IEC
Institute of Electronics and Computer

Journal of Artificial Intelligence and Systems, 2024, 6, 59-75
https://iecscience.org/journals/AIS
ISSN Online: 2642-2859

Mitigating Carbon Footprint through Green Software: A Comprehensive Framework for Energy-Efficient Data Centers and User-Friendly Carbon Footprint Calculation

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How to cite this paper: Tharun Raghavasamy.M, Ashok.M, Kumar Ramasamy (2024). Mitigating Carbon Footprint through Green Software: A Comprehensive Framework for Energy-Efficient Data Centers and User-Friendly Carbon Footprint Calculation. Journal of Artificial Intelligence and Systems, 6, 59–75. https://doi.org/10.33969/AIS.2024060104.

Received: March 9, 2024
Accepted: April 8, 2024
Published: April 10, 2024

Abstract

The carbon footprint of the world is increasing day by day by the activities caused by every citizen. This is because the demand for energy increases and due to the lack of awareness.The average carbon emission is around 4.72 tonnes per person. There are some free online tools which are available for calculating the carbon footprint of each citizen. But those work as a datacentre in which data must be entered manually by the user which makes it quite inefficient. The existing methods do not meet the requirement of ease of handling the data.This software and the datacentres were developed which includes the availability of a user-friendly interface.Data centers also play a major role in carbon footprint, they emit CO2 and consume more energy. Data centers and new technology adoptions are mainly causing this carbon emission.These Data Centres use cloud energy to serve the user-generated requests and this energy consumption is the basic cause of carbon emission. Therefore, the energy efficiency of the data center must be governed. To reduce it, the concept of green software is introduced. Though hardware is seen as the main culprit for the consumption of energy, software plays a tremendous role in determining the efficiency of the hardware. Therefore, software must be energy efficient to handle the data center in low cost, low consumption, and low pressure.This led to the development of GREEN Software. The implementation of green software involves various factors.To reduce it, data center simulators are being used. This

simulator calculates the amount of energy consumed and the amount of CO2 emitted, which as a result computes the change in carbon footprint due to it. This green software design framework provides a separate track session on energy consumption by the data center and cloud service provider along with the acquired energy efficiency level by the specific center.

Keywords

Carbon footprint, Green software, Data center, Data center efficiency, Energyconsumption, User-friendly interface

1. Introduction

The accelerating pace of technological advancements and the burgeoning demand for digital services have led to an unprecedented surge in global carbon emissions. With the average carbon footprint per person soaring to 4.72 tonnes, primarily driven by escalating energy demands and a pervasive lack of environmental awareness, urgent measures are imperative to mitigate this concerning trend. While numerous free online tools exist for calculating individual carbon footprints, their efficacy is hindered by manual data entry requirements, rendering them inefficient and impractical for widespread use. This limitation necessitates a pivotal shift toward more accessible and user-friendly interfaces to meet the growing need for effortless data handling. Amidst this escalating concern, data centers have emerged as significant contributors to carbon emissions, propelled by their substantial energy consumption and CO2 emissions. The proliferation of cloud services, powered by energy-intensive data centers, stands as a primary catalyst for this environmental challenge. Addressing the burgeoning energy consumption of data centers led to the inception of the innovative concept of green software. Contrary to conventional perceptions that hardware bears the sole responsibility for energy consumption, this paradigm underscores the pivotal role of software in optimizing hardware efficiency. As a result, the development of energy-efficient software has become pivotal, aiming to streamline data center operations by significantly reducing costs, energy consumption, and environmental impact. The evolution of green software entails multifaceted approaches. Data center simulators have emerged as indispensable tools, offering comprehensive insights into energy consumption and CO2 emissions. These simulators effectively compute the resultant changes in carbon footprints, offering a clearer understanding of the environmental implications of data center operations and cloud service provisioning. This paper delves into the intricate framework of green software, offering a comprehensive exploration of its multifaceted implementation. In particular, it emphasizes the critical role of energy-efficient software in reshaping the landscape of data center operations, offering insights into energy consumption, and paving the way towards a sustainable, low-impact digital future.

2. Literature Review

Carbon footprint calculation can be made for a product building and the services or activities of the product involved in its usage. The analysis for a product is done from cradle to grave i.e., from the stage of extraction of raw materials to the building of the final product. The analysis of the services of products is made by the activities

involved in using it for the respective purposes. Thus, computational software can be made with the static data i.e., the end-to-end process involved in building a product and the dynamic data which involves the use of the product. Existing systems are analysed in Table1.

2.1. Carbon computational software

2.1.1 Sphera/GaBi Software

GaBi is the leading product sustainability solution for Life Cycle Assessment with over 10,000 users globally. It qualifies various business organizations that are seeking sustainability development to measure their carbon footprint at the product level through innovative solutions. Countless organizations, companies, and individuals use GaBi quality data for calculating their GHG protocol results. GaBi data is compliant with ISO 14040/44 and the EU Commission's ILCD DN entry-level requirements. The datasets of Gabi are fully refreshed which a unique annual upgrade program is providing users with the most current Life Cycle Inventory data and impact methodologies.

Companies are facing increasing pressure to address the environmental impact of their products[1]. Sustainability has become a crucial aspect of business, not just for meeting regulatory standards but also for aligning with changing consumer preferences and investor demands for eco-conscious practices. Analysing scope 1, 2 and 3 emissions at product levels are necessary to reduce the risk of shifting the environmental burden from one resource to another. The product level footprint denotes the level of emission from cradle to grave of the product design that creates an impact on the sustainable seeking environment which permits manufacturers to minimize emissions and maximize sustainable production practices. Analysing product-level footprint allows businesses and various organizations to systematically analyse the potential environmental impacts of their products throughout the entire life cycle and is a key part of any decarbonization strategy. Sphera is recognized consecutively as a global sustainability leader by the Business Intelligence Group. It has also been awarded the Top Product of the Year award from Environment + Energy Leader for the robust capabilities that the software solutions provide, recognized as a global leader for cloud computing 2023, and recognized as a leader in EHS software by Verdantix.

2.1.2 Cool Climate

To make a transition to a clean economy, Cool Climate provides smart decision-making tools and programs. They engage in innovative research, pushing the boundaries of carbon footprint benchmarking. On integrating insights from behavioral sciences, they craft customized climate solutions for diverse users and populations, ensuring our approach is tailored to the unique needs of each.

The journey of a cool climate began by developing the first carbon footprint calculators to account for the greenhouse gas emissions of all transportation, energy, food, goods, and services purchased by households and businesses[2]. The idea of permitting households, businesses, and communities to estimate their complete

carbon footprints extends with the online tool. This tool compares their results to similar users and develops personalized climate action plans to reduce their contribution to climate change.

The Cool Campus Challenge, a significant behaviour change initiative across the 10 University of California (UC) campuses, aims to make UC carbon neutral by 2025. In 2015, nearly 20,000 participants engaged, taking approximately six actions each to reduce their greenhouse gas emissions. The 2019 program is set to launch soon.

Additionally, the Cool California Challenge involved over 10,000 households across 30 cities in California for three years. Participants tracked their electricity, natural gas, and vehicle usage, earning points for reducing emissions. This initiative demonstrated a 14% electricity reduction in its pilot year compared to a control group. Notably, the top-performing cities were honoured as "Cool California Cities," with Davis, Riverside, and Claremont emerging as winners in consecutive years.

2.1.3 Build Carbon Neutral

Creating new structures with minimal environmental impact follows three key principles: minimize, regenerate, and compensate. Compensating involves measuring the carbon footprint of a project and counterbalancing it by investing in resources or initiatives like renewable energy and land conservation. These resources contribute to the well-being and preservation of the Earth. The tool calculates the energy embedded within construction materials and the resulting carbon emissions. It considers building materials, procedures, and carbon released from ecosystem deterioration or absorbed through landscape installation or rehabilitation. The calculator is accurate to about 25%, plus or minus. The building carbon model's effectiveness grows with user input and expanded datasets. Initially, the model distributes the total building square footage equally across floors. To accommodate excavation work and soil removal from below-grade stories, a higher carbon footprint per square foot is assumed for these areas. This ensures a more accurate reflection of environmental impact throughout the building's construction process.

The Embodied Carbon Emission guidance and Buy Clean concrete guidelines were developed, and implemented by New York State, making it a milestone to reduce carbon emissions. The CLF Staff Jordan Palmeri and Megan Lewis made this possible by approaching them to share their expertise, provide data and an understanding of what other states were doing, and participate in all staff webinars educating New York state staff about Embodied Carbon and EPDs.

2.1.4 Epic

Epic, an online platform, offers an easy-to-use graphical interface enabling users to enter project details such as square footage, program type, and location. It analyses the carbon footprint associated with various overarching strategies, like adopting all-electric systems or using steel structures[3]. EHDD has integrated EPIC into several projects to evaluate both operational and embodied carbon impacts. The firm intends to make this software available to the public for free by June.

The American Institute of Architects' Washington, D.C. headquarters underwent a lengthy and challenging construction process in the 1970s. The resulting building, a concrete and glass structure, reflected the architectural style of its time but was less energy efficient. The new design aims to transform the headquarters into a sustainable model, surpassing contemporary standards. The renovation seeks to achieve net-zero operational impact and compensate for its carbon footprint.

During the renovation planning, EHDD architects utilized EPIC, a newly developed carbon modeling software created within the firm. EHDD partner Brad Jacobson clarifies that EPIC isn't a life-cycle assessment tool but rather a directional one. It empowers designers to make early decisions guiding them toward achieving carbon neutrality, serving as a guide for informed and environmentally conscious design choices.

2.1.5 Kaleidoscope

Kaleidoscope is a valuable tool aiding in Life Cycle Assessments (LCAs) during the initial design phase. It provides designers with a comprehensive understanding of the embodied carbon impacts associated with different design choices, facilitating informed decision-making. LCAs, such as those supported by Kaleidoscope, gauge the environmental impacts of materials used, encompassing everything from energy expended during extraction to emissions generated during demolition. This holistic view informs sustainable choices throughout the design process. Kaleidoscope is designed to supplement, not replace, whole-building LCA in early design phases. It is meant to be a reference for the order of magnitude of early LCA decisions allowing designers to quickly compare the embodied carbon impacts of various standard building systems and design options.

Kaleidoscope has received a 2021 AIA Innovation Award. The Innovation Awards recognize the exemplary use and implementation of innovative technologies and progressive practices among architects and designers, their collaborators, and their clients, in support of the design, delivery, and operation of buildings or research in practice or academia. It is also the recipient of one of ARCHITECT magazine’s 16th Annual R+D awards. This award program honours research and technologies at every scale that has advanced the profession, such as design strategies, fabrication methods, installations, and software.

2.1.6 One Click LCA Planetary

One Click LCA stands as the global leader in user-friendly, automated life cycle assessment software, facilitating the computation and mitigation of environmental footprints across buildings, infrastructure, renovation projects, and various construction products. It empowers manufacturers to produce and release third-party verified Environmental Product Declarations (EPDs). Operating in over 140 countries, it is relied upon by prominent businesses and organizations worldwide. This comprehensive software encompasses a vast database of construction material EPDs and aligns with over 60 standards and certifications. Founded in Finland in

2001, One Click LCA operates with a team of over 110 experts spanning all continents.

Milan, Italy, July 2023 – Harpaceas, a pioneering force in digitizing the construction sector, and One Click LCA have forged a partnership focused on advancing sustainable building practices and reducing environmental impact. This collaboration aims to streamline the design and construction of low-carbon buildings and infrastructure. The assessment of embodied carbon—measuring the carbon dioxide emissions associated with the creation and upkeep of building materials—is gaining traction in the construction industry. There's a growing industry-wide call to manage a building's carbon footprint. Several European governments, including Italy, are initiating regulations mandating declarations of embodied carbon, and introducing limits on emission values in construction projects.

2.1.7 EPA's Carbon Footprint

It is an American-based organization that works on providing clean air, land, and water, simply the mission of the organization is to provide a harmless climate that does not include changes in rainfall, which results in more floods, droughts, or intense rain, as well as more frequent and severe heat waves.

As the footprint of an individual can be based on the location, habits, and personal choices, the focusing areas in order to estimate the carbon footprint includes Home Energy, Transportation, and Waste. Gathering utility bills such as electricity, natural gas, fuel oil, propane, etc are used to calculate the average use over a year.

The Great Lakes supply drinking water for more than 40 million people and provides opportunities to sustain the lives of various species. They are important, providing water to lots of people, and helping local economies. President Biden wants to invest in keeping them healthy. But there are still places around the lakes that are polluted from a long time ago when people didn't care about the environment. These areas, called "Areas of Concern," are causing problems for neighbourhoods nearby, especially for poorer and minority communities. It's a big issue that needs fixing. For many areas throughout the Great Lakes, including Milwaukee a place in America, these historical industrial discharges have left a disastrous aftermath. These “Areas of Concern” have been polluted for years, and many of the neighbourhoods surrounding these areas, and the people who live in them — often low-income communities and communities of colour — have been left behind.

The Milwaukee Estuary, a highly polluted area, needed a cleanup for the health of the local communities and Lake Michigan. Michael Regan, the EPA Administrator, announced over $450 million for a big cleanup project. They'll work with local groups and remove about two million yards of polluted stuff from the harbour and rivers, making things cleaner and better for everyone. The project agreement provides joint funding between the EPA and five non-federal sponsors who will contribute over 170 million dollars to the cleanup, with more than 275 million dollars coming from the EPA, through the Bipartisan Infrastructure Law. This is the largest cleanup project ever under EPA’s Great Lakes Restoration Initiative—cleaning up approximately two million yards of contaminated sediment from the Milwaukee Harbor and the

three rivers.

2.1.8 Sima Pro

The software is used in Life Cycle Assessment (LCA), the methodology exploited to estimate and evaluate the environmental impacts of a product or service throughout its life cycle. It considers every phase of the product from cradle to grave such as extraction of raw materials, manufacturing, distribution, and use, to disposal or recycling. The software evaluates the impact of a product based on its manufacturing and its process throughout its life cycle. These factors include energy usage, greenhouse gas emissions, water consumption, and resource depletion associated with different stages of a product's life. Various businesses and organizations benefited from the estimation provided by Sima Pro. Evaluating these estimations, the organizations can now concentrate on the quality based on its impact on the environment of the product. To increase the accuracy, Sima Pro applies various technologies and methodologies such as using Monte Carlo uncertainty analyses to measure data uncertainty, getting access to the most recent and up-to-date environmental databases, like eco-invent, Agri-footprint, or AGRIBALYSE, with different allocation choices and system models. Thus, software provides loopholes to achieve sustainability. Sima Pro also offers a multi-user feature, to collaborate and share results with friends, and colleagues.

Trouw Nutrition, Nutreco's feed business, has a rich history of innovating livestock feed for healthier farm animals sustainably. With a global presence and a dedicated team, they're committed to providing science-backed, sustainable nutrition solutions. They aim to enhance swine production's environmental friendliness by guiding customers with science-based sustainability choices.

With guidance from Trouw Nutrition's experts, sustainability consultants from PRé developed a parameterized LCA model. Farmer's input directly influences this model, facilitated by connecting to the SimaPro calculation engine through the SimaPro API. This thorough assessment looks at everything involved in all the processes from cradle to grave. This analysing method follows specific rules and methods set by environmental standards. To provide accurate information, data from various databases and institutions are being taken.

2.1.9 Open LCA

The software provides an estimation of the results of a carbon footprint based on the product's life cycle[5]. The life cycle includes from cradle to grave that is., from the extraction of raw material and throughout its functioning. Its features include providing a user-friendly interface, allowing users to conduct comprehensive life cycle assessments by modelling and analysing environmental impacts, and promoting the user to input and manage extensive data related to processes, materials, energy, emissions, and more. It also offers various impact assessment methods to evaluate environmental impacts based on different perspectives, such as carbon footprint, water footprint, toxicity, etc. Based on this the detailed model of a product can be customized that provide an impact in a sustainable way to the environment. The results provided with accuracy are done by integrating with databases like eco-invent, which provides a wide range of data on environmental impacts across various

industries. Various organizations and businesses benefited from using the Open LCA tool.

2.1.10 Carbon Footprint

The Carbon footprint calculator enables various organizations to look after their carbon footprint. For example, various organizations such as businesses, travel across the world which creates an impact on carbon footprint count. The app provides efficient and suitable sustainable ways to reduce the carbon footprint[4].

Excluding what an organization provides, whether it is a product or service-based company, Carbon Trust aids businesses in formulating and implementing effective strategies to decrease their carbon footprint. Through advisory services and software solutions, organizations can identify opportunities for energy efficiency and sustainable practices. Carbon trust can evaluate carbon footprint based on the product an organization provides such as manufacturing or the service they provide. Utilizing various databases provides an estimation of the steps involving measuring, managing, and reducing their carbon footprint depending on the organization's needs.

2.1.11 CO2 AI

Utilizing various methodologies and technology such as artificial intelligence, machine learning, and advanced analytics to help organizations measure, analyse, and strategize the doors that are opened to the increase of carbon emission and also enables to provide a precise value of the carbon emission[7]. Making use of various organization's cravings to attain net zero targets, CO2 AI was created to help complex organizations manage their carbon reduction journey by focusing on what matters most. It helps organizations measure, manage, and reduce their carbon footprint. The platform oversees over 130 million tons of CO2e, assisting sizable and intricate enterprises in effectively handling their environmental impacts on a large scale. Crafted and developed by a team of sustainability specialists and data scientists, CO2 AI directly tackles the primary obstacles companies encounter when starting their path toward carbon reduction.

Their recognitions can be seen in their awards such as the Sustainability Awards 2022 Packaging Europe, DataIQ Awards 2022: Sustainability and Environmental Data, SIIA Codie Award: Best Emerging Technology, MIT Innovator Under 35 Europe, and various other recognitions.

2.1.12 Climatic API

The Climatiq API is designed to help developers build tools to automate the calculation of the environmental impact of any business or organization's activity. Transforms any business activity data into carbon insights. They pile up data from various carbon emissions databases to compute the carbon footprint of an individual or an organization.

2.1.13. CO2NSensus/Connector Pro

Co2nnectorPro is one of the world's first carbon calculators compliant with ISO 14064-1 and verified by RINA. It provides comprehensive calculations in scopes 1, 2&3 and the most up-to-date reference points based on IPCC, DEFRA, and Eco invent databases. It provides the user with 100% accurate solutions, Fast and effective website applications, Easy management of footprint records, helps organizations choose the most suitable plans for their business requirements, and enables organizations to become carbon-neutral companies with certificates.[12]

2.1.14. Sustrax

Sustrax MX is the turn-key cost-effective solution that enables the user to control and compute their carbon emissions and also provides an opportunity to track progress against climatic changes, and other KPIs for compliance and voluntary reporting needs - such as SECR, CDP, and many more. It is fully equipped for global enterprises, being designed with multi-user and multi-language capabilities.

Various organizations such as MACE, HISCOX, Schuh, Cynergy bank, Genesco, epam, and several other organizations have expressed their user experience as fulfilment in the reports of their carbon footprint from the calculator they get. The satisfaction is for their accuracy and ease access of to footprint data, providing a simple understandable report enables organizations to reduce their carbon footprint.

One of the organization's users has conveyed their user experience as a helpful and informative resource as the calculator provides detailed and useful feedback.

2.1.15. Joro

The App aims to evaluate the carbon footprint of every individual. It spectates every social-related activity that causes environmental impacts, and guide and provide them with a way of sustainable solutions[6]. Factors such as Transportation, Energy production, waste production, shopping patterns, and various other factors are involved in evaluating the carbon footprint. The precise estimation of carbon footprint is provided by utilizing Machine Learning algorithms to quantify the carbon footprint of each transaction, giving users a detailed breakdown of their emissions across different categories. Varieties of suggestions are provided to the user to carry a sustainable lifestyle, also enabling scoreboards such as displaying points of progress in visual methodology, making each citizen look after their environment.

2.1.16. Klima

Klima helps every citizen to measure their carbon footprint in a user-friendly manner. This calculation is carried out by monitoring the lifestyles of the users which involves various factors such as Energy Usage, Transportation, Consumer goods, and a lot of others[8]. Klima makes the process of carbon offsetting transparent and accessible, allowing users to track their contributions and see the direct impact of their support on these projects. This user-friendly platform provides various sustainable suggestions to the users, allowing them to take necessary steps and actions that lead

to a healthy environment.

2.1.17. Adva

Adva is an app crafted to inspire a worldwide environmental movement by encouraging individual actions and learning. It fosters sustainable lifestyle habits by integrating them into daily routines and offers rewards as an incentive for positive changes toward a greener world[11]. Adva showcases itself as a solution-providing interface by introducing a lifestyle quiz which by answering it, helps us understand the impact of the lifestyle that we live, provides reward-earning tasks to enable an interactive interface with the user, and various other activities to ensure a sustainable environment. Their vision is to foster a community where the tiniest steps toward individual change converge into significant waves of sustainable impact. The power to shape our world rests in our hands, urging us to take responsibility for the future we desire.

2.1.18. Capture

To yield a Climate-friendly lifestyle, the daily activities of individual citizens are guided in a way to executes possible[9]. To make the platform more interactive and user-friendly platform, it provides us with a gamified learning experience with in-app challenges and sustainable lifestyle programs and allows you to earn rewards. The interactive experience includes sustainability challenges, a gamified interface, learning hub that enables users to carry a sustainability journey and track the progress.

Capture conducted a comprehensive 'Sustainability at Work' survey between August and September 2022. They engaged employees from diverse backgrounds, including junior and senior positions across various industries and company sizes. The top industries represented in the survey were manufacturing (11%), education (10%), healthcare (9%), IT (9%), and construction (8%). Among the respondents, 54% worked in companies with over 501 employees, while 46% were from smaller companies with 0 to 500 employees. In total, Capture collected and analysed data from 500 individuals across 64 countries through an online questionnaire. The Sustainability at work began.

2.1.19. Path Finder

This web-based tool assists registered users in estimating the carbon footprint and the time it takes for landscape projects to achieve carbon neutrality based on their design and management choices[10]. The tool collects user input on three key design factors: the amount of carbon-emitting materials used (like pavement), the volume of carbon-absorbing materials (like plants), and the expected carbon-emitting maintenance activities (such as mowing or fertilizing). Using data from the Athena Impact Estimator for Buildings and the U.S. Forest Service, the app computes a Climate Positive score. This score indicates when the project's carbon-absorbing elements will offset both its embodied and operational carbon footprint. Based on integrations from 20 case studies with practical interventions, the current goal for achieving carbon neutrality is estimated at five years for parks and campuses, and 20 years for plazas and streetscapes.

Users input project specifics like materials, paving, walls, fences, drainage, irrigation, and more. They can also detail carbon sink features such as wetlands, trees, lawns, and shrubs, as well as maintenance practices involving equipment and fertilizer. The tool generates a Climate Positive Design Scorecard, displaying estimated years until carbon neutrality, carbon sequestered, net impact over up to 100 years, and an embodied carbon profile. Moreover, the platform offers design suggestions to aid in reducing the project's carbon footprint during the design phase.

Table 1 Filtered Summary of Carbon Footprint Calculations

Summary	Carbon Footprint Calculators	Merits and Demerits of Calculators Merits	Demerits
1.	SPHERA/GABISOFTWARE:	ISO Compliance: Data compliant with ISO 14040/44 and EU Commission's ILCD DN entry-level requirements. Annual Updates: Regularly refreshed datasets provide up-to-date information. Business Integration: Used by over 10,000 users globally, indicating industry acceptance.	***Possibly Limited Scope: May focus primarily on product-level assessments, potentially limiting broader environmental impact analysis.***
	2. COOL CLIMATE:	Innovative Approach: Uses insights from behavioural sciences to tailor climate solutions.Community Engagement: Successful engagement withUC campuses and households across California.	Limited Geographical Focus: Initial emphasis on specific regions like California might limit applicability elsewhere.
	3. BUILD CARBON NEUTRAL:	Holistic Approach: Focuses on minimizing, regenerating, and compensating environmental impacts. Guidelines Impact: Development and implementation of guidelines impacting states like New York .	Accuracy Limitations: ±25% accuracy might be considered significant for certain precision-focused assessments.
	4. EPIC:	Architectural Integration: Integrated into architectural projects for early-stage environmental impact assessments.Operational Focus: Assists in achieving net-zero operational impactsin building renovations.	Not Comprehensive: Doesn't substitute for a life-cycle assessment, offering directional guidance instead.
	5. KALEIDOSCOPE:	LCA (LIFE CYCLE ASSESSMENT) Support: Aids in Life Cycle Assessments during early design phases. Recognition and Awards: Acknowledged for innovation and progressive practices.	Supplemental Nature: Meantto complement, not replace, whole-building LCA (LIFE CYCLE ASSESSMENT), limiting standalonefunctionality.
	6. ONE CLICK LCA(LIFE CYCLE ASSESSMENT) PLANETARY:	Global Usage: Operates in over 140 countries, catering to diverse construction projects. Comprehensive Database: Aligns with over 60 standards and certifications, ensuring wide applicability.	Market Dependency: Its efficacy might rely on market acceptance and use in specific industries or regions.

7. EPA(ENVIRONMENTAL PROTECTION AGENCY)'s CARBON FOOTPRINT:	Environmental Mandate: Focuses on providing clean air, land, and water, aligned with EPA (ENVIRONMENTAL PROTECTION AGENCY)'s mission. Impactful Initiatives: Large-scale cleanup projects like the Milwaukee Estuary demonstrate tangible results.	Geographical Limitations: Primarily focused on American contexts, potentially limiting global applicability.
8. SIMA PRO:	LCA (LIFE CYCLE ASSESSMENT) Methodology: Applies Life Cycle Assessment methodologies for productand service evaluation. Technology Integration: Utilizes Monte Carlo uncertainty analyses and up-to-date environmental databases.	Data Dependency: Relies on external databases and methodologies, which may affect accuracy.
9. OPEN LCA(LIFE CYCLE ASSESSMENT):	Environmental Analysis: Conducts comprehensive life cycle assessments. Diverse Impact Assessment: Offers various impact assessment methods for different perspectives.	Complexity: The extensive data input and analysis might be complex for non-experts.
10. CARBON FOOTPRINT:	Business Focus: Aids businesses in formulating strategies for energy efficiency and sustainability. Diverse Assessments: Estimates carbon footprint for various organizational functions.	Dependence on Data: Accuracy hinges on the quality and reliability of input data.
11. CO2 AI:	Technological Integration: Utilizes AI and advanced analytics for precise carbon emission calculations. Large-Scale Impact: Oversees substantial CO2e and helps complex enterprises manage environmental impacts.	Potentially Specialized: May be more suitable for complex organizations rather than smaller-scale users.
12. CLIMATIQ API:	Automation Capability: Helps automate carbon footprint calculations based on business activities. Data Compilation: Compiles data from various carbon emissions databases for accurate calculations.	Technical Dependency: The functionality and accuracy might depend on database updates and accessibility.
13. CO2NSensus/Connector Pro:	ISO Compliance: Compliant with ISO 14064-1, verified by RINA for accurate calculations. User-Friendly Features: Provides efficient, fast, and effective website applications.	Potential Limitation: Might cater more to certain standards and user types than others.
14. SUSTRAX:	Global Applicability: Designed for global enterprises with multi-user and multi-language capabilities. Positive User Feedback: Acknowledged for accuracy and simplicity by various organizations.	Specialization: May be more suited for larger enterprises than individualusers.

15. JORO:	Individual Focus: Aims to evaluate and guide individuals in measuring their carbon footprint. Machine Learning: Utilizes ML algorithms for detailed and personalized carbon footprint estimations.	User Engagement: Relies on sustained user interaction, which might be challenging.
16. KLIMA:	User-Friendly Interface: Provides a user-friendly way to measure carbon footprints. Carbon Offsetting: Offers options for users to track their contributions and impact on climate projects.	Scope Limitation: May cater more to individual users than larger organizations.
17. ADVA:	Education and Awareness: Encourages environmental movement by integrating sustainability into daily routines. Interactive Interface: Provides rewards and interactive tasks for users to engage in sustainability.	Dependence on User Engagement: Relies on user participation for impactful change.
18. CAPTURE:	Gamification: Uses gamified challenges to engage users in sustainability. Survey and Research: Conducts comprehensive sustainability surveys for valuable insights.	Scope Limitation: Focused on specific initiatives and user engagement, possibly limiting broader impact.
19. PATH FINDER:	Landscape Project Focus: Helps estimate carbon footprints and timeframes for landscape projects. Practical Insights: Integrates data from case studies for practical interventions.	Landscape Project Focus: Helps estimate carbon footprints and timeframes for landscape projects. Practical Insights: Integrates data from case studies for practical interventions.

3. Proposed System

The proposed mathematical equation for calculating the carbon footprint in the context of the given title can be expressed as follows:

Carbon Footprint=((Total Carbon Emissions)/(Energy Efficiency Factor))

Where: Total Carbon Emissions represents the overall carbon emissions generated by the data center, taking into account factors such as energy source, equipment efficiency, and cooling systems.

Energy Efficiency Factor is a metric reflecting the energy efficiency of the data center, considering both hardware and software optimizations. The derivation and determination of the specific components within the equation would involve a detailed analysis of the energy consumption patterns, environmental impact factors, and efficiency metrics associated with the operation of data centers.

Total Carbon Emissions (Total CE):

This encompasses the entire spectrum of carbon emissions from the data center, including those from energy production, equipment manufacturing, and operational activities.

Total CE =CEenergy + CEmanufacturing + CEoperations

Energy Efficiency Factor (EEF):

Reflects the overall energy efficiency achieved by the data center, considering optimizations in both hardware and software.

EEF=Energy Utilized by IT Equipments/Total Energy Consumed by Data Center Substituting these components back into the original equation:

Carbon Footprint=(CEenergy+CEmanufacturing+CEoperations)/(Energy Utilized by IT Equipments/Total Energy Consumed by Data C)

Further refinement may involve detailed assessments and measurements to quantify each component accurately. This comprehensive approach provides a holistic view of the carbon footprint, integrating considerations for energy efficiency and emissions across the data center's lifecycle.

4. Conclusion

The process of monitoring the environment based on carbon footprint assessments and mitigation strategies has evolved significantly with the plethora of innovative software and initiatives introduced to measure, analyse, and reduce carbon emissions across diverse sectors and activities. Though each tool such as SPHERA/GABI SOFTWARE, KALEIDOSCOPE, CO2NSensus/connector pro-SIMA PRO, etc provide several paths to calculate different segments of the sources of carbon footprint such as life cycle assessment of a product, Integration of Behavioural Science, etc, the limitations of these software haven’t solved by the single software at once. The requirements and the advantages of software for assessing the carbon footprint were cleaved in various software. Thus there leads to the need for software that tackles all the limitations faced by the above software which also includes all the advantages that have been provided.Despite SPHERA/GABI SOFTWARE has its extensive datasets and compliance with standards, it might struggle to quickly adapting swiftly to emerging environmental norms. Its annual data refresh might not keep pace with real-time changes, potentially impacting the accuracy of assessments over time.Though cool climate pioneering in behavioral science integration, it might encounter limitations in addressing industry-specific emissions. Essentially, it might not address the specific environmental impacts and complexities related to industries and their extensive supply chains, focusing more on individual and community-level actions.Build carbon Neutral which is a construction based tool is notable for its accuracy in estimation, around 25%, which is quite good. However the accuracy is not fit for the larger projects. This assumption overlooks the detailed nuances involved in construction, potentially impacting the accuracy of its assessments,

especially for larger-scale projects where precision is crucial.Epic tool serves as a helpful pointer at early stages, guiding design choices towards environmentally conscious decisions. The initial guidance that it provides might lack the depth needed for a complete life cycle assessment, which is crucial for achieving absolute carbon neutrality. It might not delve deeply enough into the comprehensive assessment required for an exhaustive carbon neutrality strategy.

This limitation might restrict its ability to provide a full-fledged analysis necessary for achieving complete carbon neutrality throughout a project's life cycle.Rest of the apps includes Lack of Real-time and Dynamic Updates, Limited Scope and Focus, Complexity and Accessibility, Data Accuracy and Standardization, etc.

On considering and overviewing the limitations of various tools, a sustainable and adoptable software must be built. The software must include which can

1. Integrate diverse data sources from existing tools while ensuring standardization in calculation methodologies. This integrated system would enhance accuracy and reliability.

2. Providing user friendly and attractive interfaces gamified learning, and interactive features that encourage widespread user engagement, especially among businesses, individuals, and organizations

3. Using technology that can quickly adapt to changes in the environment or standards without requiring significant reconfiguration or overhaul.

4. Introducing AI and ML algorithms to analyze complex data sets, predict trends, and offer tailored suggestions for minimizing carbon footprints across various sectors.

5. Building a collaborative network where data sharing and best practices exchange occur among users, organizations, and policymakers, fostering a collective effort towards sustainability.

In summary, the diverse range of carbon footprint assessment tools and initiatives highlighted in this survey signifies a collective effort towards a sustainable future. By amalgamating these approaches, a potential methodology or technology could emerge, addressing the limitations of current carbon footprint assessment tools. This solution aims to empower users, businesses, and policymakers with comprehensive, accurate, and actionable insights, fostering a collective responsibility towards a sustainable future.

Conflicts of Interest

Conflict of Interest Statement: The authors declare no conflicts of interest related to the research presented in this paper. However, it is important to note that while advocating for energy-efficient data centers and green software, some authors have previously received research grants or consultancy fees from companies involved in sustainable technology development, though none of these affiliations pose a direct conflict with the findings or perspectives shared in this manuscript.

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