Weekly Summary

Economics of Climate Change

February 21, 2025

Real-Time CO2 Tracking: A Trade-off Between Higher Frequency and Greater Reliability

Carbon Monitor, a high-frequency CO2 emissions tracker, demonstrates the advantages of real-time monitoring -particularly for tracking sectoral and regional trends- while aligning with IPCC guidelines for emissions measurement. However, caveats remain for daily estimates, both in terms of accuracy and, thus, in the real utility of this very high-frequency analysis.[1]

To effectively assess the impact of human activity on climate change, accurate quantification of emissions is essential. The Intergovernmental Panel on Climate Change (IPCC)[2] established the foundation for emissions inventories worldwide with its 2006 IPCC Guidelines for National Greenhouse Gas inventories.[3] These guidelines provide a **standardized framework for countries to estimate emissions accurately**.[4]

IPCC's Approach to Emissions Estimation. The IPCC employs a simple but adaptable method for estimating emissions, based on the equation:

*Emissions = Activity data (AD) * Emission Factor (EF)*

Here, activity data refers to human activities that generate emissions (e.g., fuel consumption in the energy sector), while emission factors quantify the emissions per unit of activity (e.g., CO2 emitted per unit of fuel burned).

The IPCC provides thousands of emissions factors with varying levels of granularity[5], allowing for more precise estimations, ranging for more general estimations of the emissions factors (tier 1) to more refined, national emissions factors (tier 2), or technologies and facilities specific emissions factors (tier 3)[6]. In stationary combustion, for example, the tier 3 method incorporated factors such as combustion technology, maintenance quality, operating conditions, and equipment age - offering a more refined assessment beyond basic fuel type considerations. The equation presented is:

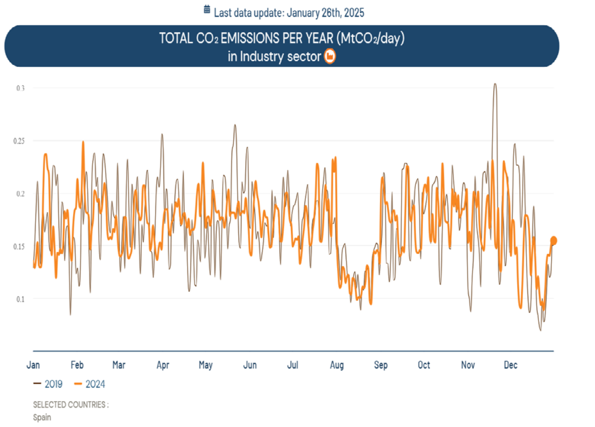
$$Emissions_{GHG,fuel} = \sum_{technologies} Fuel\ Consumption_{fuel,technology} * Emission\ Factor_{GHG,fuel,technology}$$

While official national inventories are typically published annually, often with one to two year lag, some platforms provide more frequent estimates. This is the case of the Carbon Monitor, a dataset that **tracks daily**

1: By presenting the methodologies and limitations of high-frequency emissions estimation, this article aims to inform researchers about the strengths and challenges of using such tools. Understanding these caveats is essential for interpreting the data correctly. Nonetheless, more frequent emissions estimation than what is currently provided by national inventories is crucial in a rapidly evolving environmental landscape.
2: The IPCC is an UN body created in 1988 for assessing the science related to climate change, its implications, and potential risks, as well as putting forward adaptation and mitigation strategies.
3: In 2019, a refinement to these guidelines was introduced. However, the methodology for quantifying the emissions remains the same.
4: For instance, Spain publishes its National Inventory of Greenhouse Gases, aligning with IPCC methodologies.
5: The number of emission factors is dynamic and constantly updated, even open to data proposals. See: IPCC Emission Factor Database (EFDB).
6: A tier represents a level of methodological complexity. Tier 1 is the basic method, Tier 2 intermediate and Tier 3 most demanding in terms of complexity and data requirements. Tier methodological complexity

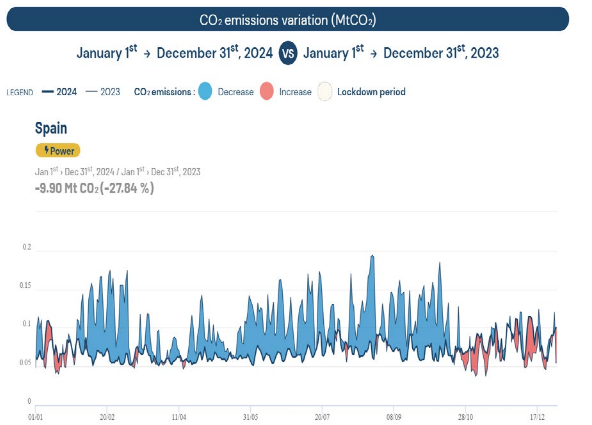
CO2 emissions from fossil fuel combustion and cement production at a national level. A high-frequency monitoring helps capture real-time emissions trends, assessing the effectiveness of decarbonization strategies and other policies in real-time. **Time granularity** is particularly valuable for detecting **short-term fluctuations**, such as those caused by **energy crises**, **regulatory changes**, or **shifts in transportation patterns**. It allows for a **much faster response** to these changes and **enables more efficient reactions**, as well as an **almost immediate analysis** of how certain global or local events affect emissions.

Figure 1. **Industry emissions in Spain in 2019 and 2024 (MtCO2/day)**



Source: Carbon Monitor

Figure 2. **Inter-annual emission growth of power sector in Spain 2023-2024. (MtCO2)**

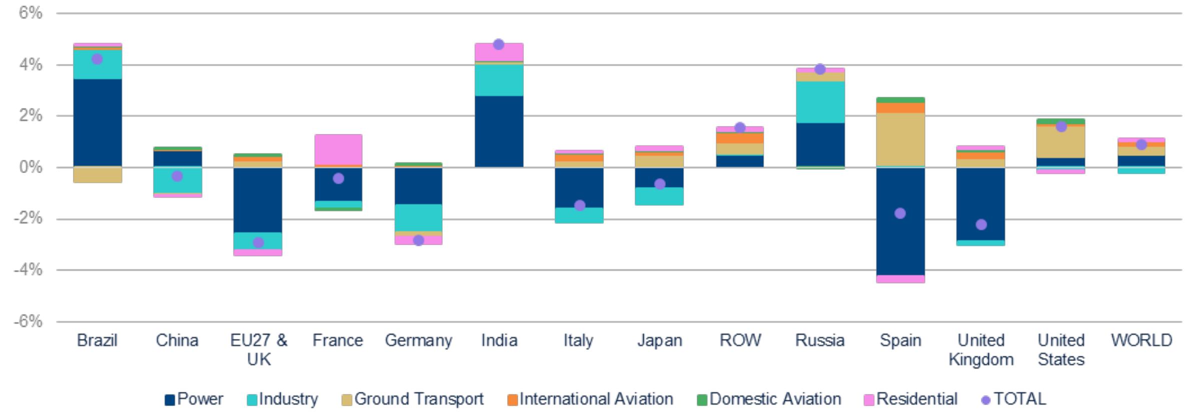


Source: Carbon Monitor

Figure 1 and 2 present the two main analyses this dataset provides: a daily CO2 emissions graph, and a daily CO2 emission variation analysis. **Carbon Monitor** is able to provide this information disaggregated in six different sectors: Industry, power, residential, ground transport and air traffic; and it can be divided by selected countries or the entire world. In order to estimate this detailed daily data, Carbon Monitor makes assumptions for each sector that allow them to **relate available high-frequency activity data with the CO2 emissions published at national levels with a lower frequency** (see Box 1 for details).

Figure 3 shows the variation in CO2 emissions across all sectors and countries analyzed by the Carbon Monitor. The graph presents **disaggregated daily CO2 emissions data for each country, comparing 2024 with 2023 in MtCO2 emissions per day**. Globally, there is a slight increase in CO2 emissions by the end of 2024 compared to 2023. However, many European and some Asian countries have experienced a decline in their total emissions over the past year. In contrast, Brazil, India and Russia have seen a sharp rise in emissions compared to other regions studied. **Among the sectors, the power sector exhibits the most significant changes across all countries, followed by ground transport and residential emissions.**

Figure 3. **CO2 Emissions Variation (% and contributions) per sector. 2024**



Source: BBVA Research from Carbon Monitor

Box 1. Methodologies for estimating each sector CO2 emissions in Carbon Monitor

Methodology for the Power Sector. Following the IPCC´s approach, Carbon Monitor estimates the yearly emissions with the activity data and the emission factor of each fuel[7]. After making an annual estimation of the emissions, the data source use this information and the daily activity data of electricity production with fossil fuels to estimate the daily emissions for the current year following the equation[8]:

$$Emis_{daily(t)} = Emis_{yearly(t-1)} * (AD_{daily(t)} / AD_{yearly(t-1)})$$

This equation assumes that the emission factor does not change from one year to another, which is not a strong assumption, as the emissions factors variations are much smaller than those observed in the activity data. Even so, this estimation could be biased due to a change in the electricity mix among the fossil fuels (p.e, this equation is not able to capture the increase in the emissions derived by an increase on the use of more emission-intensive fossil fuels).

Methodology for the Industry sector. The activity data of the industry sector is given by the industrial production index (IPI), which is given by most of the country on a monthly basis. This index allows Carbon Monitor to estimate the aggregate monthly emissions of the industry sector for each country[9], based on the equation:

$$Emis_{monthly(t)} = Emis_{yearly(t-1)} * (IPI_{monthly(t)} / IPI_{yearly(t-1)})$$

After estimating the monthly emissions, the data source uses the high-frequency data of electricity consumption to estimate the daily emissions of the industry sector. This is done with the assumption that there is a linear relationship between the electricity consumed by each industry and their industrial production.[10]

$$Emis_{daily(m)} = Emis_{monthly(m-1)} * (Elec_{daily(m)} / Elec_{monthly(m-1)})$$

Methodology for the Residential sector. The residential sector emissions could be split in two groups: the emissions derived from cooking, and those derived from heating. It could be assumed that the annual variation of the cooking emissions is not significant, and that the main driver of the residential sector emissions in the short term are the heating emissions, which depends on the population-weighted heating degree of the country[11]. Then, this variable is used to estimate the inter-monthly growth of each month compared to the baseline year (2018). [12]

$$Emis_{m,y} = Emis_{m,2018} * (\Sigma_m HDD_{d,y} / \Sigma_{m,2018} HDD_d)$$

7: The emission factor of each fuel differs for each country since an update in May 2022, following the annual IPCC update of emission factors (not country specific) with the country specific baseline emissions done in 2019 by IPCC.
8: In the equation, the "t" represents the year in which the daily emissions are being estimated. The activity data refers to the electricity generated with natural gas, coal and oil.
9: Carbon Monitor disaggregates the emission of the industry sector for China in four different industries: steel industry, cement industry, chemical industry, and other industries.
10: In the equation, the "*m*" represents the month in which the daily emissions are being estimated.
11: The population-weighted heating degrees is given by the following formula; $HDD_d = \Sigma(Pop_{grid} * (T_{grid,d} - 18)) / \Sigma(Pop_{grid})$
12: The baseline year is 2018 because the emissions of the residential sector of Carbon Monitor are based on the estimations of EDGAR database 35.

These monthly emissions are transformed into daily data using, on top of the aforementioned variables, the percentage of residential emissions from heating demand:

$$Emis_{d,y} = Emis_{m,y} * Ratio_{heating,m} * (HDD_{d,m} / \Sigma_m HDD_{d,m}) + Emis_{m,y} * (1 - Ratio_{heating,m})$$

Methodologies for the transport sector: ground transport and air traffic. For the other sectors, which are related with transport, the methodology of Carbon Monitor is based on estimating a daily proxy for the activity data of each sector and using the variation of this activity data to estimate the emissions of each sector. This can be done easily for ground transport[13] and air traffic.[14]

Nevertheless, there is a high uncertainty range on the daily emissions estimations, especially in the Industry and Residential Sector. The multiple assumptions that had to be taken to transform the annual emissions data into real-time data had a negative impact on the certainty of the emissions estimations. This affects especially to the industry and residential sector, in which the uncertainty range (measured as 1 - sigma uncertainties) are 36 and 40%, respectively (**Table 1**). For the industry sector, this uncertainty came from a Monte Carlo Simulation for China, which accounts for more than 60% of the world's total industry sector emissions. Most of the 36% uncertainty came from the frequent revisions of data after they are officially published for the first time[15]. On the other hand, for the residential sector, the 1 - sigma uncertainty is calculated based on the comparison between the daily residential emissions, derived from real fuel consumption in several European countries, and the estimations of Carbon monitor. For the other sectors a similar analysis is performed. Nonetheless, the industry sector exhibits a notably different uncertainty profile compared to other sectors. **While uncertainty in most sectors largely stems from the underlying assumptions, in the industry sector it primarily arises from revisions to official data of activity**. Consequently, the reduction in precision when using Carbon Monitor data relative to official data is much smaller than the overall uncertainty range of 36%. Finally, the overall uncertainty is estimated by calculating an emission-weighted mean of the sector-specific uncertainties.

Table 3. **Uncertainty range of daily emissions estimations for each sector**

Item	Uncertainty range
Power Sector	1.5%
Ground Transport	9.3%
Industry Sector	36%
Residential Sector	40%
Aviation	10.2%
Overall	6.8%

Source: BBVA Research from Carbon Monitor

13: To obtain a proxy for the ground transport activity data, the database used is TomTom, which gives a measure of traffic congestion, and Paris data to transform the traffic congestion into the number of cars in each city per day.
14: The activity data for air traffic was the km flown obtained from Flightradar24.
15: If there were no revisions of the official data, Carbon Monitor 1 - sigma uncertainty in this sector could be reduced to 2-12%.

In conclusion, the Carbon Monitor dataset provides valuable insights into real-time CO_2 emissions variations, complementing official national inventories with high-frequency data. By leveraging sector-specific methodologies, it can capture the short-term impact of economic activities or global and local phenomena. However, the significant uncertainty, especially for the industry and residential sectors, highlights the need for more refined data sources and estimation techniques. Daily trackers rely on scaling activity data by an emission factor, meaning the changes in emissions primarily reflect variations in activity or processes rather than actual decarbonization. To address this limitation, regular updates to emission factors are crucial to ensure that technological advancements and decarbonization efforts are properly incorporated into the estimates. Moreover, it should be considered the potential benefits of estimating emissions on a monthly or quarterly basis to improve accuracy, as the uncertainty decreases.

Highlights of the Week

- **Global | Growth in global electricity demand is set to accelerate in the coming years as power-hungry sectors expand. IEA.** The world's electricity consumption is forecast to rise at its fastest pace in recent years, growing at close to 4% annually through 2027 as power use climbs in a range of sectors across the economy.

- **China | Clean energy contributed a record 10% of China's GDP in 2024. Carbon Brief.** Clean-energy technologies contributed more than 10% of China's economic growth in 2024 for the first time ever, with sales and investments worth 13.6tn yuan ($1.9tn).

- **Americas | Macroeconomic impact of extreme weather events.** BIS. Different types of extreme weather events have different transmission channels to economic activity and inflation.

- **Europe | HSBC delays net-zero emissions target by 20 years. Reuters.** HSBC is ditching its target of reaching net-zero carbon emissions across its business by 2030 because of slow change in the economy, the bank said on Wednesday, compounding fears from campaigners that the world's biggest lenders are rowing back on climate pledges.

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