0 10.0 10.0 10.0 |
| magnesium                                                                       | 5.0 5.0   | 5.0 5.0 5.0 5.0    |
| lead, zinc                                                                      | 50.0 50.0 | 50.0 50.0 50.0 50.0 |
| glass                                                                           | 60.0 60.0 | 60.0 60.0 60.0 60.0 |
| Solvents                                                                        |           |                     |
| CO2 from Urea, Dolomite, and Limestone Application                               | C in urea fertilizer applied | 50.0 50.0 100.0 100.0 |
| Oil/Coal Fires                                                                  | 100.0 100.0 | 100.0 100.0 100.0 100.0 |
| Waste Incineration without Energy Recovery                                      | 40.0 40.0 | 40.0 40.0 40.0 40.0 |

Uncertainties from EDGAR-JRC dataset aggregated to the ECMWF group level were compared with the ones from CHE_EDGAR-ECMWF_2015, see Table S6 for selected countries. Comparison showed that uncertainties derived in this study are an upper bound of the uncertainty estimation with more detailed information. Even though sometimes differences might be quite high in %, they are usually quite small in Mtons.

Table S6: Aggregated to the ECMWF group level uncertainties (lower L and upper U bounds) in % and contributions in % to the total uncertainty (CV) for selected geographical entities from EDGAR-JRC (with extra fuel type knowledge) and CHE_EDGAR-ECMWF_2015 (with typical fuel only)

| Country | ECMWF group | EDGAR-JRC | CHE_EDGAR-ECMWF_2015 |
|---------|-------------|-----------|---------------------|
| DEU     | ENERGY_S    | 0.0 0.0   | 0.0 3.0 0.3          |
|         | ENERGY_A    | -5.6 7.1  | 67.5 8.6 19.1        |
|         | MANUFACTURING | -6.1 6.3 | 9.8 11.5 17.0 22.5   |
|         | SETTLEMENTS  | -6.8 6.9  | 12.2 12.2 10.3       |
|         | AVIATION     | -5.5 6.3  | 0.0 3.5 4.1 0.0      |
|         | TRANSPORT    | -3.9 4.0  | 4.8 -5.3 5.7 2.5     |
|         | OTHER        | -15.5 15.5| 5.8 -31.2 139.3 45.3 |
| Country | TOTAL | ENERGY_S | ENERGY_A | MANUFACTURING | SETTLEMENTS | AVIATION | TRANSPORT | OTHER | TOTAL |
|---------|-------|----------|----------|---------------|-------------|-----------|-----------|-------|-------|
| ESP     | -3.0  | 3.6      | 100.0    | -4.7          | 8.7         | 100.0     |          |       |       |
|         |       | -0.0     | 0.0      | 0.0           | 0.0         | 0.0       | 0.0       | 0.0   | 0.0   |
| FRA     | -2.7  | 2.7      | 100.0    | -5.0          | 12.4        | 100.0     |          |       |       |
|         |       | -0.0     | 0.0      | 0.0           | 0.0         | 0.0       | 0.0       | 0.0   | 0.0   |
| GBR     | -3.4  | 3.3      | 100.0    | -4.8          | 13.2        | 100.0     |          |       |       |
|         |       | -0.0     | 0.0      | 0.0           | 0.0         | 0.0       | 0.0       | 0.0   | 0.0   |
| POL     | -4.0  | 4.2      | 100.0    | -5.0          | 8.3         | 100.0     |          |       |       |
|         |       | -0.0     | 0.0      | 0.0           | 0.0         | 0.0       | 0.0       | 0.0   | 0.0   |
| BRA     | -5.2  | 5.2      | 100.0    | -6.7          | 15.4        | 100.0     |          |       |       |
|         |       | -0.0     | 0.0      | 0.0           | 0.0         | 0.0       | 0.0       | 0.0   | 0.0   |
| CHN     | -5.2  | 5.2      | 100.0    | -6.7          | 15.4        | 100.0     |          |       |       |
|         | 0.0   | 0.0      | 0.0      | 0.0           | 0.0         | 0.0       | 0.0       | 0.0   | 0.0   |
| IDN     | -5.2  | 5.2      | 100.0    | -6.7          | 15.4        | 100.0     |          |       |       |
|         | 0.0   | 0.0      | 0.0      | 0.0           | 0.0         | 0.0       | 0.0       | 0.0   | 0.0   |
|          | ENERGY_S | ENERGY_A | MANUFACTURING | SETTLEMENTS | AVIATION | TRANSPORT | OTHER | TOTAL |
|----------|----------|----------|---------------|-------------|----------|-----------|-------|-------|
| IND      | 0.0      | -6.3     | -8.5          | -5.3        | -5.6     | -4.0      | -17.3 | -4.0  |
|          | 0.0      | 5.8      | 8.4           | 5.3         | 6.4      | 3.9       | 17.4  | 3.8   |
|          | 0.0      | 63.4     | 31.0          | 1.0         | 0.0      | 1.1       | 3.4   | 100.0 |
|          | 0.0      | -8.6     | -10.7         | -12.2       | -3.5     | -5.3      | -35.0 | -35.0 |
|          | 0.0      | 8.6      | 15.2          | 12.2        | 4.1      | 7.1       | 156.7 | 156.7 |
|          | 0.0      | 23.7     | 39.4          | 5.9         | 4.0      | 0.9       | 100.0 | 100.0 |
| JPN      | -2.6     | -7.2     | -7.4          | -13.6       | -6.6     | -22.0     |       |       |
|          | 2.6      | 7.2      | 7.4           | 13.6        | 6.6      | 26.9      |       |       |
|          | 100.0    | 61.4     | 8.1           | 13.6        | 6.0      | 16.6      |       |       |
|          | -4.7     | -12.2    | -12.1         | -26.0       | -14.1    | -39.2     |       |       |
|          | 8.5      | 12.2     | 15.7          | 26.0        | 44.8     | 174.3     |       |       |
|          | 100.0    | 8.6      | 18.2          | 4.0         | 10.4     | 58.1      |       |       |
| RUS      | -4.7     | -6.2     | -7.9          | -5.5        | -4.0     | -8.6      |       |       |
|          | 4.9      | 6.3      | 8.1           | 6.4         | 5.1      | 8.8       |       |       |
|          | 100.0    | 6.2      | 12.2          | 0.5         | 30.2     | 5.0       |       |       |
|          | -6.8     | -12.5    | -12.2         | -3.5        | -5.5     | -32.1     |       |       |
|          | 16.2     | 18.9     | 12.2          | 4.1         | 8.7      | 145.2     |       |       |
|          | 100.0    | 5.9      | 3.6           | 0.0         | 8.3      | 59.9      |       |       |
| USA      | -2.3     | -6.2     | -7.9          | -5.5        | -4.0     | -8.6      |       |       |
|          | 2.5      | 6.3      | 8.1           | 6.4         | 5.1      | 8.8       |       |       |
|          | 100.0    | 6.2      | 12.2          | 0.5         | 30.2     | 5.0       |       |       |
|          | -4.7     | -12.5    | -12.2         | -3.5        | -5.5     | -32.1     |       |       |
|          | 16.2     | 18.9     | 12.2          | 4.1         | 8.7      | 145.2     |       |       |
|          | 100.0    | 5.9      | 3.6           | 0.0         | 8.3      | 59.9      |       |       |

*Data availability.* EDGARv4.3.2 data are open access and available at [http://edgar.jrc.ec.europa.eu/overview.php?v=432&SECURE=123](http://edgar.jrc.ec.europa.eu/overview.php?v=432&SECURE=123), last access: 26 February 2020, doi:[https://data.europa.eu/doi/10.2904/JRC_DATASET_EDGAR](https://data.europa.eu/doi/10.2904/JRC_DATASET_EDGAR), documented in Janssens-Maenhout et al. (2019). CHE_EDGAR-ECMWF_2015 data are freely available doi:10.5281/zenodo.3712339.

*Author contribution.* All the authors participated in the EDGAR_CHE maps generation (methodology, data generation), model experiment set-up, and analysis of the result. Margarita Choulga and Greet Janssens-Maenhout wrote the manuscript with contributions from all the other authors.

*Competing interests.* The authors declare that they have no conflict of interest.
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