Measuring Greenhouse Gas Emissions

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1. Introduction

Many of the papers I have written about climate change attempt to quantify various effects of this human-made modification of the world's climate. Since all of the world's people share an atmosphere with many strong currents, it is really difficult to measure where greenhouse gases (GHG) are coming from. In the past couple of years I have written a three part series on new technologies that can define individual sources. The last of these was pasted last April, and is described and linked below.

Damn Satellite Part 3: Super-emitters and Ultra-emitters: *The Permian super-emitters have now been located with better precision at the completion of a multi-year aerial survey, and additional surveys have been performed via multiple satellites.*

The other news is that the Environmental Protection Agency (EPA) has started a process to define new methane emission rules for oil and gas producers.

Also, an international consortium has identified a new class of methane Ultra-emitters.

Part 3 reports on all of the above new information.

https://energycentral.com/c/cp/damn-satellite-part-3-super-emitters-and-ultra-emitters

One of my primary sources is Science Magazine, and the November 4 issue had an excellent editorial by Al Gore that alerted me to a major new development that globally identifies GHG emissions sources. I've excerpted this editorial in Section 2 below. Section 3 will delve into the new organization that defines GHG sources and reviews their website, which I also reference.

2. Measure emissions to manage emissions

In the 30 years since the world began negotiating the reduction of greenhouse gas (GHG) emissions, no one has identified exactly where all that pollution is coming from. That will begin to change next week (week of 11/7) when Climate TRACE (Tracking Real-Time Atmospheric Carbon Emissions)—a nonprofit coalition of artificial intelligence (AI) specialists, data scientists, researchers, and nongovernmental organizations—releases the first facility-level inventory of the largest known individual sources of the 162 million tons of GHG pollution emitted into the troposphere every day. With thousands of businesses, banks, investors, and 88 nation-states committed to reducing emissions to net zero by 2050, comprehensively tracking progress toward that goal is essential. This is especially important given last week's United Nations Emissions Gap Report indicating that the world is far behind pace for reducing emissions by 2030.[1]

Scientists have long known the total amount of carbon dioxide (CO_2) in the atmosphere. The Keeling Curve—a daily record of global atmospheric CO_2 concentration—leaped from 313 parts per million (ppm) in March 1958 to 2021's staggering 414.72 ppm global

[1] Al Gore, Science, "Measure emissions to manage emissions," November 4, 2022, https://www.science.org/doi/10.1126/science.adf5788

average.[2] Likewise, the component parts of the emissions puzzle are well understood—the burning of fossil fuels, transportation, industry, conventional agriculture, deforestation, and other sources are continually adding to the accumulation that lingers in the atmosphere. But until now, it has not been possible to precisely map and track the specific sources of GHG pollution. Climate TRACE's global database of the most substantial individual sources of emissions across two dozen sectors of the global economy will be free and publicly available.

Author's comment: As I'm writing this it is Nov 12, and I just spent about an hour on Climate TRACE's website. This is now live, and will be described in detail in the next section.

Why is this information so essential? As the eminent physicist Lord Kelvin said nearly 140 years ago, "When you can measure what you are speaking about, and express it in numbers, you know something about it; but when you cannot measure it, when you cannot express it in numbers, your knowledge is of a meagre and unsatisfactory kind; it may be the beginning of knowledge, but you have scarcely, in your thoughts advanced to the stage of science." Efforts to limit global temperature rise to 1.5°C are currently informed by rough estimates principally derived from self-reported national inventories submitted intermittently to the United Nations (UN). As of last month, no nation has submitted a complete accounting of its emissions for 2021. Indeed, 52 countries have not submitted any emissions inventories covering the past 10 years. Moreover, the inventories that do exist often have large omissions and fail to provide the granular data needed to make decisions. For example, last year, Climate TRACE found the actual emissions from global oil and gas production collectively were around double what was self-reported to the UN in 2020. Even more oil and gas emissions went uncounted by countries that are not required to report these data.

The Climate TRACE coalition is working to advance emissions monitoring closer to "the stage of science" Kelvin once described—by training AI algorithms to fuse data across multiple wavelengths and from more than 300 satellites; 11,100 air-, land-, and sea-based sensors; and other data streams to identify all of the largest point sources and track them over time. In recent years, new satellites have begun to measure methane emissions for a limited set of sources. But the atmosphere is so enriched with CO_2 that the "signal-to-noise ratio" defies the ability to measure CO_2 point-source emissions directly, leaving AI as the best recourse. The progress demonstrated by Climate TRACE mirrors the breakthroughs in AI that are ushering in a new era of radical transparency in multiple domains—making it possible to "see" specific land-use changes more clearly, and even to identify microscopic structures inside living human cells that had been impossible to "see" previously. Climate TRACE is proving that AI can do the same for emissions monitoring—making the invisible, visible.

Lord Kelvin's dictum is commonly translated in the business world as "you can only manage what you can measure." Thanks to breakthroughs in AI and other technologies, researchers, government officials, and business leaders can now manage emissions with timely, granular, and actionable climate information at their fingertips. With no time left to wait as the world burns and drowns, we can now begin to measure emissions with the precision needed to better manage their reduction—quickly.

[2] And 416.84 ppm on Nov 14, 2022, https://keelingcurve.ucsd.edu/

3. Climate TRACE

Climate TRACE is a non-profit coalition of organizations building a timely, open, and accessible inventory of exactly where greenhouse gas emissions are coming from.[3]

With new web sites, it's pretty easy to find flaws. With incredibly ambitious (and beneficial) websites like reference 3, I would be completely blown away if it didn't have a few problems and limitations, and Climate does still have these issues as one would expect a few days after it went live. Only time will tell if these are weeded out.

3.1. Climate TRACE's Story

Goal: *We make meaningful climate action faster and easier by harnessing technology to track greenhouse gas (GHG) emissions with unprecedented detail and speed, delivering information that is relevant to all parties working to achieve net-zero global emissions.*[4]

Note that there is a nice video on the above reference's page. However, this is a new site (as of now), and still has a few bugs (like you can't stop the video from looping while on this page). See if you guess who does the sound-over for the video.

Our Purpose: *For decades, measurements such as the Keeling Curve have given us the big-picture view of how much carbon dioxide is in the Earth's atmosphere. We know emissions are on the rise, and we know it's a result of our continued use of fossil fuels.*[5]

But we need additional information about exactly where and when greenhouse gas emissions are occurring in order to set actionable goals to reduce them and to track our progress toward these emissions reduction goals. Climate TRACE was formed in order to provide this insight on a comprehensive basis across all countries, major emitting industries, and major individual sources of emissions, enabling a new era of radical transparency that will help facilitate concrete climate action.

Until now, most emissions inventories have been based on self-reported, often years-late data that relied on rough estimates, opaque methods, and inaccessible reporting. Government officials, scientists, investors, executives, and activists need better data to support the creation of policies, programs, and campaigns aimed at limiting global temperature rise to 1.5°C as agreed to under the Paris Climate Agreement.

That's where Climate TRACE comes in. We're harnessing technologies like artificial intelligence (AI) and machine learning (ML) to analyze over 59 trillion bytes of data from more than 300 satellites, more than 11,100 sensors, and numerous additional sources of emissions information from all over the world. The result is a groundbreaking approach to emissions monitoring… one that is independent, transparent, and timely.

The journey began in 2019 when two of our founding coalition members, WattTime and TransitionZero, received a Google.org grant to monitor emissions from power plants from space using satellites. The project opened conversations with many researchers and advocates around the world, who started asking: Could we monitor nearly all human-caused greenhouse gas (GHG) emissions globally?

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[3] Climate Trace, https://climatetrace.org/

[4] Our Story, https://climatetrace.org/our-story

[5] Keeling Curve, see Wikipedia article here, https://en.wikipedia.org/wiki/Keeling_Curve , and reference 2 and the link therein on this paper.

Our answer is yes. And so Climate TRACE launched in July 2020 and now counts nonprofits, tech companies, universities, and former Vice President Al Gore as members.

Climate TRACE's global emissions inventory, released in September 2021, provides the first comprehensive accounting of GHG emissions based primarily on direct, independent observation.

Together, we're making GHG emissions visible. By tracing the root of the climate crisis, we're working to help solve it.

***Roadmap:** Our work builds upon recent advances in satellite observation and artificial intelligence that are enabling breakthroughs in emissions monitoring across sectors. Our work is based on cooperation and collaboration and we aim to work with and learn from researchers and technologists around the globe.*

That means Climate TRACE is constantly evolving and improving. We aim to harness the latest improvements in technologies and methodologies to provide the most accurate picture of global emissions possible.

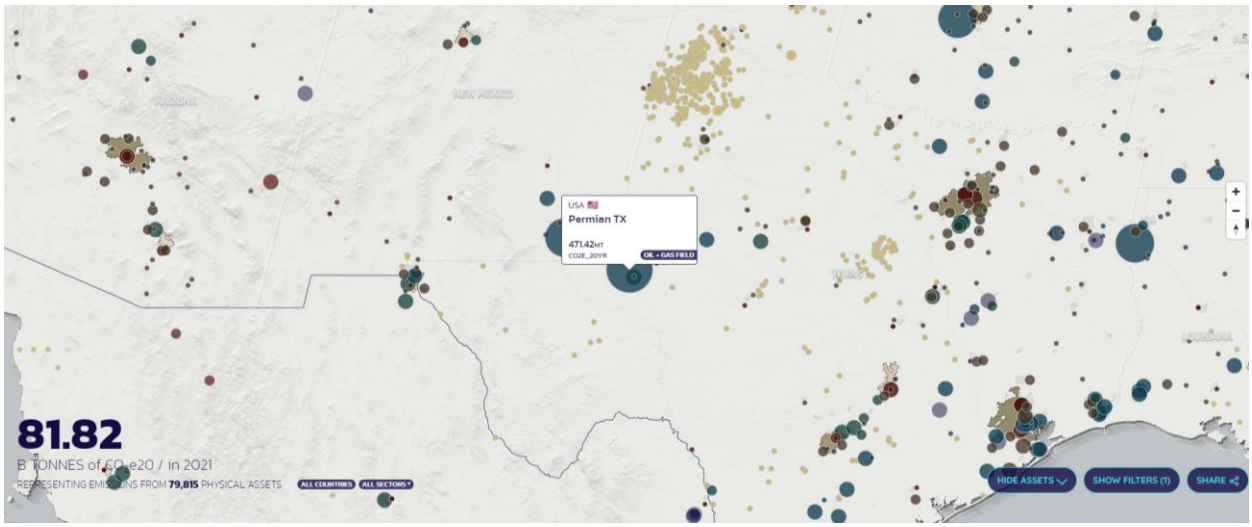
There is a detailed time line of the founding of Climate TRACE at the bottom of reference 4.

3.2. Interesting Content

I will start with the Home Page (reference 3), and perhaps visit a few more pages.

At the top of this page are two large buttons, plus a rotating globe of the Earth. I will assume that the lines radiating from the globe are proportional to GHG emissions of specific areas. The real globe is accessed by clicking the "EXPLORE THE MAP" button,

After accessing the map (by clicking on the above button), a flat map of the world is presented along with multicolor circles that appear to be emission sources. The size of the circles appears to be related to the amount of GHG emissions. When you click on one of these circles, it zooms in and pops-up a descriptive dialog box. I clicked on the approximate location of the Permian Oil Fields in West Texas, and got the image seen below.



The tag is a bit difficult to read in the above, but it says (top-to-bottom): USA, Permian, TX, 471.42 MT, CO2E_20 YR, OIL-GAS FIELD. I assume that the 471.42 MT… text-fields indicate that this source emits 42 megatons of CO_2 equivalent GHG in 20 years.

Although this is an impressive tool, it is incomplete. I found this by using the "Show Filters" button in the lower left, and filtering out everything but "Power" sources. I believe these are mainly generators. Then I was utterly amazed to see that my home state (California) didn't have any power GHG sources. Although I'm sure Governor Newsom will be delighted to hear this (take that Al!), I believe that California has around 30 large gas-fired generators. I also noted that the GHG power sources shown on the maps appeared to be only coal-fired generators.

Given the above, I would guess that (1) Climate TRACE is currently prioritizing high-emission sources for this global map and (2) will increase the lower emissions sources over time. Roaming around on my home turf, I saw other errors, but all things considered, this is an amazing effort.

Note that the other button at the top of the Home Page was "DOWNLOAD THE DATA". I played with this feature for a time, and was able to get a data-set that had U.S. generators in it, and confirmed that they were all coal-fired. If someone needs to *"…measure what you are speaking about, and express it in numbers…"* (see section 2), they will probably need more information on these data sets and methods to obtain them (probably with some help from Climate TRACE personnel).

Also note that the US Department of Energy, Energy Information Administration maintains an extensive database of all significant generators in the U.S. If you go through the link below, you will see a U.S. Map similar to Climate TRACE's world map, and scrolling down, data (XLS) files that for fairly complete information for all generators can be downloaded. The data files are chronologically listed with the most recent on top. As I am writing this (mid-November, 2022), the most recent file is from September 2022.

https://www.eia.gov/electricity/data/eia860M/

Back to Climate TRACE, from the home page, if you click on the menu symbol in the upper right corner of the page (three horizontal lines), a pull down menu of site pages will appear. If you select "Country Inventory" a page with a large dialog box will appear. This box allows you to select a sector, country or region, year, and GHG type, and either 100 year or 20 year time horizon. "TOOLS & RESOURCES from the same home page pull down menu has some information on methods and another page to download data from specific sectors and countries.

One final comment, the Climate TRACE site is probably being hammered pretty hard right now. Hopefully by the time I post this paper (about 10 days after I am writing this), things will have settled down.

3.3. Release Notes

When a new software version comes out, the release notes are notes from the developers that they believe will help users. This also applies to new web-sites. After much searching, I finally found these for Climate TRACE.

When Climate TRACE unveiled our inaugural dataset to the world last year, it included sector- and country-level emissions totals for the years 2015–2020. This year's Q4 2022 release represents a major upgrade, encompassing recent data (2021), updated

emissions totals (thanks to ever-improving methodologies and expanding data sources), more detail (such as the ability to filter by greenhouse gas and global warming potential), and most notably, asset-level data for more than 70,000 of the highest-emitting sources around the world.[6]

Author's comments: As I'm final-proofing this paper, I saw an interview with Al Gore on PBS last night, and most of the interview Climate TRACE. Note the *"…70,000 highest emitting sources…"* above. Al Gore also mentioned this in the interview, and went on to say that Climate TRACE hoped to identify and measure several million sources in the next few years. This confirms a guess I made earlier in this paper.

Here's a summary of what this 2022 release includes:

COUNTRIES: 252 countries globally (vs. 239 as of 2021 release)

SECTORS: 10 major sectors of the global economy

SUBSECTORS: 48 subsectors (+10 new subsectors vs. 38 subsectors in the 2021 release), including fluorinated gases, fossil fuel operations, waste, cropland fires, domestic and international aviation, coal mining, oil and gas refining, plus new net emissions for forestry, grasslands, and wetlands

ASSETS: added new ability to view emissions from more than 70,000 facilities and other specific sources (plus more than 7 million available for download from the fuller Climate TRACE dataset)

GREENHOUSE GASES (GHGs): new ability to view the data by carbon dioxide (CO_2), methane (CH_4), nitrous oxides (N_2O), and carbon dioxide equivalent (CO2e-20 and CO2e-100) [vs. all data reported in CO2e in the 2021 release]

GLOBAL WARMING POTENTIALS (GWPs): updated to GWPs from AR6 (vs. GWPs from AR5 in the 2021 release) and added the new ability to toggle between 20- and 100-year GWPs

INTERFACE: in addition to sector- and country-level annual totals from the 2021 release, added new features to view individual assets and to compare assets' emissions to each other

[6] Release Notes, Climate TRACE, https://climatetrace.org/news/release-notes-november-2022