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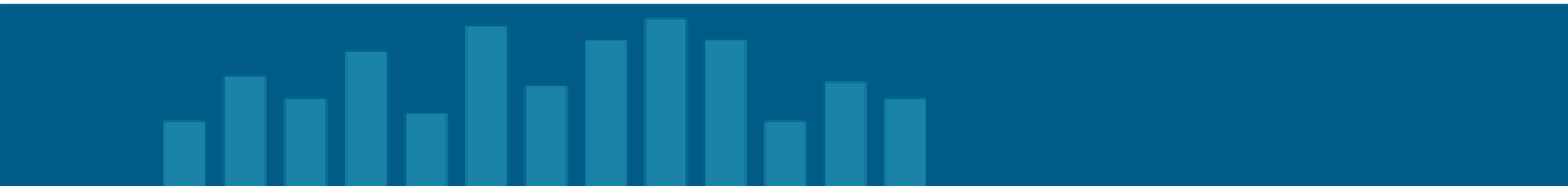
METHODS FOR ESTIMATING GREENHOUSE GAS EMISSIONS FROM FOOD SYSTEMS
PART II: WASTE DISPOSAL



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METHODS FOR ESTIMATING GREENHOUSE GAS EMISSIONS FROM FOOD SYSTEMS
PART II: WASTE DISPOSAL

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Food and Agriculture Organization of the United Nations
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Abstract

This paper is part of a series detailing novel methodologies for estimating key components of food systems emissions, with a view to disseminate the information in FAOSTAT. It provides a methodology for estimating the greenhouse gas emissions associated with emissions from waste in the food system (e.g. food-related processes in landfills, incineration, wastewater management processes), in an effort to inform countries of the environmental impacts and possible options to reduce them. Based on the proposed methodology, we build a new database of the annual carbon footprint of food disposal, on a country basis and with global coverage, for the period 1990–2019.

Our efforts help to better characterize food systems and the role they can play in achieving the Sustainable Development Goals (SDGs). In particular, they align well with SDG 12 to ensure “sustainable consumption and production patterns’’, specifically Target 12.2, “achieve the sustainable management and efficient use of natural resources” and Indicator 12.2.1, which monitors the “material footprint, material footprint per capita, and material footprint per GDP” of different products.

This paper covers four categories of food systems waste disposal: (1) solid food waste disposed in landfills; (2) domestic wastewater; (3) industrial wastewater; and (4) incineration of materials used in food systems.

Contents

Acknowledgements

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Many principles of this methodology build on previous collaborative work with the Joint Research Center of the European Commission, with thanks to M. Crippa, E. Solazzo, D. Giuzzardi, F. Monforti-Ferrario, and A. Leip. Key inputs were also provided by G. Obli Laryea, G. Conchedda and X. Pan of the FAO Statistics Division.

1 Introduction

Food systems waste, including solid food waste, domestic wastewater, industrial wastewater, and the waste of materials used in food systems, can generate significant amount of greenhouse gases (GHGs) depending on how they are managed. Through its statistical work on GHG emissions stemming from agriculture and land use, FAO provides country-level data on GHG emissions for a number of activities associated with agri-food systems (FAO, 2021). However, while GHG estimates for activities directly related to agriculture are well characterized by FAO, there is a general lack of data on anthropogenic sources of GHGs emitted from food system activities beyond agricultural production and land use (Clark *et al*., 2020). The food system contributes significant GHG emissions from a vast array of other activities, such as fertilizer production, food processing, transport and waste disposal, to name a few (Rosenzweig *et al*., 2020). New data are therefore needed to characterize processes and emissions generated by food beyond the farm boundary, i.e. arising from additional pre- and post-production activities such as industrial fertilizer production, food processing, food transport, retail and waste disposal. The most recent efforts in this area of work, developed with significant FAO contribution (Crippa *et al.,* 2021; Tubiello *et al.,* 2021), can serve as a useful basis for exploring how to extend the current FAOSTAT emissions estimates to a fuller food system boundary.

This work seeks to improve the analysis of country-level estimates of GHG emissions from waste disposal processes in food systems developed by Crippa *et al*. (2021), by disaggregating food waste from green waste, by applying additional relevant country-specific factors for waste management systems, and by extending the information over the period 1990–2019.

Our efforts help to better characterize food systems and the role they can play in achieving the Sustainable Development Goals (SDGs). In particular, they align well with SDG 12, to ensure “sustainable consumption and production patterns’’, specifically Target 12.2, “achieve the sustainable management and efficient use of natural resources” and Indicator 12.2.1, which monitors the “material footprint, material footprint per capita, and material footprint per GDP” of different products. This paper provides a methodology to estimate the GHG emissions associated with food systems waste disposal, in an effort to inform countries of the environmental impact of their food systems waste disposal systems and processes.

This paper aims provides a framework for estimating GHG emissions from four categories of waste disposal: (1) solid food waste disposed in landfills and open dumps; (2) domestic wastewater; (3) industrial wastewater from food production; and (4) incineration of materials used in food systems.

2 Solid food waste disposal

2.1 Solid food waste disposal overview

Solid food waste can be disposed of in a number of ways, including incineration, composting or utilization as an input to biogas production. In most countries, however, the majority of solid food waste ends up in landfills and open dumps where the anaerobic decomposition of organic material releases methane gas (CH_4) (Thi *et al*., 2015). The data on solid food waste can be estimated at Tier 2 following the Intergovernmental Panel on Climate Change (IPCC) 2006 guidelines and the 2019 Refinement to the 2006 Guidelines (IPCC, 2006; IPCC, 2019).

2.2 Estimating methane emissions from solid food waste in landfills

The emissions can be estimated at the country level, using the formula *Emissions = A * EF* where:

Emissions = GHG emissions in Gg CH_4 yr^{-1};

A = Activity data, mass of decomposable degradable organic carbon deposited, Gg yr^{-1};

EF = Default IPCC emission factor in Gg CH_4/C deposited (ratio).

2.2.1 Activity data

Activity data can be estimated from two main inputs— the World Bank *What a Waste Report 2.0,* which contains data on the total amount of waste deposited per country, and the Intergovernmental Panel on Climate Change (IPCC) 2019 Refinement, which contains data on the percentage of waste sent to landfills and open dumps, as well as the fraction of municipal solid waste that is food waste (Kaza *et al.*, 2018; IPCC, 2019). Where country data for the percentage of food waste and fraction of waste that is open-dumped and landfilled do not exist, regional means can be applied as set forth in the 2019 Refinement. Taken together, the World Bank and IPCC data provide information on specific modes of food waste disposal by country for the year 2016, i.e. the amounts of solid food waste disposed to landfills and open dumps. This is the information needed to estimate GHG emissions, through the decay of disposed organic matter. A new database on food waste was recently developed by the United Nations Environment Programme (UNEP, 2021), by country, for the year 2019. While the new UNEP data are not yet useful to compute GHG emissions, since they focus on food waste generation rather than disposal, FAO has already provided input to UNEP to include specific waste disposal information in their future data collection efforts. At that point, UNEP data can be integrated with those from the World Bank, to enrich and further improve our estimates.

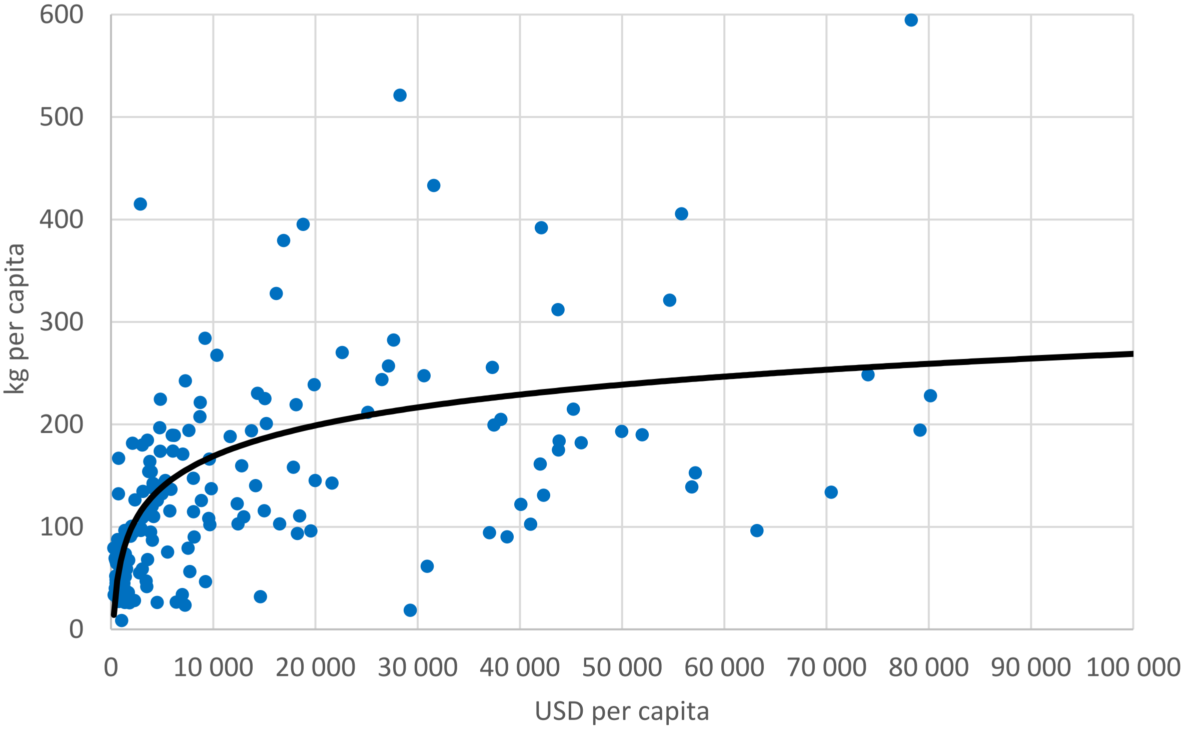
The organic matter of solid food waste decays over time, with a half-life estimated between 1.7 and 11.6 years, depending on climatic conditions, landfill site conditions and the composition of the food waste (Brown, 2016; IPCC, 2019). In order to estimate GHG emissions from landfilled food waste in a current year, it is also necessary estimate how much food was deposited in landfills 10, 20, and even 30 years before, which will continue to decay in the year of inventory. However, much of the current data on solid food waste are limited to observations in single year, such as the data collected in the recent UNEP *Food Waste Index 2021* report, or the World Bank *What a Waste Report 2*.0, which normalizes country-level waste data to the year 2016.

2.2.1.1 Back-casting activity data

To estimate greenhouse gas emissions in an inventory year, it is therefore necessary to estimate historical solid food waste deposition in landfills based on a data in a single year. In order to accomplish this, a simplified model based on the relationship between per capita gross domestic product (GDP) and per capita solid food waste deposition in landfills growth was used. The model builds on a number of food waste publications that establish a log-linear relationship between GDP and food waste – specifically, that per capita food waste increases with per capita GDP but begins to level off at a certain point. In a number of studies, the percentage change in GDP was more strongly associated with increases in solid food waste than a unitary change in GDP (Kumar *et al.*, 2018; Thi *et al.*, 2015; Xue *et al.*, 2017).

To further test this relationship, a country-level database of solid food waste per capita in 2016, built on World Bank and IPCC data, was correlated against the per capita GDP of over 200 countries and territories in that year (Kaza *et al.*, 2018; IPCC, 2019). The best fit for the data did indeed turn out to be the log-linear relationship, as shown in the figure below ($R^2 = 0.31$, $P < 0.001$).

Figure 1. Relationship between per capita solid food waste and per capita GDP



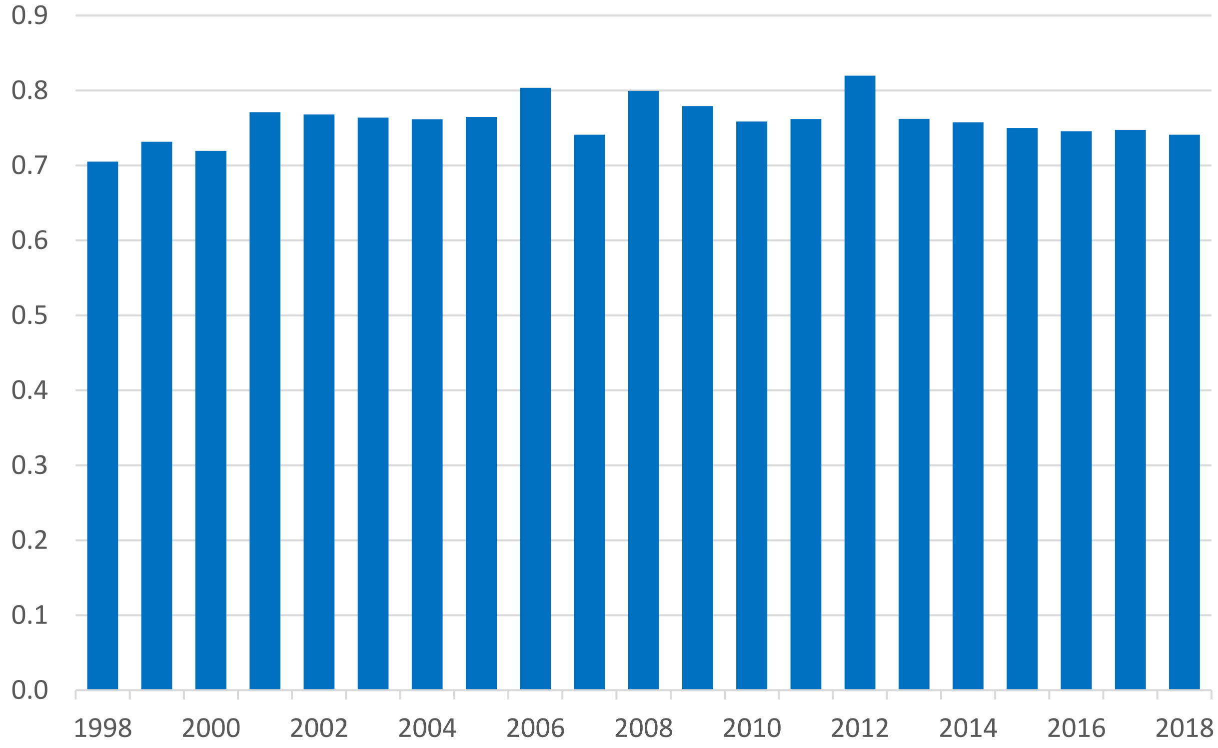
Sources: Authors' own elaboration based on World Bank and IPCC data.

2.2.1.2 Validating food systems waste disposal model with PRIMAP-hist third-party reported data

This method of back-casting activity data was validated by comparing the results of FAO solid food waste disposal emissions against total solid waste emissions (IPCC category 4A), as gathered and expressed in the PRIMAP-hist third party-reported dataset (Gütschow *et al.*, 2021). As shown in Figure 2, the global ratio hovers between 0.71 and 0.82 from 1998–2018, with both a mean and median of 0.76. Given the relative consistency of this ratio over time, it stands to reason that the log-linear functional form is indeed captured in the global solid waste emissions trends.

Nevertheless, it is preferable to use the back-casted activity data to create country- and region-specific coefficients over a range of time, such as by creating decadal averages of the ratio of solid food waste emissions to total solid waste emissions, and then applying the coefficients to PRIMAP data at the country level. Using the annual back-casted activity data estimates is discouraged due to the uncertain impact of sudden jumps in GDP per capita on solid food waste emissions (such as during an economic recession). This proposed methodology is reiterated and further explained in section 2.2.4.

Figure 2. Ratio of FAO solid food waste disposal GHG estimates to PRIMAP third party-reported total solid waste emission estimates, world (1998–2018)



Source: Authors' own elaboration based on PRIMAP-hist 2.1 third party-reported waste emissions data and FAO food systems waste disposal estimates.

2.2.2 First-order decay model values

The decay rate of methane generated from organic waste disposed in a certain year is approximated using a first-order decay model. Default IPCC values are used for climate-specific decay reaction constants (k-values) in the first-order decay model, found in IPCC (2019). Averaged reaction constants are used for countries where more than one IPCC climate zone apply, according to IPCC climate zone groupings found in IPCC (2019).

The decay model is built on an exponential factor that takes as input the estimated degradable organic carbon fraction and the decomposable organic carbon fraction of food waste. Default IPCC values are used for the degradable organic carbon fraction (i) and the decomposable degradable organic carbon fraction (ii).

(i) The degradable organic carbon fraction used is 0.15 as found in IPCC (2006).

(ii) The fraction of degradable organic carbon which decomposes for food used is the default value of 0.7 as found in IPCC (2019).

2.2.3 Emissions factors

Emissions factors are estimated at Tier 1 using IPCC guidelines, continuing to follow the first-order decay model set out in IPCC (2006). Default values, given in IPCC (2019), are used for the methane correction factor (i), oxidation factor (ii), recovery rate (iii), and fraction of anaerobic carbon that is emitted as methane (iv).

(i) The methane correction factor used for all countries is the default weighted average of 0.71 across waste sites.

(ii) The default value used for the oxidation factor is 0.

(iii) The default value for methane recovery rate is 0.

(iv) The fraction of anaerobic decomposable degradable carbon that results in methane is 0.5.

2.2.4 Creating a time series for solid food waste emissions using PRIMAP-hist emissions data

Using the back-casted activity data and IPCC emissions factors described previously, it is possible to estimate GHG emissions from accumulated solid food waste deposited in landfills in a given inventory year. Averages of country-level GHG emissions data from solid food waste disposal can then be compared against the total GHG emissions from the solid waste sector. This ratio can then be directly applied to PRIMAP-hist country-level time series data, which includes country-level estimates for CH_4 emissions from the IPCC solid waste sector dating back to 1850.

This methodology assumes that FAO solid food waste disposal estimates stay relatively constant as a fraction of total solid waste emissions over time, which is evidenced at the global level in Figure 2. One reason for the relatively constant ratio of solid food waste disposal emissions to the total solid waste sector emissions may be that the effect of per capita GDP changes on solid waste generation are already captured in the emissions data expressed in the PRIMAP-hist third party-reported dataset.

For each country, decadal averages of this ratio can be developed over the time series and then applied to the annual solid waste sector emissions in order to develop regional and country-specific estimates for emissions from solid food waste disposal from 1990 to 2019. This methodology enables solid food waste emissions estimates to follow a similar trajectory as the country-specific trends in total solid waste disposal emissions.

3 Domestic wastewater

3.1 Domestic wastewater overview

From a biological perspective, a full analysis of food systems should follow the entire food nutrient cycle. GHG emissions from domestic wastewater are a consequence of the passage of food nutrients through humans and into wastewater. For example, nitrous oxide (N_2O) emissions from wastewater are calculated by estimating per capita protein consumption, and then estimating the amount of excess nitrogen that flows into wastewater beyond what people can biologically assimilate.

This framework enables a systemic view of resource use efficiency across the food system, which could be a useful analytical lens to monitor and track limited nutrients such as phosphorous (see Forester *et al*., 2020). It also draws a stronger link between food consumption and the downstream consequences of wastewater, such as emissions, pollution and public health concerns, among other important considerations. As the focus of this report is estimating emissions associated with food systems waste disposal, it is important to consider how we dispose of all elements of the food system. The degree to which domestic wastewater produces emissions depends both on the details of a particular wastewater management system, as well as the input that the system receives.

3.2 Estimating methane emissions from domestic wastewater

GHG emissions from domestic wastewater consist of CH_4 and N_2O emitted by sewage systems, waste treatment facilities, latrines, septic systems and undefined discharge and treatment pathways. Emissions resulting from the application of sludge are not included in this analysis. The data here are computed at Tier 1 following IPCC (2006) and IPCC (2019).

Methane emissions are estimated at the country level, using the formula

$$Emissions = A * EF$$

where:

$Emissions$ = Gg CH_4 yr^{-1}

A = Activity data, total organics in wastewater post sludge removal in year, Gg BOD yr^{-1};

EF = Tier 1, default IPCC emission factors, Gg CH_4/Gg BOD

3.2.1 Activity data

Activity data are calculated from World Bank population data, as well as IPCC data on intra-country income and urbanization levels, default treatment/discharge pathway fractions for domestic wastewater for each income and urbanization group, and country-level statistics on per capita biochemical oxygen demand (BOD) found in IPCC (2019).

Where country-level data for urbanization and income groups and per capita biological oxygen demand do not exist, regional means are applied based on the regional groupings in IPCC (2019). If there are no regional values available based on these regional groups, then larger group means are applied as set forth in the country grouping found in IPCC (2006).

The fraction of organic material in wastewater removed as sludge and through biochemical decomposition is applied to each country per urbanization and income brackets and provided for septic systems (i), latrines (ii), and sewage systems (iii) using the following values from IPCC (2019):

(i) Septic tank/septic system: 0.625

(ii) Latrines: 0.7 in wet climates, according to previously defined IPCC climate zones, 0.3 in dry climates, as an average of family and communal use default values.

(iii) Sewage systems: 0.638 as an average of primary treatment and advanced treatment systems.

3.2.2 Emissions factors

Emissions factors are calculated at Tier 1 using IPCC guidelines in IPCC (2019). Emissions factors, in kg CH_4/kg BOD, are used for sewer systems (i), septic systems (ii), latrines (iii), and undefined discharge pathways (iv).

The following emissions factors are taken from IPCC (2019) and measured in kg CH_4/kg BOD:

(i) An emissions factor of 0.193 is used for sewage systems, representing the average of effluent emissions for flowing and stagnant sewers (0.15) and average emission factor for primary treated sewage from plants and untreated sewage (0.043).

(ii) An emissions factor of 0.3 is used for septic systems.

(iii) An emissions factor of 0.18 is used for latrines in dry climates (averaging between family and communal latrines), and 0.42 for wet climates according to previously defined IPCC climate regions.

(iv) The default emission factor for undefined discharge and treatment pathways is 0.068.

3.3 Estimating nitrous oxide emissions from domestic wastewater

Nitrous oxide emissions are estimated at the country level, using the formula *Emissions = A * EF*

where:

Emissions = Gg N_2O yr^{-1}

A = Activity data, total nitrogen in domestic wastewater in inventory year, Gg N yr^{-1} (1);

EF = Tier 1, default IPCC emission factors, Gg N_2O - N/Gg N (2).

3.3.1 Activity data

Activity data are World Bank population data, as well as IPCC data on intra-country income and urbanization levels, default treatment/discharge pathway fractions for domestic wastewater for each group, regional data on protein consumed as fraction of protein supply, regional data on food non-consumed in case food waste is disposed to sewers – all sourced from IPCC (2019) – and FAOSTAT data on protein supply in the Food Balance Sheets datasets.

Where country data for urbanization and income groups, protein supply, and protein consumption of supply do not exist, regional means are applied based on regional groupings in IPCC (2019). If there are no regional values based on these regional groups, then larger group means are applied as set forth in the country groups found in IPCC (2006).

3.3.2 Emissions factors

Emissions factors are calculated at Tier 1 using IPCC guidelines in IPCC (2019). Emissions factors, in kg N_2O - N/kg N, are used for sewer systems (i), septic systems (ii), latrines (iii), and other discharge pathways (iv).

All of following emissions factors are taken from IPCC (2019) and measured in kg N_2O - N/kg N:

> (i) An emissions factor of 0.0105 is used for sewage systems, representing the average emission factor for untreated and primary treated waste.
>
> (ii) An emissions factor of 0.0023 is used for septic systems, representing the average emissions factor for septic tanks and septic tanks with land dispersal fields.
>
> (iii) An emissions factor of 0 is used for latrines.
>
> (iv) The default emission factor for undefined discharge and treatment pathways is 0.005.

4 Industrial wastewater

4.1 Industrial wastewater overview

GHG emissions from industrial wastewater consist of CH_4 and N_2O emitted via wastewater generated in the production of alcohol, beer and malt, fish, meat and poultry, nitrogen fertilizer, starches, coffee, dairy, sugar, vegetable oils, wine, vinegar, and vegetable and fruit products. Pulp production for paper products utilized in food systems is also estimated. The ratio of food waste to total waste in a country – given in Kaza *et al.* (2018) – is used as a proxy for the ratio of food system pulp to total pulp produced, for relevant food system pulp categories such as carton board and packaging materials. FAOSTAT data are computed at Tier 1 following IPCC (2006) and IPCC (2019).

4.2 Estimating methane emissions from industrial wastewater

Methane emissions are estimated at the country level, using the formula

$Emissions = A * EF$

where:

$Emissions$ = Gg CH_4 yr^{-1}

A = Activity data, total organics in wastewater, Gg COD yr^{-1} (1);

EF = Tier 1, default IPCC emission factors, Gg CH_4/Gg COD (2).

4.2.1 Activity data

Activity data for industrial production are taken from the United Nations Industrial Commodity Statistics database, FAOSTAT data on the production of crops, livestock and forestry. When FAOSTAT data and United Nations Industrial Commodity Statistics data cover the same industrial products in the same year for the same country, preference is given to FAOSTAT data. While data for processed food commodities are largely FAO estimates rather than country official data, they represent the state of the art in terms of available information with global coverage.

Data on wastewater generation for each industrial category, as well as chemical oxygen demand (COD) per cubic metre of wastewater in each industrial category are taken from IPCC (2006) and IPCC (2019). For years with gaps in inventory data, missing values are imputed using linear interpolation as appropriate (i.e. in the middle of a series, where the country is still reporting GDP in that year).

The total organic material in wastewater (kg COD) is a product of the total output per industrial sector (tonnes), the amount of wastewater generated per tonne of product (m^3 /tonne), and the chemical oxygen demand (otherwise known as the industrial degradable organic component in wastewater, kg COD/m^3).

4.2.2 Emissions factors

Emissions factors employed follow Tier 1 using IPCC (2019), specifically, 0.028 kg CH_4/kg COD.

4.3 Estimating nitrous oxide emissions from industrial wastewater

Nitrous oxide emissions are estimated at the country level, using the formula

*Emissions = A * EF*

where:

Emissions = Gg N_2O yr^{-1}

A = Activity data, total nitrogen from industrial wastewater, Gg N yr^{-1} (1);

EF = Tier 1, default IPCC emission factors, Gg N_2O-N/kg N (2).

4.3.1 Activity data

Activity data and data on wastewater treatment are taken from the same sources as above for estimating methane emissions from industrial wastewater. Data on wastewater generation for each industrial category, as well as total nitrogen per cubic metre of wastewater in each industrial category are taken from IPCC (2006) and IPCC (2019).

Total nitrogen (kg N) is a product of the total output per industrial sector (tonnes), the amount of wastewater generated per tonne of product (m^3/tonne), and the total nitrogen in wastewater (kg/m^3).

4.3.2 Emissions factors

Emissions factors employed follow Tier 1 using IPCC (2019), specifically, 0.005 kg N_2O - N/kg N.

5 Incineration

5.1 Incineration overview

GHG emissions from incineration consist of carbon dioxide (CO_2) emitted from the burning of plastic and rubber materials used in food systems. The ratio of food waste to total waste in a country – given in Kaza *et al.* (2018) – is used as a proxy for the ratio of food-related plastic and rubber waste to total plastic and rubber waste per country, following a methodology used by Crippa *et al.* (2021). FAOSTAT data are computed at Tier 2a following IPCC (2006) and IPCC (2019).

5.2 Estimating carbon dioxide emissions from incineration of plastic and rubber

Carbon dioxide emissions are estimated at the country level, using the formula

$Emissions = A * EF$

where:

$Emissions$ = Gg CO_2 yr^{-1}

A = Activity data, carbon fraction of waste type deposited, Gg C yr^{-1} (1);

EF = Default IPCC emission factors, Gg CO_2/Gg C (2).

5.2.1 Activity data

Activity data are estimated from the Kaza *et al.* (2018), which contains data on the total amount of waste deposited per country in 2016, as well as the fraction of total waste that is either plastic or rubber waste. Other data inputs are taken from IPCC (2019), which contains country-level statistics and regional defaults on the fraction of waste incinerated. Where country data for the plastic and rubber waste fraction and the fraction of waste that is incinerated do not exist, regional means are applied as set forth in IPCC (2019). Where there are no applicable regional means according to these groupings, the fraction of waste incinerated is assumed to be zero. Given the lack of reliable statistics on the quantity of open-burned plastic and rubber, this methodology focuses only on countries with incineration facilities (IPCC, 2019).

5.2.2 Emissions factors

Emissions factors employed depend on the waste type and the carbon content specific to each type, as set forth in IPCC (2006).

Plastic

Food-related plastic waste incinerated (Gg) is multiplied by the dry matter content of the wet weight (100 percent), the total carbon content of the dry weight (75 percent), and the fossil carbon fraction in percent of total carbon (100 percent).

Rubber

Food-related rubber incinerated (Gg) is multiplied by the dry matter content in percent of wet weight (84 percent), the total carbon content in percent of dry weight (67 percent), and the fossil carbon fraction in percent of total carbon (20 percent).

The default conversion factor of 3.67 is then applied to convert from Gg fossil C to Gg CO_2 (IPCC, 2006). The default oxidation factor used is 100 percent (IPCC, 2006).

5.2.3 Creating a time series for emissions using country reported emissions data

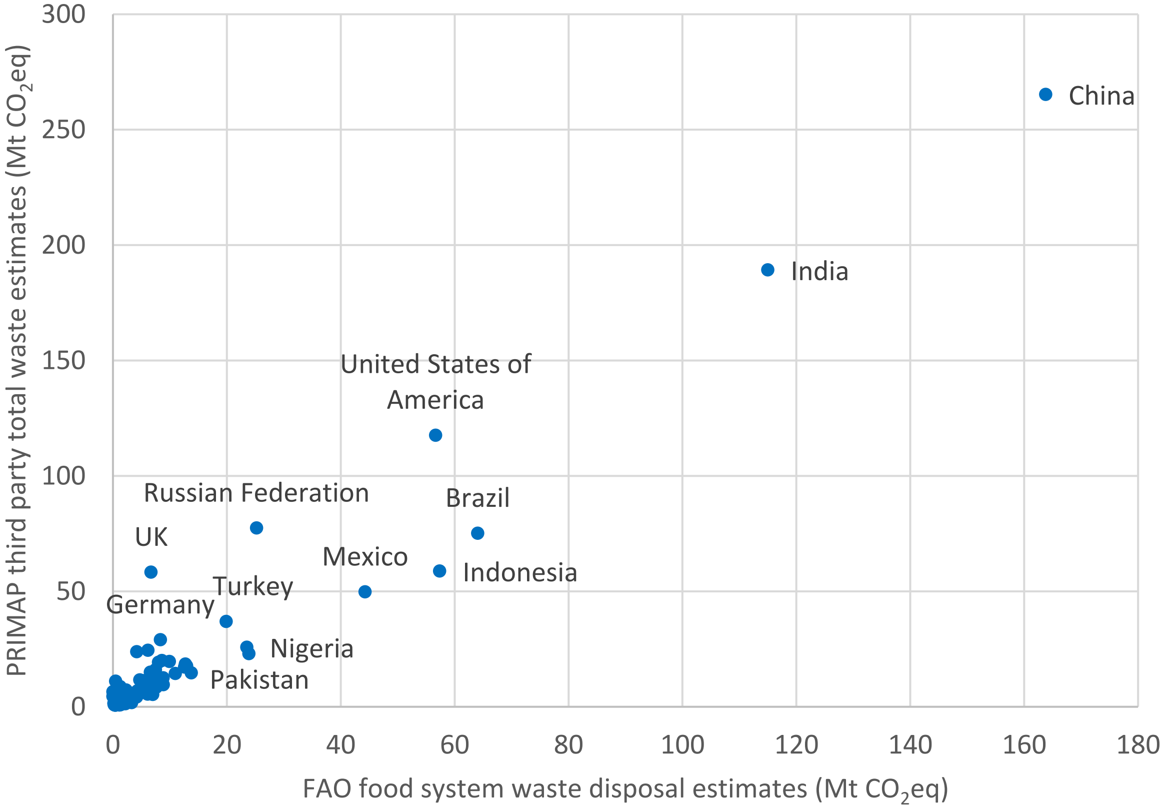
Once the country-level emissions estimates are created for the inventory year, the fraction of total waste sector emissions attributable to incinerated food systems materials can be established. Similar to the methodology for estimating emissions from solid food waste disposed to landfills, this fraction can then be applied to historical emissions data as gathered and expressed in the PRIMAP-hist third party-reported dataset to create a time series of emissions data (Gütschow *et al.*, 2019).

6 Validating food systems waste disposal emissions model

6.1 Country-level validation

Since there are no country-level databases of global coverage that contain country-reported data on the GHG emissions associated with food waste, the estimates produced by the food systems waste disposal methodology were validated against third party-reported total waste emissions as gathered and expressed in the PRIMAP-hist dataset (Gütschow *et al*., 2021). With a term coefficient of 1.6 (P <0.0001) and an R^2 equal to 0.94, the emissions data estimated through this methodology are highly correlated with third-party reported waste emissions data at the country level. Here, the decadal averages are compared for all countries in the dataset.

Figure 3. Correlation between PRIMAP third-party total waste emissions and FAO-estimated food systems waste disposal emissions (2008–2018 average)

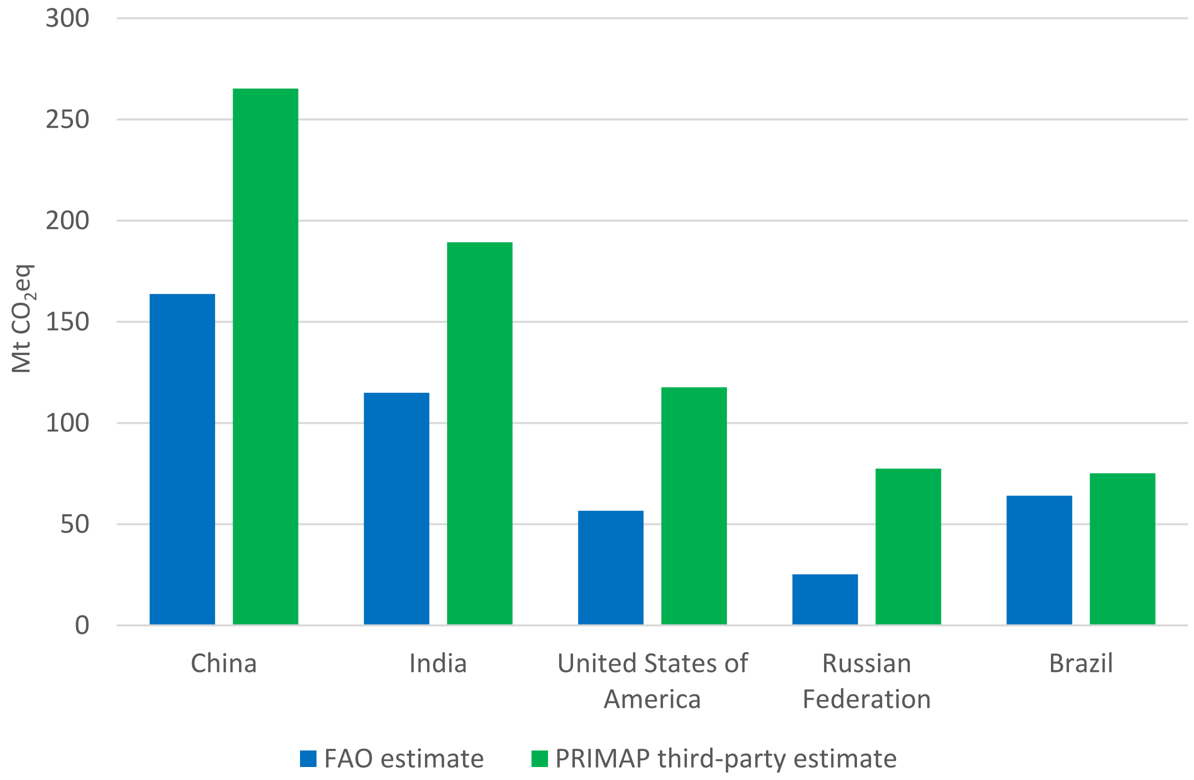


UK: United Kingdom of Great Britain and Northern Ireland

Source: Authors’ own elaboration based on PRIMAP-hist 2.1 third party-reported waste emissions data and FAO food system waste disposal estimates.

FAO food systems waste estimates from the top ten highest emitting countries (according to PRIMAP-hist) can also be used to verify the approach taken. Here, a decadal average is used to compare the data. While the emissions data estimated in this domain are highly correlated with third party-reported waste emissions data at all geographic levels, there is still a fair bit of variance between countries. For example, the ratio of FAO food systems waste disposal emissions estimates to PRIMAP third-party estimates for the top five countries (in terms of GHG emissions from the waste sector) are: 0.62 for China, 0.61 for India, 0.48 for the United States, 0.33 for Russia, and 0.85 for Brazil (see Figure 4). All of these estimates lie within the range of 0.26–0.88, used by Crippa *et al.* (2021) in the estimation of solid waste disposal emissions to total emissions (and used as a proxy here for a viable range of country-specific food share ratios to total waste).

Figure 4. Comparison between PRIMAP third party-reported total waste emissions data and FAO-estimated food systems waste disposal emissions data, top countries (2008–2018 average)

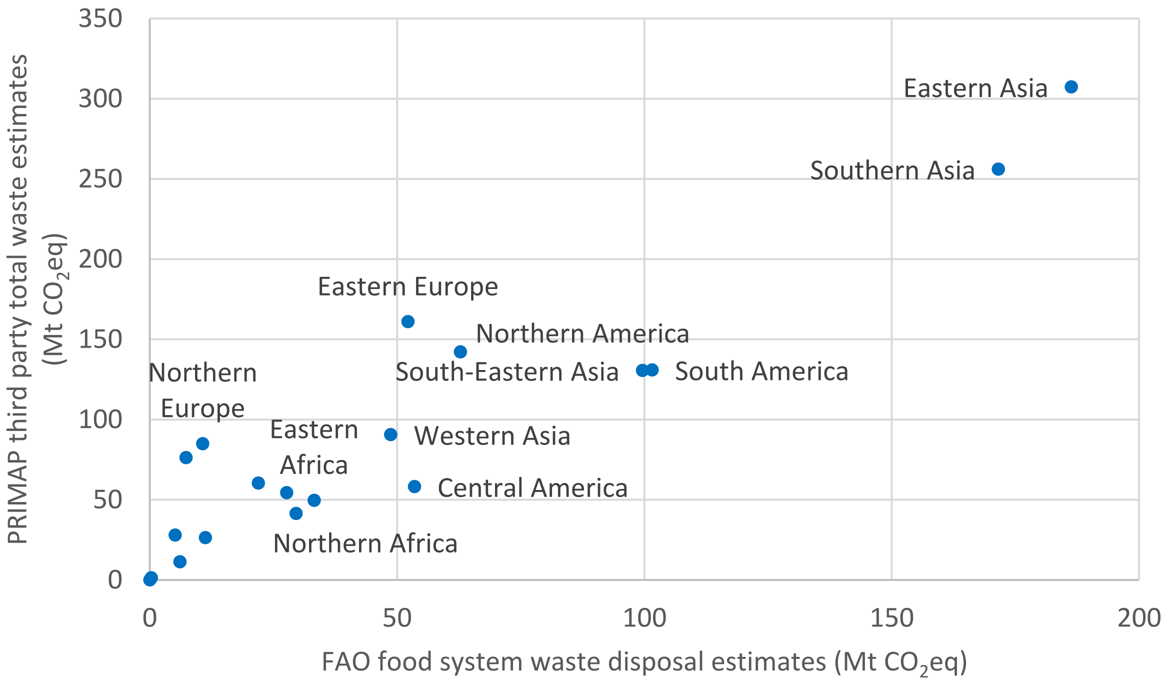


Source: Authors’ own elaboration based on PRIMAP-hist 2.1 third party-reported waste emissions data and FAO food systems waste disposal estimates.

6.2 Regional validation

Similar to the country-level comparisons, the model holds up well against regional emissions data aggregated from third party-reported data, with a term coefficient of 1.4 (P-value <0.001), and an R^2 equal to 0.87. The emissions data estimated in this domain are highly correlated with third party-reported waste emissions data at the regional level, and the model appears to capture much of the regional variance in waste emissions (see Figure 4).

Figure 5. Correlation between PRIMAP third party-reported total waste emissions data and FAO-estimated food systems waste emissions data (2008–2018 average)

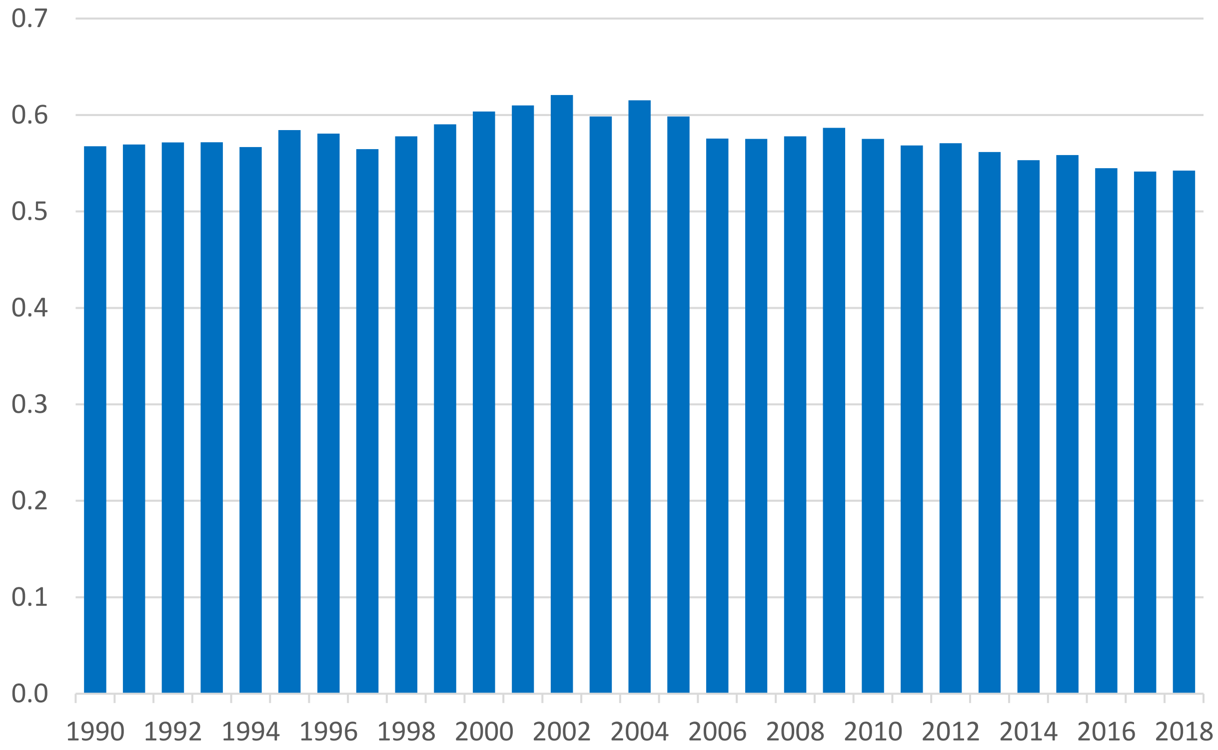


Source: Authors' own elaboration based on PRIMAP-hist 2.1 third party-reported waste emissions data and FAO food systems waste disposal estimates.

6.3 Global temporal validation

The model holds well over time, as the ratio of FAO emissions estimates to total waste disposal emissions hovers between 54 and 62 percent at the global level over the period, starting at 0.57 in 1990 and ending at 0.54 in 2019. This ratio is in accordance with Crippa *et al.* (2021), which estimates a global ratio of solid food waste emissions to total solid waste emissions of 0.26 to 0.88, a domestic wastewater ratio of 1 (since all of it is accounted for in food systems analysis), and an industrial wastewater ratio of 0.08 to 0.44. Given that those three sources represent the vast majority of all sectoral waste emissions, it is entirely reasonable that food systems waste disposal represents 50–60 percent of all GHG emissions from the waste sector.

Figure 6. Ratio of FAO total food systems waste disposal emissions estimates to PRIMAP third party reported total waste emissions estimates, world (1990–2019)



Source: Authors' own elaboration based on PRIMAP-hist 2.1 third party-reported waste emissions data and FAO food systems waste disposal estimates.

7 Notes

7.1 Global warming potentials

The emissions data described can be converted from CH_4 and N_2O to CO_2 equivalents using three different global warming potentials as found in the IPCC Second Assessment Report (SAR), Fourth Assessment Report (AR4), and Fifth Assessment Report (AR5). For comparisons with the PRIMAP database, the global warming potentials of CH_4 and N_2O in SAR were used. Details on conversions factors are below.

CO_2eq (SAR)

For CO_2eq (SAR) calculations, GWP-CH_4 = 21 (100-year time horizon global warming potential), to convert Gg CH_4 to Gg CO_2eq. GWP-N_2O = 310 to convert Gg N_2O to Gg CO_2eq (IPCC, 1996).

CO_2eq (AR4)

For CO_2eq (AR4) calculations, GWP-CH_4 = 25 (100-year time horizon global warming potential), to convert Gg CH_4 to Gg CO_2eq. GWP-N_2O = 296 to convert Gg N_2O to Gg CO_2eq (IPCC, 2007).

CO_2eq (AR5)

For CO_2eq (AR5) calculations, GWP-CH_4 = 28 (100-year time horizon global warming potential), to convert Gg CH_4 to Gg CO_2eq. GWP-N_2O = 265 to convert Gg N_2O to Gg CO_2eq (IPCC, 2014).

7.2 Uncertainty

Uncertainties in estimating GHG emissions are due to uncertainties in the emission factors and activity data. They may be related to, inter alia, natural variability, partitioning fractions, lack of spatial or temporal coverage, spatial aggregation or modelling errors. More detailed information on uncertainties associated with applying the IPCC Guidelines can be found in the IPCC report *Good practice guidance and uncertainty management in national greenhouse gas inventories* (IPCC, 2000).

In the case of solid food waste and domestic wastewater, more detailed information is available in IPCC (2019). In the case of industrial wastewater, more detailed information is available in the IPCC Guidelines: for methane, see IPCC (2006), for nitrous oxide see IPCC (2019). In the case of incineration, more detailed information is available in IPCC (2006).

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