

Analysis on Recent Updates and Positive Impacts of Carbon Footprint Measurement Techniques

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Abstract

Lately, climate shifts have grown harder to ignore. Because of this pressure, better ways to track heat-trapping gases are now vital. Not just counting pollution from factories but also daily actions matter more than before. One key method spots the full volume of emissions tied to how people live, build, and consume. This tracking system gives real numbers instead of guesses. It shows who adds what to planetary strain. With those figures, groups can decide where changes work best. Progress in these methods has unfolded slowly, step by uneven step. Much of it was shaped through studies appearing in well-known research databases across twenty-six years. Each paper added something slight yet solid to understanding. Numbers gained weight. Methods sharpened without fanfare. Better tools now help measure carbon more clearly in areas like farming, factories, power plants, transport, and tech. Back then, counting pollution meant checking how much fuel was burned or how much energy machines used. Yet those ways missed hidden emissions tied to long, tangled supply networks. So experts built broader strategies - one checks every stage a product goes through, from digging up materials to throwing it away. That method shows exactly where the most CO₂ sneaks out during making things. Another approach maps money and resources moving between industries to trace overlooked sources. One way to look at pollution is by linking industry activity to economic records - this method ties resource use to output across places and fields. Lately, experts have leaned on mixed models that pair step-by-step production reviews with broad economic flows, filling missing bits in emission numbers. By blending these views, scientists catch emissions close at hand as well as those hidden far down international supply lines. Tech tools like smart algorithms, live tracking networks, and shared eco-data platforms now play bigger roles in how footprints are tracked. With these upgrades, tallying carbon becomes quicker, less error-prone, and useful sooner for companies and officials alike. Using such methods has already led to clearer insights, better decisions, and sharper awareness

around ecological costs. Some tools let companies spot where emissions run high, boost how well they use power, while shaping greener ways to make things. Policies on climate, along with carbon fees and plans to cut pollution, take shape when governments rely on footprint numbers tied to global deals like the Paris Agreement. Labels showing carbon footprints appear more often now, alongside web-based calculators that open eyes - people start seeing their choices matter a little clearer each day. Tracking carbon flows aids business reports about green efforts, giving firms a way to watch steps forward - or backward - on paths aiming at zero emissions someday. Yet hurdles linger even amid progress; methods clash across studies, reliable data feels scarce too often, supply chains stretch so deep it gets tough to guess what is really going on underneath. One way forward might involve creating consistent worldwide rules for tracking carbon emissions. Tools like artificial intelligence could team up with massive data sets to sharpen accuracy. Real-time tracking systems may add clarity by showing changes as they happen. Progress here tends to tighten the trustworthiness of how footprints are measured. Better assessments often quietly support broader environmental goals. Clearer numbers usually help nations act with more confidence. Work in this area can ripple through policies over time. Solid methods sometimes shape stronger climate responses across regions.

Keywords: Carbon footprint, life cycle assessment, carbon accounting, greenhouse gas emissions, sustainability assessment, climate change mitigation

Introduction

Climate change and global warming have increased the urgency for efficient strategies to quantify and reduce greenhouse gases. The term carbon footprint can refer to the entirety of greenhouse gases produced by an individual, company or product (directly and indirectly) as the total carbon footprint [Ahmed *et al.* 2025]. Measurement of carbon footprint provides a quantitative indicator to assess the environmental performance of an entity and develop carbon emission reduction strategies. Numerous scientific methodologies to measure carbon emissions have been established since approximately 2000 [Du *et al.* 2024, Gameiro *et al.* 2025]. These methodologies consist of life cycle assessment, input-output analysis, hybrid assessment models and carbon accounting frameworks. Each methodology provides researchers and policymakers with the ability to assess the environmental impacts of products and services over the entire life cycle of these products/services (e.g., from cradle-to-grave). As global support

of carbon neutrality/net-zero is developing rapidly, accurately measuring the carbon footprint has become increasingly important. In addition, recent advancement of digital technologies (e.g., artificial intelligence, real-time databases, advanced modelling tools) has improved the functionality of carbon accounting systems [Jian *et al.* 2025, Marlowe and Clarke 2022, Rani *et al.* 2025].

Evolution of Carbon Footprint Measurement Techniques

Methods for Measuring Carbon Footprint have Developed Over Two Decades; In that time, the way we measure emissions has changed significantly. Initial Carbon Footprint Measurement Methods (2000-2010): The first studies on Carbon Footprint focused on the creation of a common framework to use for measuring emissions, including Greenhouse Gas Inventory (GHGI) and Carbon Accounting Methodologies (CAM). The common frameworks allowed companies to report their emissions and determine their environmental impacts using a single set of measurements [Suh *et al.* 2025, Wang *et al.* 2024, Yang *et al.* 2024]

Life Cycle Assessment Development:

The development of Life Cycle Assessment (LCA) has been one of the most widely used methodologies for measuring carbon footprints. LCA measures the emissions for all phases of a product's life cycle such as raw materials, production, transport, use, and disposal. (Frontiers) From 2010 to 2020, Carbon Footprint Analyses have Expanded to include Supply Chain, Sectoral analyses and many more: Between 2010 and 2020, carbon footprint analysis grew to include the evaluation of emissions from supply chain evaluations, industrial systems and household consumption. Research has proven that consumption patterns and industrial actions significantly contribute to global Carbon emissions. (EurekaMag) [Zhang and Wang 2024]

Major Carbon Footprint Measurement Techniques

Life Cycle Assessment (LCA)

A Life Cycle Assessment is the most effective way to calculate a product's carbon footprint, as it measures emissions from all stages of its lifecycle. It also assists in determining where emissions are created. Benefits of a Life Cycle Assessment include:

- The ability to provide a complete analysis of the environmental impact of a product
- Identifying where emissions are being generated across a supply chain

- Aiding in the design of sustainable products to compensate for the limitations of LCA's traditional approaches,

Hybrid Life Cycle Inventory approaches include data from multiple sources, thus allowing for the development of more robust models [Wiedmann and Minx 2008, Hertwich and Peters 2009]

Input–Output Analysis (IOA)

Input-Output Model is an accounting model that uses industrial production and consumption patterns to estimate carbon emissions from this economic activity. It can evaluate environmental impact at either the national or regional level; therefore, this model has broad application in macro-level environmental assessments. The Input-Output Model is also used in analyses related to trade, energy, and other sectors of the economy. Hybrid Carbon Footprint Models use both life cycle assessment and input-output based models to provide a comprehensive and accurate model of carbon emissions throughout complex supply chains. [Hertwich and Peters 2009] The results of hybrid models have been shown to improve decision-making for environmental reasons as well as provide guidance for developing sustainable industrial practices. Carbon Footprint Calculators are digital tools that provide estimates of individual or corporate carbon emissions. The calculators are frequently used in environmental education programs and as part of raising awareness about sustainability. While many organizations have developed carbon footprint calculators, recent research indicates that improving their accuracy and transparency will improve their overall utility in decision-making for environmental purposes [Pandey, *et al.* 2011]

Recent Advancements in Carbon Footprint Measurement

Dynamic Systems of Carbon Accounting Recent studies have developed dynamic models of carbon accounting that can use actual time data from commercial information systems to refine emissions estimates and are able to continuously measure emissions in real-time by monitoring carbon emissions in the entire production process. AI-Assisted Carbon Footprint Assessment The increasing use of artificial intelligence and machine learning to automate carbon accounting and increase the accuracy of the analysis of carbon data can also help improve prediction accuracy and provide real-time carbon monitoring by enabling the integration of multiple large data sets [Wiedmann *et al.* 2007]. These advanced tools increase

the efficiency of carbon accounting, while at the same time supporting the sustainable management of industries. (arXiv) Remote Sensing Technology and Carbon Monitoring The use of remote sensing technologies and environmental monitoring systems is increasingly used to estimate the carbon storage and carbon emissions of ecosystems such as forests and agricultural systems. These technologies provide significantly improved accuracy in assessing both the carbon sequestration and carbon dynamics of ecosystems. The Positive Impacts of Carbon Footprint Measurement Supporting Climate Change Mitigation By measuring carbon footprints, businesses can make it easier to find sources of emissions and develop strategies for reducing the emission of greenhouse gases. Promoting Sustainable Production By using carbon footprint assessment techniques, industries can improve the efficiency of energy use and reduce their overall environmental impacts during the production of goods and services. Improving Environmental Policy and Decision-Making The data on carbon footprints is relied upon by governments when developing the overall framework for making decisions about environmental policies and mitigation strategies related to climate change [Finkbeiner 2014, Hauschild *et al.* 2018]

Enhancing Consumer Awareness

Carbon footprint labels and calculators provide individuals' incentives to be sustainable in their consumption patterns. Supporting Carbon Neutrality Goals Carbon accounting enables organizations to accurately track their progress towards net-zero emissions and achieving sustainable development goals.

Challenges in Measuring Carbon Footprint While significant advancements have been made in this area, there are still many challenges to overcome, including:

- Standardization of methods
- Lack of reliable data; incomplete datasets
- Limited linkage of economic to environmental data
- Limited ability to identify indirect emissions throughout a global supply chain

Improving the quality of carbon-related data, developing standardized processes for measuring carbon footprints, is necessary to resolve these issues.

Future Areas for Research Future areas for research should be:

- Integration of artificial intelligence and big data into measurement of carbon footprints
- Creation of standardized carbon accounting frameworks globally

- Creation of real time monitoring systems for carbon
- Improved models on estimating supply chain carbon emissions.

The continuing advancement in digital technology and environmental data systems will significantly enhance the accuracy of measuring carbon footprints [de Bortoli *et al.* 2025, Kim *et al.* 2025]

Conclusion

The methods available to measure Carbon Footprint have changed significantly during the last 20 years. The development of Life Cycle Assessment, input-output analysis, hybrid models, and digital carbon accounting systems have increased the accuracy of emissions assessments as well as their scope. Recent developments in technology (including AI-based carbon accounting and real-time monitoring tools) have also been instrumental in improving the accuracy of carbon footprint analysis. In addition, these newly developed techniques will support sustainable production, provide information to guide policy related to the environment, and help reduce global climate change. Ongoing research and technological development will continue to improve the reliability and standardization of methods used to measure carbon footprint.

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