Manufacturing and Industrial Processes sector:
Chemicals, and Pulp and Paper Emissions

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1. Introduction

Chemical and pulp and paper industries are both energy and emissions intensive and account for 2% and 0.5% of global carbon dioxide (CO_2) emissions annually, respectively (IEA, 2024a; 2024b). Chemical production serves enormous value in society, such as through the production of ammonia fertiliser which is responsible for 50% of the world's food supply (Boerner, 2019). Pulp and paper have a relatively greener production process where waste products from the pulp making process are often used to generate its own power. However, production has increased 25% since 2000 and with it an increase in energy demand by 6%. In this work we lay out the foundational work for estimating facility-level emissions in the chemicals and pulp and paper industry.

2. Materials and Methods

We investigated each major processing route independently using publicly available data. This section provides a high-level overview of the datasets and associated pipelines used to derive emission estimates for the chemicals (further split into: ammonia, methanol, and soda ash) and pulp and paper industries.

Given the lack of source-level emission data publicly available, a standardised “bottom-up” approach was used to quantify the emissions. This process was characterised by first estimating production levels for each plant and then applying a calculated emissions factor to estimate emissions.

To estimate source-level production, a disaggregation method was applied to Climate TRACE identified plants for years 2021 to 2023.

2.1 Datasets employed

For each of the sectors we ascertained source level (where possible) data, country-level production data, and respective emissions factors.

2.1.1 Asset inventory data sets

Climate Trace has identified various facilities with information including capacity, type, location. The numbers of assets covered for each sector are shown below -

- Ammonia: 221 assets in 37 countries
- Methanol: 114 assets in 31 countries.
- Soda ash: no asset data was available at the time of this work.
- Pulp and paper: 258 assets in 34 countries.

2.1.2 Production data sets

Aggregated production was utilised in all our models. For pulp and paper, this information was sourced from FAO (2024) at the national level. For ammonia, methanol and soda ash, national production data was retrieved from USGS (2024a, 2024b).

2.1.3 Emissions factor dataset

Emissions factors were sourced separately for each material with ammonia from the Hoxha and Christensen (2019), methanol from IPCC (2024), soda ash from US EPA (2024) and pulp and paper from Tomberlin *et. al* (2020).

2.2 Methods

2.2.1. Production methodology

The first step in quantifying emissions for each facility was estimating the associated activity in each time period. To do this, a disaggregation method was applied: for each facility, its share of national capacity was computed before multiplying this number by the national production to derive the facility's contribution. An illustrative example is shown below where a country has two plants A and B (with capacities C_A and C_B respectively) and a total production P_m for a given month m, the capacity-based production estimates for these two plants are (respectively $P_{A,m}$ and $P_{B,m}$):

- $P_{A,m} = \frac{C_A}{C_A + C_B} \times P_m$
- $P_{B,m} = \frac{C_B}{C_A + C_B} \times P_m$

2.2.3. Emissions methodology

With the production estimates generated for each asset, the emission estimates were derived by multiplying the production by the relevant emission factors. The overall methodology is summarised in Figure 1.

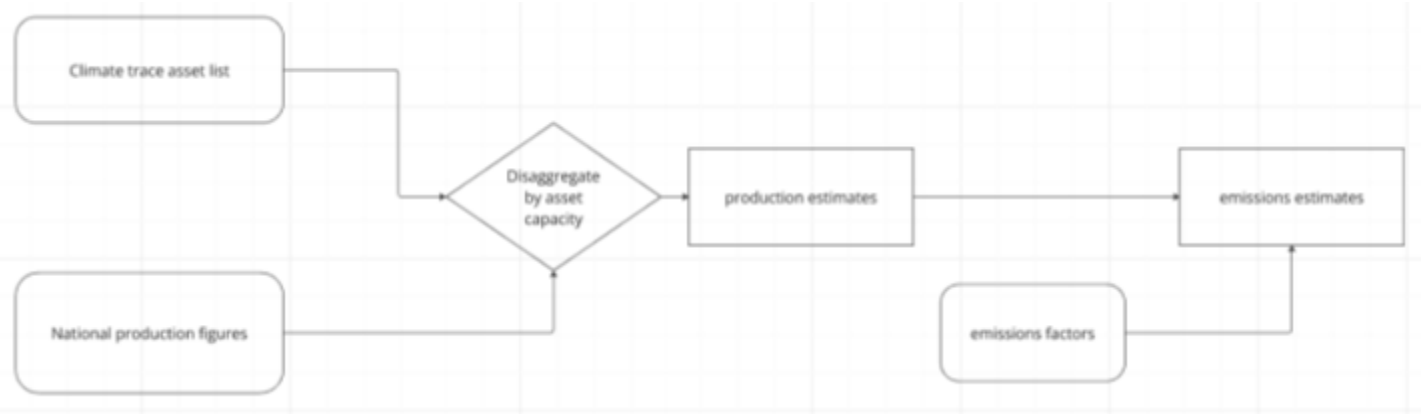

Figure 1 Flowchart of the methodology to calculate plant level emissions for the chemical and pulp and paper assets.

3. Results

Figure 2 displays the total global annual CO_2 emission estimates for the chemicals and pulp and paper industries. Of the four sub-sectors, ammonia emissions are the largest with emissions greater than 300 Mt-CO_2. Methanol is the second largest emitter, with emissions steadily rising over the past few years from 150 Mt-CO2 to 180 Mt-CO2. Soda ash and pulp and paper have relatively lower emissions around 70 Mt-CO2 and 100 t-CO_2 respectively.

Tables 1 to 4 list the largest emitters in the ammonia, methanol, soda ash, and pulp and paper industries.

- **Ammonia**: China leads in emissions, followed by Russia and India.
- **Methanol**: China is the primary emitter, accounting for most of the sector's emissions.
- **Soda Ash**: China is again the top emitter, with the U.S. and Turkey following.
- **Pulp and Paper**: The U.S. has the highest emissions, followed by Brazil and China.

This breakdown highlights China's significant role in emissions across multiple industries, with other countries leading in specific sectors.

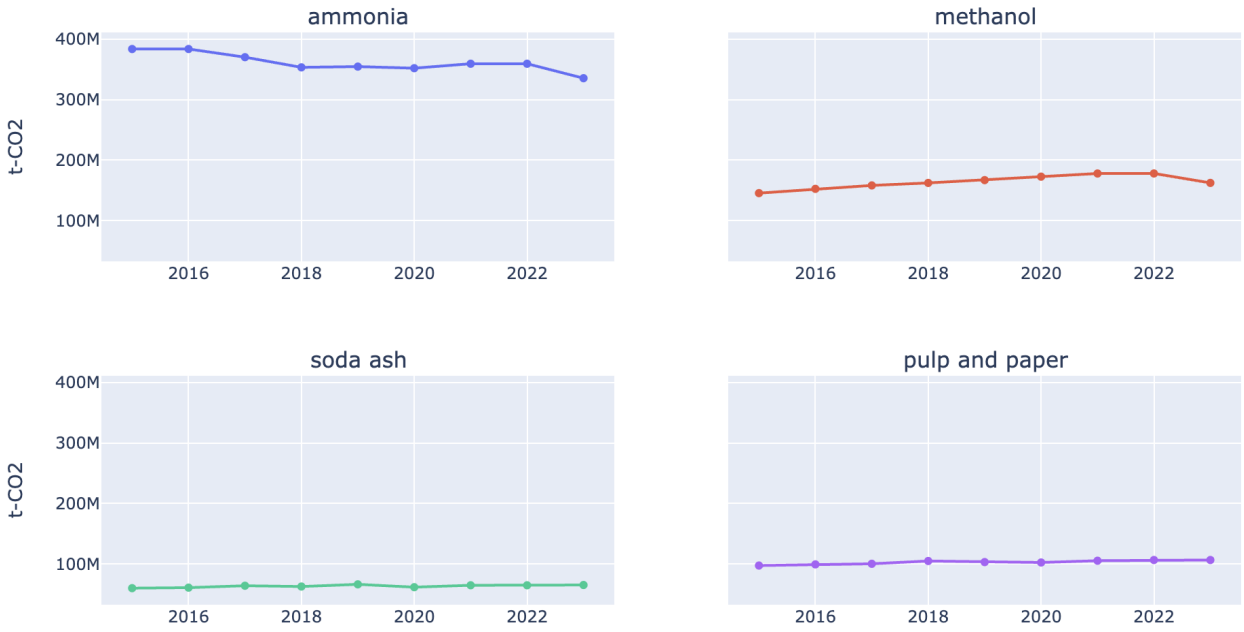

Figure 2 Global annual Climate TRACE estimated CO_2 emissions for Ammonia (top left), Methanol (top right), Soda Ash (bottom left), and Pulp and Paper (bottom right) for years 2015 to 2023.

Table 1 Top 10 emitters in the ammonia sector in 2023

country	CO_2 Emissions ($MtCO_2$)
China	125.5
Russia	46.3
India	32.8
U.S.A.	24.1
Canada	11.5
Pakistan	11
Poland	9.3
Ukraine	8.4
Egypt	8
Germany	7.2

Table 2 Top 10 emitters in the methanol sector in 2023

country	CO_2 emissions ($MtCO_2$)
China	131
Iran	6
Russia	3.9
U.S.A.	3.7
Saudi Arabia	2.2
Egypt	2
Trinidad & Tobago	1.5
Malaysia	1.4
Canada	1.2
New Zealand	1.2

Table 3 Top 10 emitters in the soda ash sector in 2023

Country	CO_2 Emissions ($MtCO_2$)
China	31.6
U.S.A.	11.6
Turkey	3.6
Russia	3.1
Germany	2.7
India	2.2
Poland	1.2
France	1.1
Bulgaria	0.9
Ukraine	0.8

Table 4 Top 10 emitters in the pulp and paper sector in 2023

country	CO_2 emissions ($MtCO_2$)
U.S.A.	27.1
Brazil	14.5
China	12.5
Canada	7.9
Indonesia	5.2
Sweden	6.6
Finland	6.1
Russia	5.1
Japan	4.4
Chile	2.7

4. Discussion & Conclusions

In this work, CO_2 emissions were provided for the chemicals and pulp and paper sectors. Emissions estimates are at the facility-level for pulp and paper, ammonia, and methanol, and at the country-level for soda ash with all estimates provided on a monthly basis.

To estimate emissions at the facility-level, our methodology disaggregates national production numbers to assets based on the share of their capacity to the total national production capacity. Consequently, the accuracy of these estimates can be considered limited. Nevertheless, this work serves as a foundational piece for the estimating CO_2 emissions in the pulp and paper and chemical sector and may be utilised to develop more detailed estimates in the .

5. Supplementary metadata section

5.1 Chemicals

The chemicals sector CO_2 emissions were reported for individual assets for the years 2021 to 2023. The emissions described here represent a subset of specific country-level emissions estimates from the Climate TRACE manufacturing sector. All data is freely available on the Climate TRACE website (https://climatetrace.org/). A detailed description of what is available is described in Tables 5 to 7.

Table 5 Details on the chemical assets metadata

General Description	Definition
Sector definition	*Emissions from chemicals production*
UNFCCC sector equivalent	*2.B.1 (Ammonia), 2.B.8.a. (Methanol), 2.B.7. (Soda ash)*
Temporal Coverage	*2021 - 2023*
Temporal Resolution	*Monthly*
Data format	*CSV*
Coordinate Reference System	*None. ISO3 country code provided*
Number of emitters available for download	*221 ammonia sources and 114 methanol sources*
What emission factors were used?	*global emission factors*
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 modelled, this is represented by "NULL/none/nan"*

General Description	Definition
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*

Table 6 Definition of the fields in the chemicals asset dataset

Data attribute	Definition
sector	manufacturing
source_sub-sector_name	chemicals
source definition	emissions from chemicals production
start_date	start date for time period of emissions estimation (YYYY-MM-DD format)
end_date	end date for time period of emissions estimation (YYYY-MM-DD format)
asset_identifier	internal identifier
asset_name	name of the facility
iso3_country	ISO 3166-1 alpha-3 country code
location	well-known text (WKT) point location
type	chemicals type (ammonia, methanol, soda ash)
capacity	monthly plant capacity (tons)
capacity_factor	utilisation rate of plants
CO2_emissions_factor	direct emissions factor (t-CO_2/ton of chemicals)
CH4_emissions_factor	not used; N/A
N2O_emissions_factor	not used; N/A
CO2_emissions	Direct emissions (t-CO_2)
CH4_emissions	not used; N/A
N2O_emissions	not used; N/A
total_CO2e_100yrGWP	100 years global warming potential (t-CO_2e)
total_CO2e_20yrGWP	20 years global warming potential (t-CO_2e)
other1	not used; N/A
model_number	version of the model (e.g. 1,2...)

Table 7 Definition for confidence and uncertainty in emissions.

Data attribute	Confidence Definition	Uncertainty Definition
type	● *Very low:* Based on highly speculative or obsolete information. Very low level of confidence in the accuracy of asset classification. ● *Low:* Limited or somewhat outdated data. Low level of confidence in the classification's correctness. ● *Medium:* A mix of historical and more recent data. A medium level of confidence in its accuracy. ● *High:* Grounded in comprehensive and recent data. A high level of confidence in the precise classification of the asset. ● *Very high:* Extensive, up-to-date, and verified data. A very high level of confidence in the accurate and detailed identification of the asset.	Not used; N/A
capacity	● *Very low:* Limited or outdated data, and significant uncertainties exist. ● Low: Outdated and/or incomplete data. ● *Medium:* A mix of historical and recent data. ● *High: Comprehensive* and recent data updates. High level of certainty. ● *Very high:* Extensive, up-to-date, and verified data. Very high level of certainty.	Not used; N/A
capacity_factor	● *Very low:* Data is sparse or highly unreliable. Considerable uncertainty in capacity factor estimations. ● *Low:* Moderate uncertainty in capacity factor calculations. ● *Medium:* Data is sufficiently available, though not comprehensive. No absolute accuracy in capacity factor estimations. ● *High:* High confidence in the accuracy of capacity factor calculations. ● *Very high:* Derived from thorough and validated data sources. Very high precision of capacity factor estimations.	Not used; N/A
activity	● *Very low:* Largely speculative or based on outdated information. A very low level of confidence in activity assessments. ● *Low:* Limited or somewhat outdated sources. A low level of confidence in the activity assessments. ● *Medium:* A mix of historical and more recent data. Medium level of confidence in activity insights. ● *High:* Detailed and current operational data ensures a high level of confidence in the accuracy of activity assessments. ● *Very high:* Extensive, verified, and up-to-date data. A very high level of confidence in their accuracy.	±10% of production estimates (based on IPCC)

Data attribute	Confidence Definition	Uncertainty Definition
CO2_emissions_factor	● *Very low:* Highly uncertain due to insufficient or unreliable data. ● *Low:* Estimated from incomplete data. Low confidence level in its precision. ● *Medium:* A mix of historical and more recent data. Medium level of confidence in their accuracy. ● *High:* Derived from comprehensive and recent data. A high level of confidence in their precision. ● *Very high:* Based on extensive and validated data, providing a very high level of confidence in their precision.	±25% of assumption (based on IPCC)
CH4_emissions_factor	Not used; N/A	Not used; N/A
N2O_emissions_factor	Not used; N/A	Not used; N/A
CO2_emissions	● *Very low:* Based on very rough estimations or outdated information. A very low level of confidence in its accuracy. ● *Low:* Estimated from incomplete data. Low confidence level in its precision. ● *Medium:* A mix of historical and more recent data. Medium level of confidence in their accuracy. ● *High:* Derived from comprehensive and recent data. A high level of confidence in their precision. ● *Very high:* Based on extensive and validated data, providing a very high level of confidence in their precision.	±35% of emissions estimates
CH4_emissions	Not used; N/A	Not used; N/A
N2O_emissions	Not used; N/A	Not used; N/A
total_CO2e_100yrGWP	● *Very low:* Based on very rough estimations or outdated information. A very low level of confidence in its accuracy. ● *Low:* Estimated from incomplete data. Low confidence level in its precision. ● *Medium:* A mix of historical and more recent data. Medium level of confidence in their accuracy. ● *High:* Derived from comprehensive and recent data. A high level of confidence in their precision. ● *Very high:* Based on extensive and validated data, providing a very high level of confidence in their precision.	±35% of emissions estimates

Data attribute	Confidence Definition	Uncertainty Definition
total_CO2e_20yrGWP	• *Very low:* Based on very rough estimations or outdated information. A very low level of confidence in its accuracy. • *Low:* Estimated from incomplete data. Low confidence level in its precision. • *Medium:* A mix of historical and more recent data. Medium level of confidence in their accuracy. • *High:* Derived from comprehensive and recent data. A high level of confidence in their precision. • *Very high:* Based on extensive and validated data, providing a very high level of confidence in their precision.	±35% of emissions estimates

5.2 Pulp and paper

The pulp and paper sector CO_2 emissions were reported for the individual emitting sources for the years 2021 to 2023. The emissions described here represent a subset of specific country-level emissions estimates from the Climate TRACE manufacturing sector. All data is freely available on the Climate TRACE website (https://climatetrace.org/). A detailed description of what is available is described in Tables 8 to 10.

Table 8 Details on the pulp and paper assets metadata

General Description	Definition
Sector definition	*Emissions from pulp and paper production*
UNFCCC sector equivalent	*2.H.1 Pulp and paper*
Temporal Coverage	*2021 - 2023*
Temporal Resolution	*Annual*
Data format	*CSV*
Coordinate Reference System	*None. ISO3 country code provided*
Number of emitters available for download	*258 pulp and paper sources*
What emission factors were used?	*global emission factors*
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 modelled, this is represented by "NULL/none/nan"*

General Description	Definition
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*

Table 9 Definition of the fields in the pulp and paper asset dataset

Data attribute	Definition
sector	manufacturing
source_sub-sector_name	pulp and paper
source definition	emissions from pulp and paper production
start_date	start date for time period of emissions estimation (YYYY-MM-DD format)
end_date	end date for time period of emissions estimation (YYYY-MM-DD format)
asset_identifier	internal identifier
asset_name	name of the facility
iso3_country	ISO 3166-1 alpha-3 country code
location	well-known text (WKT) point location
capacity	monthly plant capacity (tons of pulp and paper)
capacity_factor	utilisation rate of plants
activity	production of pulp and paper (tons)
CO2_emissions_factor	direct emissions factor (t-CO2/ton of pulp and paper)
CH4_emissions_factor	not used; N/A
N2O_emissions_factor	not used; N/A
CO2_emissions	direct emissions (t-CO_2)
CH4_emissions	not used; N/A
N2O_emissions	not used; N/A
total_CO2e_100yrGWP	100 years global warming potential (t-CO_2e)
total_CO2e_20yrGWP	20 years global warming potential (t-CO_2e)
other1	not used; N/A
model_number	version of the model (e.g. 1,2...)

Table 10 Pulp and paper sector description for confidence and uncertainty in emissions.

Data attribute	Confidence Definition	Uncertainty Definition
type	● *Very low:* Based on highly speculative or obsolete information. Very low level of confidence in the accuracy of asset classification. ● *Low:* Limited or somewhat outdated data. Low level of confidence in the classification's correctness. ● *Medium:* A mix of historical and more recent data. A medium level of confidence in its accuracy. ● *High:* Grounded in comprehensive and recent data. A high level of confidence in the precise classification of the asset. ● *Very high:* Extensive, up-to-date, and verified data. A very high level of confidence in the accurate and detailed identification of the asset.	Not used; N/A
capacity	● *Very low:* Limited or outdated data, and significant uncertainties exist. ● *Low:* Outdated and/or incomplete data. ● *Medium:* A mix of historical and recent data. ● *High:* Comprehensive and recent data updates. High level of certainty. ● *Very high:* Extensive, up-to-date, and verified data. A very high level of certainty.	Not used; N/A
capacity_factor	● *Very low:* Data is sparse or highly unreliable. Considerable uncertainty in capacity factor estimations. ● *Low:* Moderate uncertainty in capacity factor calculations. ● *Medium:* Data is sufficiently available, though not comprehensive. No absolute accuracy in capacity factor estimations. ● *High:* High confidence in the accuracy of capacity factor calculations. ● *Very high:* Derived from thorough and validated data sources. Very high precision of capacity factor estimations.	Not used; N/A
activity	● *Very low:* Largely speculative or based on outdated information. A very low level of confidence in activity assessments. ● *Low:* Limited or somewhat outdated sources. A low level of confidence in the activity assessments. ● *Medium:* A mix of historical and more recent data. Medium level of confidence in activity insights. ● *High:* Detailed and current operational data ensures a high level of confidence in the accuracy of activity assessments. ● *Very high:* Extensive, verified, and up-to-date data. A very high level of confidence in their accuracy.	±10% of production estimates (based on IPCC)

Data attribute	Confidence Definition	Uncertainty Definition
CO2_emissions_factor	● *Very low:* Highly uncertain due to insufficient or unreliable data. ● *Low:* Estimated from incomplete data. Low confidence level in its precision. ● *Medium:* A mix of historical and more recent data. Medium level of confidence in their accuracy. ● *High:* Derived from comprehensive and recent data. A high level of confidence in their precision. ● *Very high:* Based on extensive and validated data, providing a very high level of confidence in their precision.	±25% of assumption (based on IPCC)
CH4_emissions_factor	Not used; N/A	Not used; N/A
N2O_emissions_factor	Not used; N/A	Not used; N/A
CO2_emissions	● *Very low:* Based on very rough estimations or outdated information. A very low level of confidence in its accuracy. ● *Low:* Estimated from incomplete data. Low confidence level in its precision. ● *Medium:* A mix of historical and more recent data. Medium level of confidence in their accuracy. ● *High:* Derived from comprehensive and recent data. A high level of confidence in their precision. ● *Very high:* Based on extensive and validated data, providing a very high level of confidence in their precision.	±35% of emissions estimates
CH4_emissions	Not used; N/A	Not used; N/A
N2O_emissions	Not used; N/A	Not used; N/A
total_CO2e_100yrGWP	● *Very low:* Based on very rough estimations or outdated information. A very low level of confidence in its accuracy. ● *Low:* Estimated from incomplete data. Low confidence level in its precision. ● *Medium:* A mix of historical and more recent data. Medium level of confidence in their accuracy. ● *High:* Derived from comprehensive and recent data. A high level of confidence in their precision. ● *Very high:* Based on extensive and validated data, providing a very high level of confidence in their precision.	±35% of emissions estimates

Data attribute	Confidence Definition	Uncertainty Definition
total_CO2e_20yrGWP	• *Very low:* Based on very rough estimations or outdated information. A very low level of confidence in its accuracy. • *Low:* Estimated from incomplete data. Low confidence level in its precision. • *Medium:* A mix of historical and more recent data. Medium level of confidence in their accuracy. • *High:* Derived from comprehensive and recent data. A high level of confidence in their precision. • *Very high:* Based on extensive and validated data, providing a very high level of confidence in their precision.	±35% of emissions estimates

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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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