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

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## 1. Introduction

Chemical and pulp and paper industries are both energy and emissions intensive and account for 2% (IEA, 2022a) and 0.5% (IEA, 2022b) of global $CO_2$ emissions annually, respectively. 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 are a relatively more green production process where waste products from the pulp making process are often used to generate its own power. Despite this, 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 chemical 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 asset-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 (in tons of ammonia produced for an ammonia plant, for instance) before then subsequently applying a calculated emissions factor (tons of $CO_2$ per ton of ammonia produced for instance) to generate emissions estimates.

To estimate asset level production, a basic disaggregation method was applied between 2015 and 2021. 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 timeframe. For country-level statistics, these point-source estimates were then aggregated.

### 2.1 Datasets employed

For each of the aforementioned industries (chemicals, pulp and paper) we ascertained asset level (where possible) data, country level production data and production-to-emissions ratios data, otherwise known as emissions factors.

#### 2.1.1 Asset inventory data sets

Industrial Info Resources (IIR) (IIR, 2022) provided facility and country level information, including owner, capacity, technology type, and start/closing date. For chemicals, ammonia, methanol and soda ash emissions were estimated. Facility level characteristic data was available for ammonia (278 assets) and methanol (172 assets). Soda ash was handled at the country level (34 countries) where asset level data was not available during the scope of this work. Characteristic data for pulp and paper were available for a total of 378 assets. An overview of the country coverage for chemicals and pulp and paper can be found in Figure 1 and Figure 2, respectively.

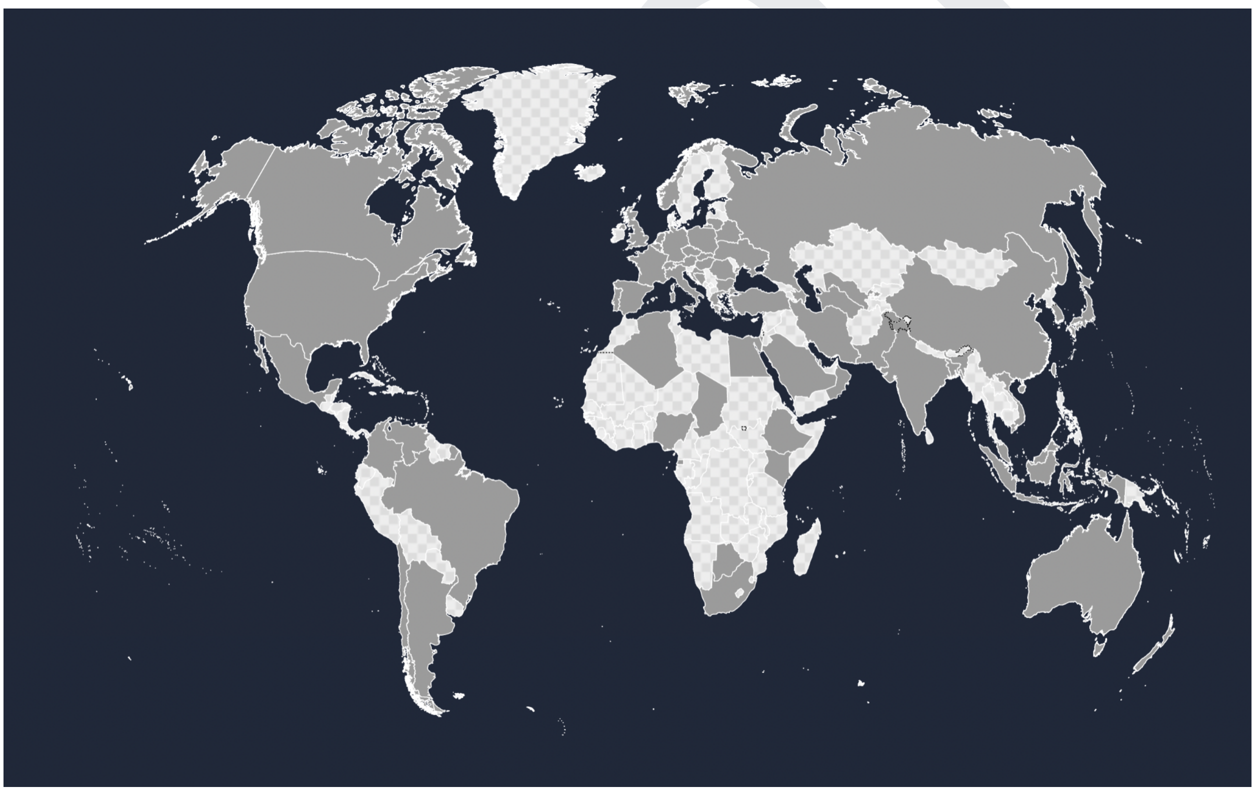

**Figure 1** Country coverage for the chemical's subsector (ammonia, methanol and soda ash). Covered countries are represented in gray.

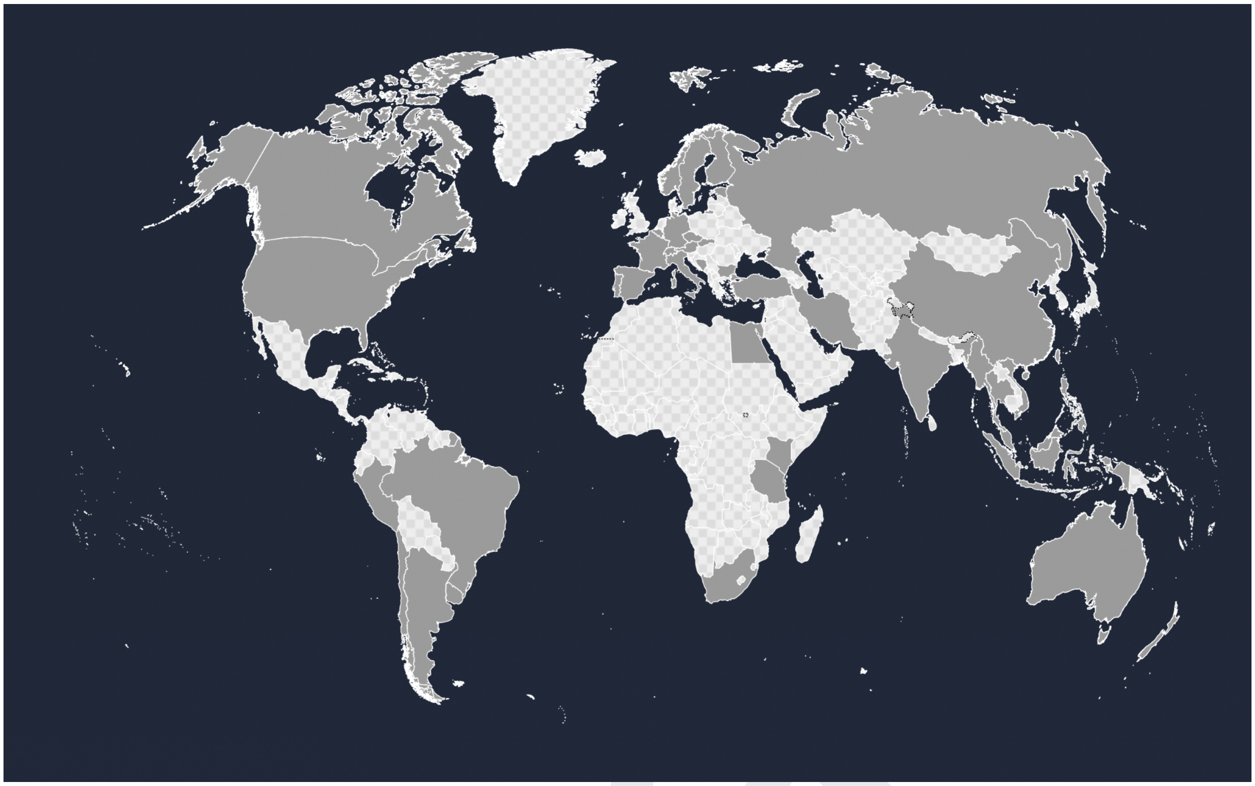

**Figure 2** Country coverage for pulp and paper. Covered countries are represented in gray.

### 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) up to 2020. 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). All aggregated production statistics were sourced on an annual basis. All countries demonstrate production values for the period starting January 2015 through to December 2021.

### 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 EU Emissions Trading System (EU-ETS) (Ecofys, 2009) with caveats that we only consider emissions associated with the line kilns operation in kraft pulping. Methanol and ammonia emissions were listed based upon fuel type. Ammonia was also further dependent based upon geographical location. Power generation related emissions are excluded from these emission factors (when applicable) as these emissions are already accounted for in the Climate TRACE Electricity generation sector. A breakdown of emissions factors can be found in Appendix 1.

## 2.2 Methods

### 2.2.1. Production methodology

The first step in quantifying emissions for each asset 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, we computed its share of national capacity before multiplying this number by the country's remaining 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 asset, 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.

## 3. Results

The results of this analysis can be summarised with the following set of figures as illustrated in Figure 3 for the chemicals and pulp and paper industries. Figure 3 shows the global Climate TRACE $CO_2$ emissions estimates at yearly scale. Of the four sub sectors, ammonia emissions are the largest contributor, with emission above 300 metric tonnes per year. Methanol, the second largest, has emissions values between 100 and 200 metric years for 2015 to 2020 and displays increasing emissions through the time period. Soda ash and pulp and paper have relatively lower emissions, less than 100 metric tonnes for each year.

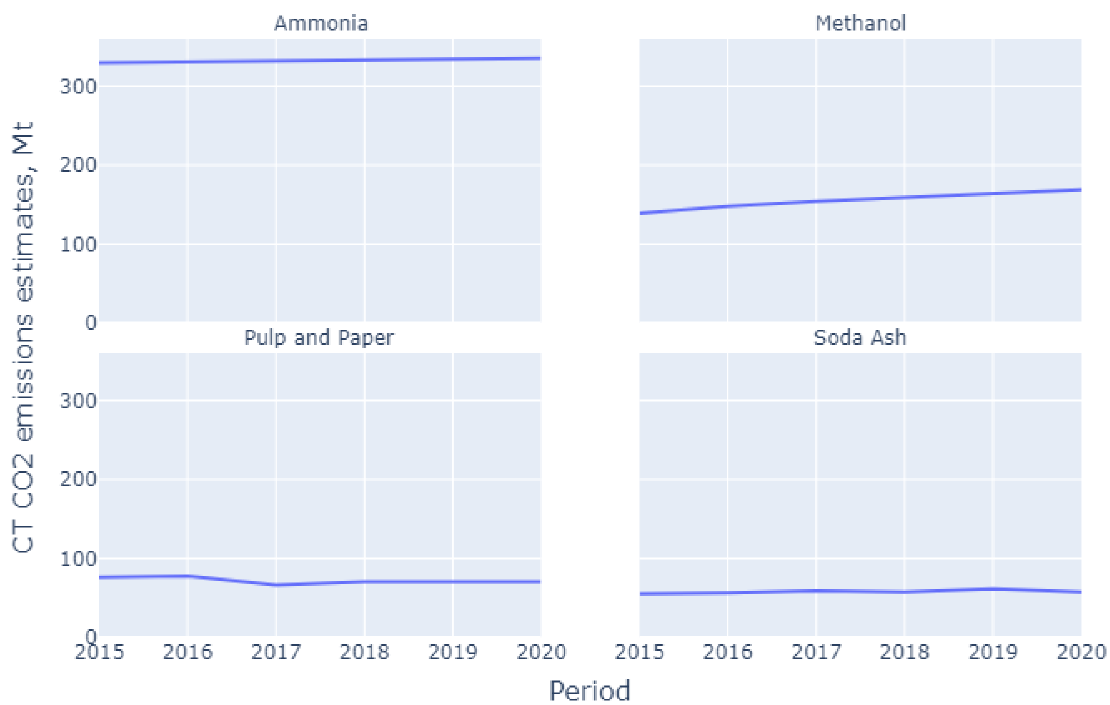


**Figure 3** Annual Climate TRACE $CO_2$ emissions estimates for Ammonia, Methanol, Pulp and Paper, and Soda Ash.

## 4. Discussion & Conclusion

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

To estimate emissions at the asset level our methodology takes known asset 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 is relatively simple and makes several assumptions about each asset, such as the production of a given asset is relative to that of national production. Additionally, it assumes that all operational assets are functioning within a nation, or that all assets are documented within our asset database to assign the correct proportion of national production. As a consequence, the accuracy of these estimates is considered to be limited and edge cases may be present which impact these assumptions. Nevertheless, this work serves as a strong foundational work piece for the estimation of $CO_2$ emissions in the pulp and paper and chemical industries which may be utilised to develop more detailed estimates in the future.

## 5. Appendices

**Appendix 1: Industry emissions factors**

**Pulp and paper:**

The emissions factors given for pulp and paper are dependent upon the manufacturing process. Both sulphite and sulphate driven processes yield 480 kg of $CO_2$ per ton of pulp produced (Ecofys, 2009).

**Methanol:**

Methanol emissions factors are dependent on the fuel type and technology at the facility. Their respective values are listed below in Table 1.

**Table 1** 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 (450 kg), 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 categorised dependent upon fuel type and geography. Their respective values are listed below in Table 2.

**Table 2** 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 |

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