Manufacturing sector: Chemicals, Pulp and Paper Manufacturing Emissions

Andrew Isabirye[1,3], Ashank Sinha[1,3], and Lekha Sridhar[2,3]
1) *TransitionZero 2)WattTime, 3) Climate TRACE*

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, 2022a; 2022b). Chemical production serves enormous value in society, such as through the production of ammonia fertilizer 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 timely and granular emissions in the chemicals and pulp and paper industry.

2. Materials and Methods

We investigated each major processing route independently using a combination of publicly reported data and academic papers. 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 standardized “bottom-up” approach was used to quantify the emissions. This process was characterized by first estimating production levels for each plant (in tons of product) before then subsequently applying a calculated emissions factor (tons of CO_2 per ton of product) to estimate emissions.

To estimate source level production, a disaggregation method was applied to identified plants for years 2015 and 2022. This was determined by calculating each plant's share of national capacity, before multiplying this number by the country's production to derive the plant's contribution for the given year. To generate country-level emissions, each point-source within a country was aggregated to estimate total emissions.

2.1 Datasets employed

For each of the aforementioned industries (chemicals, pulp and paper) we ascertained source level (where possible) data, country-level production data and respective emissions factors.

2.1.1 Emitting source inventory data sets

Industrial Info Resources (IIR) provided facility and country level information, including owner, capacity, technology type, and start/closing date (IIR, 2023). For the chemicals sector - ammonia, methanol and soda ash were covered. Facility level characteristic data was available for ammonia (278 sources) and methanol (172 sources). Soda ash was handled at the country-level (34 countries) where source level data was not available during the scope of this work. Characteristic data for pulp and paper were available for a total of 378 sources. An overview of the country coverage for chemicals and pulp and paper can be found in Figure 1 and Figure 2, respectively.

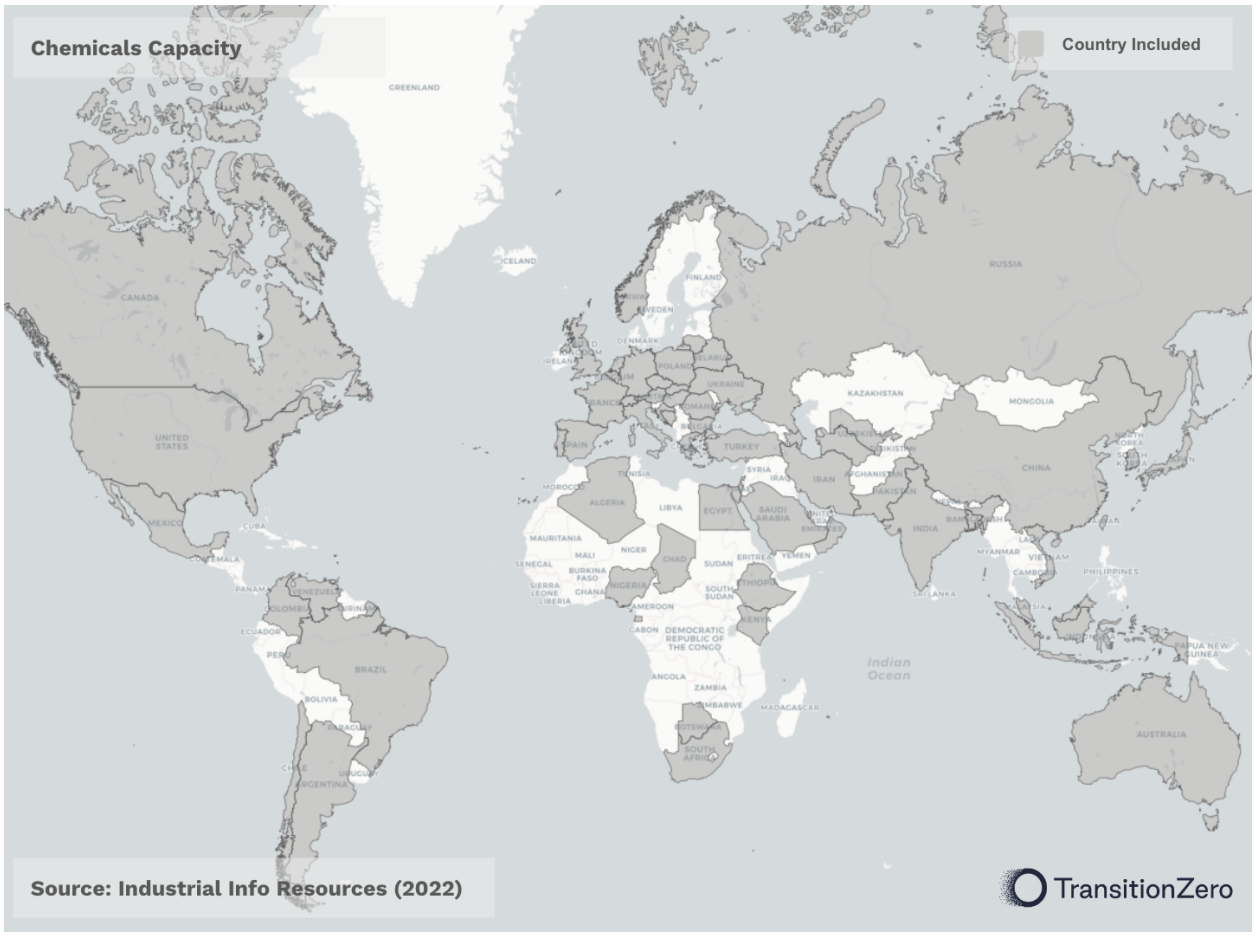

Figure 1 Country coverage for the chemical's subsector (ammonia, methanol and soda ash), represented in gray.

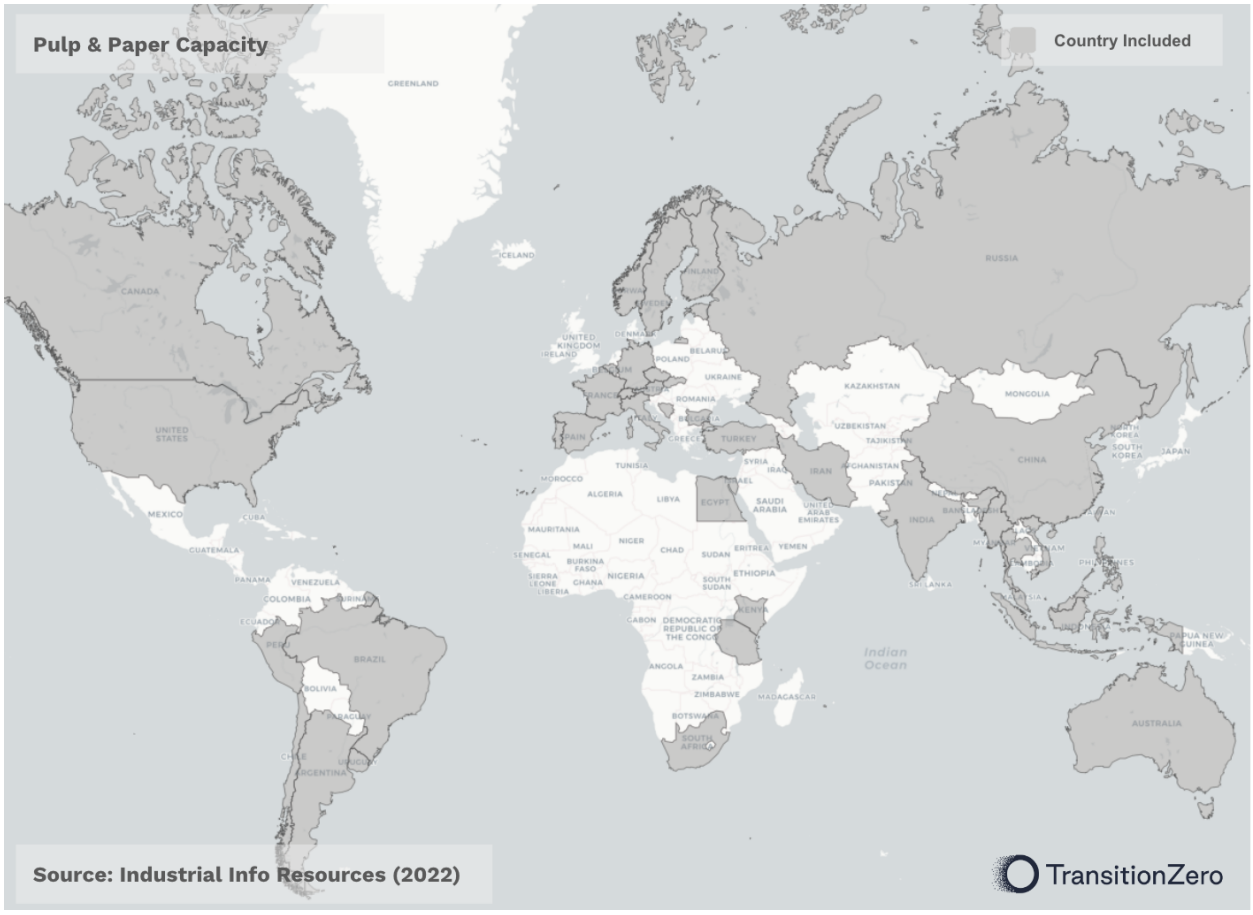

Figure 2 Country coverage for pulp and paper, represented in gray.

2.1.2 Production data sets

Aggregated production was utilized in all our models. For pulp and paper, it was sourced from the Food and Agriculture Organization of the United Nations (FAO) (FAOSTAT, 2022) at the national level. For chemicals, historical data was sourced from the United States Geological Survey (USGS) (USGS, 2022). More recent production data was inferred using the ISIC 20 Chemicals and Chemical products index sourced from the United Nations Industrial Development Organization (UNIDO) (UNIDO, 2022).

2.1.3 Emissions factor dataset

Emissions factors were sourced separately for each material with: ammonia from the International Fertiliser Society (IFS) (Hoxha and Christensen, 2019), methanol from Intergovernmental Panel on Climate Change (IPCC) (IPCC, 2022), soda ash from the Environmental Protection Agency (EPA) (EPA, 2022), and pulp and paper from Tomberlin et. al (2020). Methanol and ammonia emissions were listed based upon fuel type. Ammonia was also further dependent upon geographical location.

2.2 Methods

2.2.1. Production methodology

The first step in quantifying emissions for each emitting source was estimating the associated activity, expressed in tons of product in a given 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 for the given timeframe. An illustrative example of a country with two plants A and B (of capacities C_A and C_B respectively) and a total production P_m for a country/region and a given month m, the capacity-based 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 emitting source, the emission estimates were derived by multiplying the production by the relevant emission factors. Electricity-related emissions were excluded from these emission factors (when applicable) as these emissions are already accounted for in other parts of the Climate TRACE Electricity generation sector. The overall methodology is summarized in Figure 3.

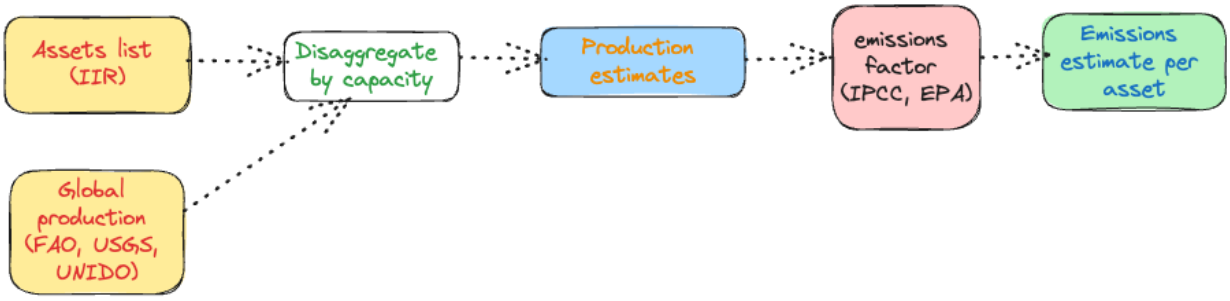

Figure 3 Flowchart of the methodology to calculate plant level emissions for emitting sources.

3. Results

Figure 4 shows the global annual CO_2 emission estimates for the chemicals and pulp and paper industries. Of the four sub sectors, ammonia emissions are the largest above 300 tCO_2 per year. Methanol, the second largest, with emissions steadily rising during the time period. Soda ash and pulp and paper have relatively lower emissions below 100 tCO_2.

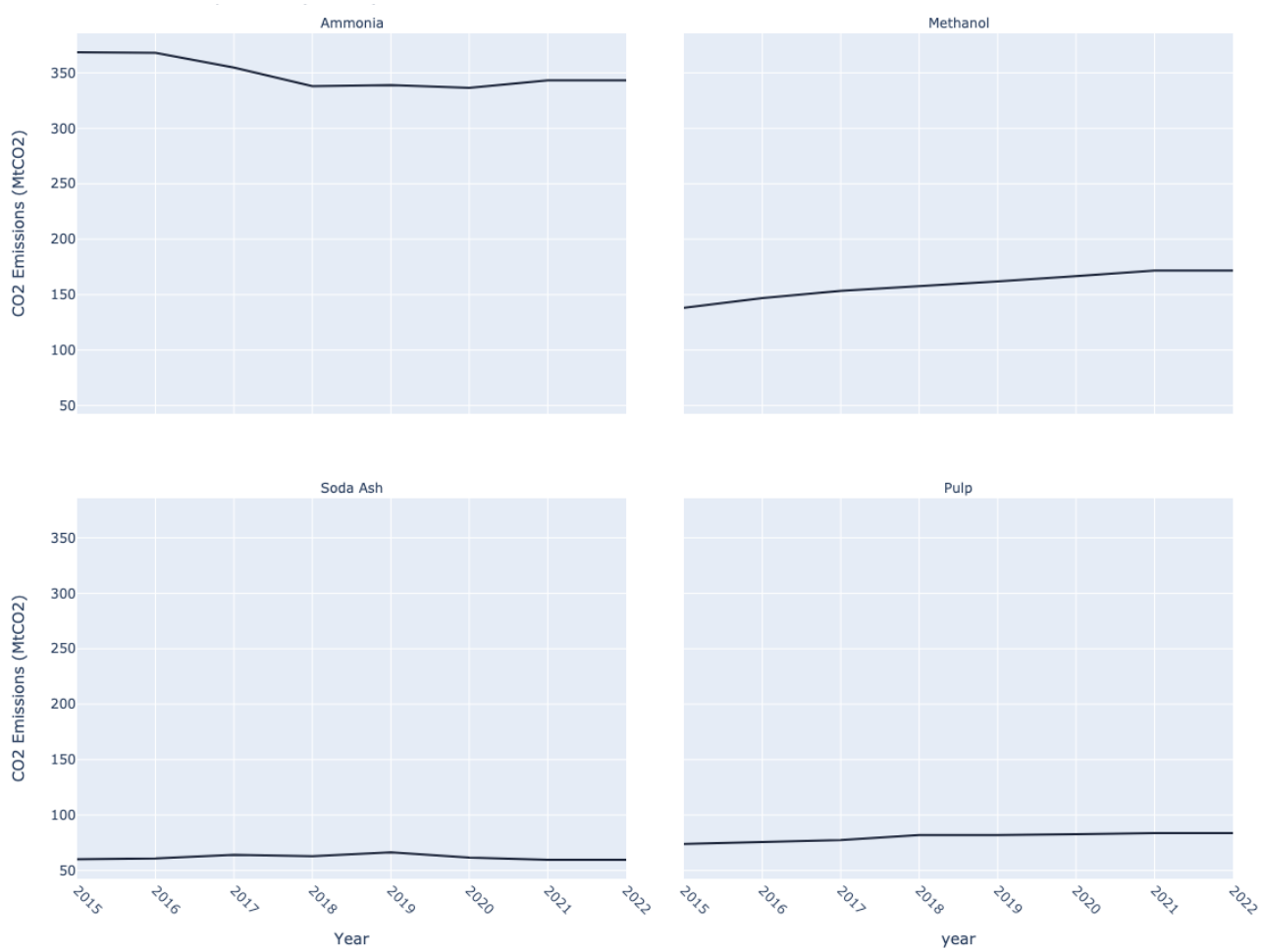

Figure 4 Global annual Climate TRACE estimated CO_2 emissions for Ammonia (top left), Methanol (top right), Soda Ash (bottom left), and Pulp and Paper (bottom right) for years 2015 to 2022.

Tables 1 to 4 show the biggest producers and emitters in the ammonia, methanol, soda-ash and pulp and paper industry, respectively.

Table 1 Top producers and emitters in the ammonia sector.

Country	CO_2 Emissions ($MtCO_2$)	Production (Mt)
China	125.2	35.2
Russia	50.4	17.6
India	37.5	12.5
USA	24.1	8.1
Canada	11.5	3.9
Pakistan	11	3.7
Poland	9.3	2.8
Ukraine	8.4	2.9
Egypt	7.4	2.8
Germany	7.2	2.6

Table 2 Top producers and emitters in the methanol industry.

Country	CO_2 emissions ($MtCO_2$)	Production (Mt)
China	138.9	31.4
Iran	6	8.9
Russia	3.9	5.7
USA	3.7	5.6
Saudi Arabia	2.7	4
Egypt	2	3
Trinidad & Tobago	1.5	2.3
Malaysia	1.4	2.1
Canada	1.2	1.8
New Zealand	1.2	1.8

Table 3 Top producers and emitters in the soda ash industry.

Country	CO_2 Emissions ($MtCO_2$)	Production (Mt)
China	25.7	24.5
USA	11.8	11.3
Turkey	3.6	3.4
Russia	3.1	3
Germany	2.7	2.6
India	2.2	2.1
Poland	1.2	1.2
France	1.1	1
Bulgaria	0.9	0.8
Ukraine	0.8	0.7

Table 4 Top producers and emitters in the pulp and paper industry.

Country	CO_2 emissions ($MtCO_2$)	Production (Mt)
USA	25.6	44
Brazil	12.7	21.9
China	12	20.6
Indonesia	5	8.6
Canada	4	7.6
Sweden	4	7.3
Finland	4	6.9
Russia	3.5	6
Chile	2.8	4.8
Uruguay	1.6	2.8

4. Discussion & Conclusions

CO_2 emissions estimates were provided for the chemicals and pulp and paper industries. Emissions estimates are at the source level for pulp and paper, ammonia, and methanol, and at the country-level for soda ash with all estimates provided on an annual basis.

To estimate emissions at the source level, our methodology takes known facility capacities as a fraction of the national share and uses this information to allocate a proportional share of the known national production. The approach itself does make several assumptions about each emitting source, such as the production of a given at a facility relative to that of national production. Additionally, it assumes that all operational facilities were functioning within a nation, or that all emitting sources were documented within our database to assign the correct proportion of national production. As a consequence, the accuracy of these estimates was considered to be limited and edge cases may be present which can impact these assumptions. Nevertheless, this work serves as a strong foundational piece for the estimation of CO_2 emissions in the pulp and paper and chemical industries which may be utilized to develop more detailed estimates in the future.

5. Supplementary metadata section

5.1 Chemicals

The chemicals sector CO_2 emissions were reported for individual source-level for the years 2015 to 2022. 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 and 6.

Table 5 Metadata for Emissions for chemicals sector**.**

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	*2015 – 2022*
Temporal Resolution	*Monthly*
Data format	*CSV*

Coordinate Reference System	*None. ISO3 country code provided*
Number of emitters available for download	*278 ammonia sources, 172 methanol sources, soda ash (34 countries)*
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"*
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 Chemicals 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 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 source. • *Very high:* Extensive, up-to-date, and verified data. A very high level of confidence in the accurate and detailed identification of the source.	Not used; N/A
capacity_description	• *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_description	• *Very low:* Data is sparse or highly unreliable. Considerable uncertainty in capacity factor estimations. • *Low:* Moderate uncertainty in capacity factor calculations.	Not used; N/A

	• *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.	
activity_description	• *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 emitting source level production (based on IPCC)
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 source level emission factor (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
other_gas_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.	35% of source level emissions

	● *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.	
CH4_emissions	Not used; N/A	Not used; N/A
N2O_emissions	Not used; N/A	Not used; N/A
other_gas_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 source level emissions
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 source level emissions

5.2 Pulp and paper

The pulp and paper sector CO_2 emissions were reported for individual emitting sources for the years 2015 to 2022. 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 7 and 8.

Table 7 Metadata for Emissions for pulp and paper sector**.**

General Description	Definition
Sector definition	*Emissions from pulp and paper production*
UNFCCC sector equivalent	*2.H.1 Pulp and paper*
Temporal Coverage	*2015 – 2022*
Temporal Resolution	*Annual*
Data format	*CSV*
Coordinate Reference System	*None. ISO3 country code provided*
Number of emitters available for download	*378 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"*
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 8 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 source 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 source. ● *Very high:* Extensive, up-to-date, and verified data. A very high level of confidence in the accurate and detailed identification of the source.	Not used; N/A
capacity_description	● *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_description	● *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_description	● *Very low:* Largely speculative or based on outdated information. A very low level of confidence in activity assessments.	10% of emitting source production (based on IPCC)

	• *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.	
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 emitting source emission factor (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
other_gas_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 emitting source emissions
CH4_emissions	Not used; N/A	Not used; N/A

N2O_emissions	Not used; N/A	Not used; N/A
other_gas_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 emitting source emissions
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 emitting source emissions

Citation format: Isabriye, A., Sinha, A., Sridhar, L. (2023). *Manufacturing Sector - Chemicals, Pulp and paper sector emissions*. TransitionZero, UK, Climate TRACE Emissions Inventory. https://climatetrace.org [Accessed date]

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.

6. References

1. Boerner, L., 2019. Industrial ammonia production emits more CO2 than any other chemical-making reaction. Chemists want to change that [WWW Document]. Chem. Eng. News. URL https://cen.acs.org/environment/green-chemistry/Industrial-ammonia-production-emits-CO2/97/i24 (accessed 9.27.22).
2. EPA, 2022. Inorganic Chemical Industry: Sodium Carbonate [WWW Document]. URL https://www.epa.gov/sites/default/files/2020-09/documents/8.12_sodium_carbonate.pdf (accessed 10.3.22).
3. FAOSTAT, 2022. FAOSTAT [WWW Document]. URL https://www.fao.org/faostat/en/#home (accessed 9.26.22).
4. Hoxha, A., Christensen, B., 2019. The carbon footprint of fertilizer production: regional reference values, Proceedings / International Fertiliser Society. International Fertiliser Society, Colchester.
5. IEA, 2022a. Chemicals - Fuels & Technologies [WWW Document]. IEA. URL https://www.iea.org/fuels-and-technologies/chemicals (accessed 9.27.22).
6. IEA, 2022b. Pulp and Paper [WWW Document]. IEA. URL https://www.iea.org/reports/pulp-and-paper (accessed 9.27.22).
7. IIR, 2023. Industrial Info Resources | Providing Constantly Updated Global Industrial Market Intelligence [WWW Document]. URL https://www.industrialinfo.com/ (accessed 9.26.22).
8. IPCC, 2022. IPCC — Intergovernmental Panel on Climate Change. URL https://www.ipcc.ch/ (accessed 9.26.22).
9. Tomberlin, K., Venditti, R., and Yao, Y. (2020). "Life cycle carbon footprint analysis of pulp and paper grades in the United States using production-line-based data and integration," BioRes. 15(2), 3899-3914.
10. UNIDO, 2022. UNIDO | United Nations Industrial Development Organization [WWW Document]. URL https://www.unido.org/ (accessed 9.27.22).
11. USGS, 2022. USGS.gov | Science for a changing world [WWW Document]. URL https://www.usgs.gov/ (accessed 9.27.22).

7. Appendices

Appendix 7.1: Industry emissions factors

Pulp and paper:

The emissions factors given for pulp and paper are dependent upon the manufacturing process. For this study, we have used emission factors for the chemical wood pulping process (Tomberlin et. al, 2020).

Methanol:

Methanol emissions factors are dependent on the fuel type and technology at the facility. Their respective values are listed below in Table 9.

Table 9 Methanol emissions factors (IPCC, 2022).

Technologies / Practices	Value	Unit	Source fuel
Conventional Steam Reforming, without primary reformer; Process Feedstock: Natural Gas (Default process technology and default feedstock)	670	kg CO2 / tonne methanol	Natural Gas (Default process technology and default feedstock)
Conventional Steam Reforming Process with Primary Reformer; Process Feedstock: Natural Gas	497	kg CO2 / tonne methanol	Natural Gas
Conventional Steam Reforming Process with Integrated Ammonia Production; Process Feedstock: Natural Gas	1020	kg CO2 / tonne methanol	Natural Gas
LURGI Conventional Steam Reforming Process; Process Feedstock: Natural Gas	385	kg CO2 / tonne methanol	Natural Gas
LURGI Conventional Steam Reforming Process; Process Feedstock: Natural Gas plus Feedstock CO2	267	kg CO2 / tonne methanol	Natural Gas plus Feedstock CO2
LURGI Low Pressure Steam Reforming Process; Process Feedstock: Natural Gas	267	kg CO2 / tonne methanol	Natural Gas
LURGI Combined Steam Reforming Process; Process Feedstock: Natural Gas	396	kg CO2 / tonne methanol	Natural Gas
LURGI Mega Methanol Steam Reforming Process; Process Feedstock: Natural Gas	310	kg CO2 / tonne methanol	Natural Gas
Partial Oxidation; Process Feedstock: Oil	1376	kg CO2 / tonne methanol	Oil
Partial Oxidation; Process Feedstock: Coal	5285	kg CO2 / tonne methanol	Coal
Partial Oxidation; Process Feedstock: Lignite	5020	kg CO2 / tonne methanol	Lignite

Soda ash:

Soda ash emissions factors are sourced from the EPA (EPA, 2022) and dependent upon the technology type at the facility. There are four main types of technology which yield: solution mining (450kg), trona mining (750kg), Solvay process mining (1050kg) and Hou process mining (1,100kg) of CO_2 per ton of soda ash respectively.

Ammonia:

Ammonia emissions factors are categorized depending upon fuel type and geography. Their respective values are listed below in Table 10.

Table 10 Ammonia emissions factors (Hoxha and Christensen, 2019).

Geography	Fuel type	Value (kg CO_2 per tonne)
China	Natural Gas	2741
China	Coal peat and oil shale	4160
Europe	Natural Gas	2656
Europe	Coal peat and oil shale	4147
CIS	Natural Gas	2667
Africa	Natural Gas	2552
North America	Natural Gas	2810
Latin America	Natural Gas	2434
Middle East	Natural Gas	2417
Southeast Asia	Natural Gas	2501
South Asia	Natural Gas	2688
Oceania	Natural Gas	2520