Agriculture sector:
Rice Cultivation Emissions Estimates using FAOSTAT

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Sector Overview

The Climate TRACE coalition provides rice cultivation emission estimates using three different methods. A summary of these approaches is described in the [Climate TRACE GitHub methodology repository].

- First, our highest resolution modeling is conducted using Sentinel-1A synthetic aperture radar (SAR) and -2A/B 10m spatial resolution time-series data. The data from these satellites were applied to estimate rice cultivation emissions in the largest rice producing countries for 2022 and, in some cases, 2021. This highest resolution approach is documented in detail in the publications, "Automated near-real-time mapping and monitoring of rice extent, cropping patterns, and growth stages in Southeast Asia using Sentinel-1 time series on a Google Earth Engine platform" (Rudiyanto et al. 2019) and "High-Resolution Mapping of Paddy Rice Extent and Growth Stages across Peninsular Malaysia Using a Fusion of Sentinel-1 and 2 Time Series Data in Google Earth Engine" (Fatchurrachman et al. 2022).
- Second, a model was developed that used 500m data from the Moderate Resolution Imaging Spectroradiometer (MODIS) on the Terra and Aqua satellites (https://modis.gsfc.nasa.gov/about/). Rice cultivation emissions were estimated for years 2015 to 2022. A detailed explanation of these methods can be found in the "Agriculture sector- Rice Cultivation Emission Estimates using MODIS" methodology.
- Third, for countries not modeled using the first two approaches, appropriate emission factors derived from literature review were applied to country-level data provided by The Food and Agriculture Organization (FAO) FAOSTAT.

Here, this document describes the third approach, estimating rice cultivation emissions using FAOSTAT data.

1. Introduction

The following methodology estimates methane (CH_4) emissions from rice production using regional emissions factors (EFs) and nationally reported harvested rice area estimates, for countries where spatial delineation of rice paddies have not yet been independently modeled.

Climate TRACE member Universiti Malaysia Terengganu modeled rice cultivation emissions for 23 major rice producing countries globally, for years 2015 to 2022, using methods that incorporated local emissions factors, satellite imagery, and other independent approaches to detect where rice production occurred, the number of harvests in each paddy, and annual methane emissions. For the remaining countries that have rice cultivation but were not modeled, an approach was developed using emission factors from Universiti Malaysia Terengganu methodology (Table S1) and The Food and Agriculture Organization (FAO) FAOSTAT reported country-level rice paddy area harvested. This was done to produce a comprehensive global rice emissions dataset that employs rice emission factors that are more reflective of rice cultivation conditions within a country or region.

2. Materials and Methods

The following datasets were used to estimate rice cultivation emissions for the non-modeled 93 countries.

2.1 Datasets

Seasonally integrated methane emission factors (EF) from different countries and regions are described in Table S1. These emission factors reflect regional and national differences in rice emissions, collected from published data, taken from Universiti Malaysia Terengganu's methodology. Additionally, to better reflect regional emissions in African countries, a rice EF from Zimbabwe taken from Nyamadzawo *et al.* (2013).

For countries and regions that were beyond the spatial mapping threshold set in this work (see section 2.2.1) the IPCC default arithmetic mean EF applied to those countries, taken from Table 6 in IPCC (2001). IPCC provides the default emissions factor of 200 kg CH_4 ha^{-1} $season^{-1}$ (converted from the 20 g CH_4 m^{-2} $season^{-1}$). The IPCC mean EF was applied to avoid skewing rice emissions estimates for countries where the Universiti Malaysia Terengganu EFs were not representative.

FAOSTAT reported country-level rice area harvested for years 2015 to 2021 under the domain "Crops and livestock products" was used to estimate rice cultivation emissions (https://www.fao.org/faostat/en/#data/domains_table). The last update of this data was on March 23, 2023. While FAOSTAT does provide "Emissions from Rice cultivation" in the domain "Agrifood systems emissions", the most recent data was from 2020 and the last update of this data was on Nov. 2, 2022. We opted to use the most up-to-date data for this emission estimate work.

2.2 Methods

2.2.1 Spatial mapping of EFs

A spatial mapping technique was applied to match countries to the geographically closest EF employed in Table S1 and Nyamadzawo *et al.* (2013). A distance threshold was set to 1000 km (a self-defined threshold choice) to identify the closest EF to apply to a specific country. This approach was considered to provide a more reasonable representation of rice EFs in a region. Table 1 highlights the total number of countries mapped to specific EFs.

Table 1 Total count of countries that were matched to country-specific EF, employed by the Universiti Malaysia Terengganu, or IPCC default EF. Totals based on 2021 FAOSTAT data.

Country-specific or IPCC EF	Total countries	Country-specific or IPCC EF	Total countries
IPCC	64	MMR	1
BGD	1	MYS	2
BRA	14	PHL	1
CHN	8	THA	2
ESP	4	TWN	1
IDN	4	USA	4
IND	6	VNM	1
ITA	18	ZWE	9
JPN	1	MMR	1
KHM	1	*Total countries that used a country-specific EF = 80*	

2.2.2 Model

To estimate rice emissions FAOSTAT countries, the following equation was used by IPCC (1997), and used in the Universiti Malaysia Terengganu methodologies:

$$Emission_i = A_i \text{ x } EF_i \text{ (Eq.1)}$$

Where *Emission* is the CH_4 emissions (kg CH_4/ha/season), *A* is FAOSTAT country-level rice paddy area harvested (m^2) and *EF* is the emission factor for seasonal rice cultivation (kg CH_4/ha/season) and subscript *i* is for the country-specific or IPCC EF based on the distance threshold described in section 2.2.1. To estimate the annual emissions, we assumed the CH_4/ha/season represented the total methane emitted per hectare per year. While this assumption may undercount emissions from systems with multiple harvests, these methods are not typical of the countries evaluated under this methodology and are more typical in China and Southeast Asia where Climate TRACE delineated harvest intensity using the MODIS and Sentinel-1A and -2A/B approaches (Waha et al. 2020).

FAOSTAT reported only country-level rice paddy area harvested for years 2015 to 2021. To estimate 2022 emissions, 2021 country-level rice area harvested was forwarded-filled to 2022. At the time of this work, FAOSTAT did not publish the 2022 country-level rice area harvested.

3. Discussion and Conclusion

This approach was created to apply rice emission factors to countries outside of the major producing rice countries. In many regions, like South America and southern Africa, EFs were used from peer-reviewed papers that differ significantly from the default IPCC emission factor. The goal was to provide a more up-to-date and reasonable rice cultivation emissions in these locations that currently lack their own country-specific emission factor. At Climate TRACE, these EFs are preferred since they are based on recent research specific to the region and can reflect recent rice cultivation practices employed to that region. In other regions, like western Africa, default IPCC emission factor was employed, essentially mirroring established practices.

The accuracy of this data could potentially increase as country and regionally specific emissions factors are identified. Western Africa is a region which would particularly benefit from further study, as it contains Nigeria, which is a large rice producer not modeled by Universiti Malaysia Terengganu. Unfortunately, there has not been sufficient study of rice emissions in this region. To confirm the approach developed here, identifying *in situ* rice field methane measurements can potentially confirm Climate TRACE emissions estimates and be applied to this approach to better reflect rice cultivation conditions within a country or region. Further model training that relates remote sensing-derived variables to methane production rates in rice cropping systems, may create higher resolution EFs and extend models to regions without *in situ* data.

Supplementary materials metadata

Table S1 documents the EFs used to estimate each country's rice cultivation emissions. Included are the mean emissions and standard deviation associated with each EF. These EFs are the same used in the MODIS and Sentinel-1A and -2A/B approaches.

Tables S1 Seasonally integrated methane emission factors (EFs) in various conditions and locations of the world that were used in this study. Mean emission factors and standard deviation (SD) are provided.

Country	ISO3 country	Mean CH_4 Emission (kg CH_4/ha/season)	SD CH_4 Emission (kg CH_4/ha/season)	References
Bangladesh	BGD	168.2	80.4	(Islam *et al.*, 2020)
Brazil	BRA	430.1	149.6	(Camargo *et al.*, 2018; Zschornack *et al.*, 2018)
China	CHN	249.4	112.1	(Wang *et al.*, 2021)
Egypt	EGY	183.6	51.04	(Mboyerwa, 2022)
Ethiopia	ETH	183.6	51.04	(Mboyerwa, 2022)
Spain	ESP	405.7	202.9	(Moreno-García, Guillén and Quílez, 2020; Martínez-Eixarch *et al.*, 2021)
Indonesia	IDN	339.8	102.1	(Setyanto *et al.*, 2018)
India	IND	81.0	42.5	(Bhatia *et al.*, 2005; Kritee *et al.*, 2018; Oo *et al.*, 2018)
Iran (Islamic Republic of)	IRN	81.0	42.5	India EF
Italy	ITA	292.0	116.0	(Lagomarsino *et al.*, 2016; Mazza *et al.*, 2016; Meijide *et al.*, 2017)
Japan	JPN	469.8	302.4	(Camargo *et al.*, 2018; Toma *et al.*, 2019)

Cambodia	KHM	145.3	31.0	(Vibol and Towprayoon, 2010)
Korea (the Republic of)	KOR	349.4	93.0	(Gutierrez, Kim and Kim, 2013; Lim *et al.*, 2021)
Lao People's Democratic Republic (the)	LAO	78.3	31.6	Thailand EF
Sri Lanka	LKA	81.0	42.5	India EF
Myanmar	MMR	30.1	12.5	(Win *et al.*, 2020)
Malaysia	MYS	178.3	118.5	(Fazli and Man, 2014)
Nepal	NPL	81.0	42.5	India EF
Pakistan	PAK	81.0	42.5	India EF
Philippines (the)	PHL	258.0	192.7	(Alberto *et al.*, 2014; Sander, Samson and Buresh, 2014; Sibayan *et al.*, 2018)
Korea (the Democratic People's Republic of)	PRK	349.4	93.0	Korea (the Republic of) EF
Thailand	THA	78.3	31.6	(Maneepitak *et al.*, 2019)
Taiwan (Province of China)	TWN	112.0	91.4	(Chang, 2001)
United States of America (the)	USA	202.0	121.9	(Hatala *et al.*, 2012; Humphreys *et al.*, 2019; Della Lunga *et al.*, 2021; Karki *et al.*, 2021)
Viet Nam	VNM	296.4	192.9	(Vo *et al.*, 2020)

The Agriculture sector: Rice Cultivation Emissions Estimates using FAOSTAT reports the following data on the Climate TRACE website:

- Country-level enteric fermentation CH_4, and 20 and 100 year GWPs emissions from rice fields

Emissions estimates were reported for years 2015 to 2022, with 2022 emissions data forward filled with 2021 emissions data. The data generated here has been combined with the remote sensing approaches to estimate rice cultivation emissions globally. All data is freely available on the Climate TRACE website (https://climatetrace.org/). A detailed description of what is available is described in Table S2.

Table S2 Metadata for Rice Cultivation Emissions Estimates.

General Description	Definition
Sector definition	*Country-level rice cultivation emissions*
UNFCCC sector equivalent	*3.C Rice Cultivation*
Temporal Coverage	*2015 – 2022*
Temporal Resolution	*Annual*
Data format	*CSV*
Coordinate Reference System	*None. ISO3 country code provided*
Number of countries available for download	*250 countries*
Ownership	*Country*
What emission factors were used?	*IPCC CH. 10 and 11 EFs*
What is the difference between a "0" versus "NULL/none/nan" data field?	*"0" values are for true non-existent emissions. If we know that the sector has emissions for that specific gas, but the gas was not modeled, this is represented by "NULL/none/nan"*
total_CO2e_100yrGWP and total_CO2e_20yrGWP conversions	*Climate TRACE uses IPCC AR6 CO_2e GWPs. CO_2e conversion guidelines are here: https://www.ipcc.ch/report/ar6/wg1/downloads/report/IPCC_AR6_WGI_FullReport_small.pdf*

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Geographic boundaries and names (iso3_country data attribute): The depiction and use of boundaries, geographic names and related data shown on maps and included in lists, tables, documents, and databases on Climate TRACE are generated from the Global Administrative Areas (GADM) project (Version 4.1 released on 16 July 2022) along with their corresponding ISO3 codes, and with the following adaptations:

- HKG (China, Hong Kong Special Administrative Region) and MAC (China, Macao Special Administrative Region) are reported at GADM level 0 (country/national);
- Kosovo has been assigned the ISO3 code 'XKX';

- XCA (Caspian Sea) has been removed from GADM level 0 and the area assigned to countries based on the extent of their territorial waters;
- XAD (Akrotiri and Dhekelia), XCL (Clipperton Island), XPI (Paracel Islands) and XSP (Spratly Islands) are not included in the Climate TRACE dataset;
- ZNC name changed to 'Turkish Republic of Northern Cyprus' at GADM level 0;
- The borders between India, Pakistan and China have been assigned to these countries based on GADM codes Z01 to Z09.

The above usage is not warranted to be error free and does not imply the expression of any opinion whatsoever on the part of Climate TRACE Coalition and its partners concerning the legal status of any country, area or territory or of its authorities, or concerning the delimitation of its borders.

Disclaimer: The emissions provided for this sector are our current best estimates of emissions, and we are committed to continually increasing the accuracy of the models on all levels. Please review our terms of use and the sector-specific methodology documentation before using the data. If you identify an error or would like to participate in our data validation process, please contact us.

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