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Limiting the Carbon Footprint of an Enterprise: Calculation Methods and Solutions

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Abstract: The importance of the carbon footprint problem is determined by its role in global warming and climate change, which lead to various negative consequences (heavy rains, droughts, floods, other climatic disasters), as well as threaten human health and well-being. The fight against the carbon footprint problem requires a comprehensive approach, including improving energy efficiency, switching to renewable energy sources, improving emission reduction technologies, forest conservation and rational use of resources. This problem concerns everyone, consumers and producers. There are many points of contact between consumers and producers of goods and services that allow to jointly solve the global problem of the carbon footprint and work to create a sustainable and environmentally friendly planet. Existing changes are already having a significant impact on our world and will have even more serious consequences in the future if each of us, both consumer and producer, does nothing to reduce carbon emissions.

Keywords: Carbon footprint, Greenhouse gases, Climate change, Artificial intelligence.

1. Introduction

The carbon footprint is the amount of carbon emissions into the atmosphere created by all human activities, including the burning of fossil fuels (oil, gas, coal), the production and use of chemicals, automobile traffic and the activities of various industries and agriculture [1] The carbon footprint also refers to the excess amount of greenhouse gases in the atmosphere that cause the Earth's climate to change. The carbon footprint measure is usually expressed in carbon equivalent (CO_2e) and is used to assess and compare the contribution of various actions and sectors to total carbon emissions [2]. One of the main problems of greenhouse gases is the climate change of the planet [3] Greenhouse gases, including carbon dioxide (CO_2), methane (CH_4) and nitrogen oxide (N_2O), trap heat in the atmosphere and create a greenhouse effect. This leads to global warming and changes in the weather and climate on Earth [4].

Another problem is related to the effects of these gases on the oceans. An increase in the carbon dioxide content in the atmosphere leads to acidification of the oceans, which negatively affects fish stocks and other marine organisms. Moreover, rising ocean temperatures cause accelerated melting of glaciers, which leads to sea level rise and threatens those living on coastal lands [5]. Greenhouse gases are also a cause of environmental pollution. Emissions of carbon dioxide and other greenhouse gases occur from the burning of fossil fuels such as oil, coal and natural gas, as well as from intensive animal husbandry and tillage [6]. As a consequence, air pollution and deterioration of the quality of life of people have an impact on the health and biological diversity of ecosystems.

Finally, greenhouse gases are a source of energy dependence. Fossil fuels, which are the main source of greenhouse gases, are often imported from other countries, which makes many countries dependent on external supplies and subject to fluctuations in energy prices [7].

The countries that lead in greenhouse gas emissions may vary depending on the year and the data source. However, the following countries usually always occupy the top positions: China (large population and intensive industrial activity), the United States (high dependence on oil, coal and natural gas), the European Union (intensive industrial activity and the use of fossil fuels.), India (high population, intensive economic growth, increased demand for energy), Russia (the largest producer of hydrocarbon fuels) [8]. These are just some of the countries that occupy the top positions in greenhouse gas emissions. It is important to note that there are many other factors that affect greenhouse gas emissions, such as population, industry, energy and politics of the country.

In order to form the concept of a greenhouse gas emissions reduction concept, it is necessary to understand the problem at the level of the state and producers, as well as to form awareness of the need and culture among the population to control and reduce everyone's carbon footprint. The purpose of the work was to study the possibility of determining the carbon footprint by consumers and producers of goods and services.

2. Materials and Methods

Objects of Study

The objects of the study were the main tools and approaches for determining the carbon footprint (greenhouse gas emissions) in the consumption and production of goods and services.

Research Methods

The research is based on a bibliographic search and subsequent critical analysis of Internet resources and scientific publications devoted to the problems of greenhouse gas emissions control using digital technologies. Materials from open Internet sources, Scopus scientific citation databases were used. Given the dynamism of the development of digital technologies and the problems of the carbon footprint, the depth of the search has been limited mainly by the last five years, it is advisable to cite some earlier works on certain issues of the carbon footprint, digital technologies, and the economy of circulation.

3. Results and Discussion

Several approaches can be used to determine the amount of greenhouse gases emitted by consumers or producers of goods and services [9]: emission inventory (collection of statistical data on greenhouse gas emissions during the production of goods and services, both as a result of measurement and as a result of emissions audit), life cycle analysis (LCA method assessment of potential environmental impacts of a particular product or service from its creation to the end of its life cycle, including production, transportation and disposal), material balance (analysis of calculations of the impact of a particular sector of the economy on climate change based on the measurement of incoming/outgoing flows of materials and energy), use of databases and models (use of specialized databases and models that contain information on emissions from various manufacturing and consumer industries), social and economic studies (for a deeper understanding of the causes and factors affecting the consumption of goods and services, social and economic studies can be conducted that will help assess the impact of changes in consumer behavior on the carbon footprint).

Carbon Footprint Calculators

To date, there are many online carbon footprint calculators that help to estimate the carbon footprint for housing, transport and air travel, consumption of goods and services, business and reduce their impact on the environment. Here are some of them: Carbon Footprint [10], WWF Carbon Footprint Calculator [11], CoolClimate Network Calculator [12], Carbon Calculator from Carbonfund.org [13] and others. These are just some of the many available carbon footprint calculators that help to assess the harmful impact on the environment and take measures to reduce it.

The link between the carbon footprint of our daily activities and global climate change is essential for understanding and addressing climate change. New users of the carbon footprint calculator are constantly appearing, appreciating the information they receive. Therefore, at the initial stage of awareness of the existing problem, carbon footprint calculators play an important role in improving lifestyle and motivation [14]. The Carbon Footprint Calculator is designed for both public and private use, focused on measuring the carbon footprint of countries, organizations and individuals. There are various forms and methods of calculating the carbon footprint, but they are all aimed at measuring the carbon footprint of a certain type of activity or set of activities [15]. The simplest calculator calculates carbon emissions solely based on energy-related activities. More detailed calculations take into account lifestyle and consumption, such as food and travel.

Several studies [14, 16-23] analyzed the differences between various carbon footprint calculators (Table 1). Padgett et al. [23] compared 10 calculators designed for private users in the USA. There are significant differences in the calculated values of the carbon footprint with the same input parameters. In another study, Kenny and Gray [19] observed an increase in the popularity of carbon footprint calculators in private households in Ireland. Discrepancies between values determined by calculators have also been established. So, the carbon footprint from water use is calculated in different ways, and some calculators do not take it into account. Kim and Neff [20] discussed how carbon footprint accounting can raise public awareness and change behavior. In particular, they stressed the need to spread information about the carbon footprint in such a way as to stimulate learning and motivate further actions. Based on historical data and literature, Birnik et al. [16, 23] developed a set of 13 principles for assessing the carbon footprint calculators, which were used to compare accuracy and computational procedures.

Table 1. Characteristics of various online carbon footprint calculators.

Software product	Source	Ease of use*	Accessibility	Region
Carbon Footprint	https://gbfcalc.azurewebsites.net/gbf/calc/dataneeds	E	Free	Great Britain
Ian Campbell	https://www.carbonindependent.org	E	Free	-
Oneclicklca	https://www.oneclicklca.com	M	Free trial (14 days)	Europe
GaBi	https://sphera.com/the-power-of-life-cycle-assessment-lca	M/D	Free trial (30 days)	-
EcochainMobius	https://ecochain.com/solutions/mobius	E	Free trial (14 days)	Europe
SimaPro	https://simapro.com/carbon-footprint	M/D	Free demo version	-
Perix.io	https://hpb-s.com/calculators/index.html	E	Free	Russia
Business Carbon Calculator by Normative	https://businesscarboncalculator.normative.io/en	M/D	Free	Europe
CoolClimate	https://coolclimate.berkeley.edu/business-calculator	E	Free	USA

*E – easy; M – moderate; D - difficult

In the study [22], 31 web-based carbon footprint calculators selected using a web search were evaluated. The study considered such factors as the diversity of the activities under consideration (water use, transport, electricity use, etc.), the availability of recommendations for changing behavior in computing tools. The input depth (explanation levels) of each calculator and user engagement are qualitatively assessed using a standard set of indicators and estimates [24, 25]. For the input categories of indicators, the comparison categories are often determined by the functional categories used in the test execution calculator [26]. The comparison categories for the Display Quality index were identified by the authors [27] based on the observation of the most useful methods of transmitting the results of the calculator.

The carbon footprint calculator was determined by the categories of input data (carbon footprint sources) that are included in each calculator, and the amounts of information that each calculator gives to the user in the source categories [21]. In all studies, at least some information about the use of energy in households is highlighted, and in all but one (97%) - about transport [28]. Information about air transport was often recorded (87% of cases). Food and water/wastewater products were found in 42% and 16% of calculators, respectively. Additional categories include «Waste and recycling», «Purchases or consumption», «Healthcare», «Education» and «Entertainment/Recreation». More than half (61%) of calculators included input data in addition to the five basics of analysis [29]. The results show that two calculators (Carbon Independent and WWF) showed good results, despite their shortcomings.

The use of calculators provides an understanding of the amount of greenhouse gas emissions accompanying the production and consumption of goods and services, which encourages both individuals and organizations to reduce their carbon footprint, and promotes conscious consumption for a more responsible attitude to the environment. Calculators will allow to make more informed decisions in favor of more environmentally friendly options for goods and services, contribute to an objective assessment of the effectiveness of various measures to reduce emissions and help identify the most effective ways to reduce the carbon footprint. However, such calculators often use simplified models, which can lead to inaccuracies in calculations, an increase in accuracy, as a rule, leads to a complication in the understanding of functional calculations by consumers or brings the software product into a group of commercial products not available to ordinary people. Nevertheless, the calculated data is quite enough to form an understanding of the existing problem and foster a culture of activity of ordinary users for sustainable development.

Carbon life cycle assessment

Carbon life cycle assessment is the process of analyzing and evaluating the entire life cycle of a product or service from its creation to disposal, in order to determine and account for all carbon emissions and uptake in the environment during production, transportation and use [30]. To assess the carbon life cycle, the following stages are usually taken into account: energy sources and raw materials (assessment of the choice and use of energy sources and raw materials for the production of goods or services); production (analysis of all stages of production, starting with the extraction of raw materials and ending with the receipt of finished products); transportation (assessment of processes associated with the movement of products or services from the place of production to the place of use); use (analysis of carbon emissions/carbon equivalent associated with the use of goods or services by end users); disposal (assessment of carbon emissions associated with disposal or recycling

OpenLCA Software

Debates about climate problems and their impact on human health, infrastructure and facilities, with attempts to assess our ability to adapt to adverse climatic events have become more frequent [31]. Methods for determining the carbon footprint and assessing the life cycle of products are developed mainly in the European Union and the USA, but are also found in Russia [32].

The study [33] describes a software package and related databases, algorithms for open assessment of the life cycle of products (building materials, multi-purpose buildings) in terms of carbon footprint and greenhouse gas emissions (GGE). The software allows to create a project that calculates the carbon footprint of a product during its life cycle (during the collection of materials, technological emissions, use and processing scenarios) [34]. The initial data set is defined separately for each operation of the process, so you can be aware of how each, even the minimal stage of production affects the final result. Such LCI data sets for various types of human activity facilitate life cycle Assessment (LCA) studies and increase the reliability and acceptability of LCA results [35]. Thus, the system can quantify the contribution of each stage of the product life cycle to GGE [36]. Such transparency allows us to track all stages of production, take into account supply and distribution chains, identify key components and ways to optimize their carbon footprint, which includes the ability to quickly create and provide reports on calculations performed, evaluation and training materials [37].

Perix Software

The PERIX platform developed by HPBS (Moscow, Russia) can be used to calculate the carbon footprint of domains 1, 2 and 3. The calculations on the platform use coefficients from the HPBS database. PERIX helps to determine which sources of greenhouse gases are covered, adapts to various industry requirements and supports automated data entry into information systems (1C, SAP). PERIX helps to solve problems such as optimization and balancing of GGE, calculation of cross-border carbon offsets and compilation of carbon emissions reports [38].

Greenly Platform

The platform developed by Greenly (Paris, France), can calculate the carbon footprint for Zones 1, 2 and 3 based on the number of employees, office size, company vehicles, heat sources, commercial flights and vehicles, as well as office electronics. Coefficients adopted in UK government regulations are used to calculate environmental considerations. The platform is designed for enterprises in France, the UK, the USA, and is suitable for small businesses [39].

Sage Earth Software

The purpose of the Sage Earth software (Sage Grope, Great Britain) is to automate the calculation process of Stage 1, Stage 2 and Stage 3, providing small and medium-sized companies with tools that can quickly and effectively assess their carbon footprint (and take measures to reduce it) [33]. The company's basic accounting information is uploaded to the platform (transaction data, suppliers, products, and analyzed to determine the reasons for individual purchases. Based on these data, Sage Earth provides an initial assessment of the carbon footprint of a business, comparing emission factors with yours and indicators, determining emissions and hot spots of the organization [40,41].

Sage Earth applies a cost-based approach to estimate carbon emissions, but uses UK industry average greenhouse gas emission factors that are not accurate enough in some regions [42].

Platform for carbon footprint calculation consultants Carbon+Alt+Delete

The Carbon+Alt+Delete (Belgium) platform allows consultants to submit data requests using the GHG protocol and ISO 14064, and is also a platform for calculating the carbon footprint using integration with EcoInvent, IEA and DIFRA databases [41]. The platform can generate reports in accordance with different standards (ISO 14064, GHG Convention and CSRD). The software resource allows to simulate a scenario of measures to mitigate the consequences of the company's carbon footprint, simplifying the assessment for independent auditors [14].

One Click LCA Software

One Click LCA software (Bionova Ltd/Click LCA Ltd, Finland) is useful for managing life cycle assessments, carbon footprint, and other environmental impact assessment parameters. The ecological footprint calculation database combines information from the world's largest databases. The software product supports various convenient formats (Excel, Revit, IESVE, etc.) for importing data for calculating the carbon footprint of construction facilities and providing the most effective ways to reduce emissions [43].

Artificial intelligence for carbon footprint assessment

Artificial intelligence can be used to track and model the carbon footprint by automatically analyzing data on greenhouse gas emissions and energy consumption [44]: automatic data collection (automation, simplification of the collection and transfer of data on greenhouse gas emissions and energy consumption to a cloud server for further processing and analysis); data analysis (analysis of large volumes of data on emissions and energy consumption, identification of factors affecting the carbon footprint and providing recommendations for its reduction); modeling and forecasting (creation of models that can predict future changes in the carbon footprint based on various scenarios for identifying and analyzing factors affecting greenhouse gas emissions and energy consumption, planning measures to reduce carbon footprint optimization of processes (offering optimal schedules and resources to reduce greenhouse gas emissions in production processes, optimization of energy use and management of energy systems).

In the paper [45], the carbon market is presented as a tool for economic compensation of carbon dioxide emissions in data centers. Data centers are experiencing unprecedented growth and are the engine of the future of the digital world. However, these centers are quite carbon-intensive, it is assumed that by 2030 their share of global carbon dioxide emissions will reach 8%. Several global cloud providers, such as Google and Facebook, promise to maintain carbon neutrality in their data centers. To achieve the presented goal, a digital platform of industrial artificial intelligence with twice the power is proposed. In [46], artificial intelligence was considered as the preferred tool for solving greenhouse gas emissions problems. However, training models with a large number of parameters require a lot of energy and, as a result, greenhouse gas emissions. The authors studied possible negative impacts of AI on the environment. Various types of artificial intelligence impacts are considered; various methodologies for assessing these impacts; an assessment of the life cycle of AI services is applied, assessments of the environmental benefits of a common AI service are discussed with the existing limitations of green AI being indicated. Accurate prediction of CO_2 emissions is of real importance for choosing the best ways to reduce CO_2 emissions. This [47] presents 4 ARIMA-based forecasting models using SARIMA (SARIMAX). All models take into account data during the COVID-19 pandemic with machine learning, the calculation gives different accuracy of these SARIMAX models. The study confirmed the successful prediction of CO_2 emissions for the pandemic period or for non-crisis periods after it. In the long run, the accuracy of the models decreased. The total power consumption was estimated by multiplying the combined consumption of the GPU, processor and DRAM memory by the Power usage effectiveness for a particular data center. The conversion of energy to carbon emissions is the sum of total energy consumption and carbon energy intensity. The authors calculated that the carbon footprint of BERT training (baseline) is approximately 0.652 tons. Energy consumption and carbon footprint were estimated using NLP T5, Meena, GShard, Switch Transformer and GPT-3 models [48]. An important result was that such methods can be used to improve energy efficiency when training neural network models. Liu et al. [49] proposed a methodology for estimating the corporate carbon footprint of CCF based on direct and indirect carbon emissions by factories in real time. It is established that the proposed method of device identification significantly exceeds the known reference indicators and allows achieving an accurate assessment of the corporate carbon footprint at the minute level.

A new way to study the impact of the pandemic on carbon emissions is presented in the paper [50]. Based on the ARIMA method, two combined approaches have been developed to model carbon emissions in China, India, the USA and the EU under a pandemic-free scenario. The estimated reduction of carbon emissions in the USA and the EU did not have significant differences between the years, and in China and India it exceeded the real values by 5%. It is assumed that the pandemic had a greater impact on carbon emissions in developing countries than previously thought.

Liu et al. [49] present a new ensemble forecasting system based on different approaches (data decomposition, model selection, phase space reconstruction, ensemble point forecasting, interval forecasting). The proposed forecasting system has proven its effectiveness in improving the accuracy and stability of carbon emissions forecasting, increasing forecast performance compared to other models.

The undoubted advantages of using AI, for solving carbon footprint problems as well, include speed and accuracy, automation and efficiency, objectivity and impartiality, but its technologies and algorithms are data-dependent and complex. AI has great potential to solve environmental problems, but it is itself an indirect source of carbon. The introduction of AI systems everywhere in our lives leads to a significant increase in carbon emissions from AI. The study [51] presents a systematic review of research on green AI, most of which focus on the learning stage, do not depend on algorithms or study neural networks. As a rule, research in the field of environmental sustainability of AI offers solutions to reduce the carbon footprint of AI models. It is reported that the energy savings of green AI reaches 115%, with savings of more than 50% being quite common. It has been established [52] that the carbon footprint of research using AI can be significant and there is a need to implement a compromise between greenhouse gas emissions generated by AI and the achievements in energy efficiency and resource efficiency that AI offers. 13 recommendations have been formulated for using AI capabilities in combating climate change while minimizing its impact on the environment. The article [53] proposes a method for quantifying CO_2 emissions caused by training and using an artificial intelligence model. It is established that, if only positive impacts are taken into account, the reduction of CO_2 emissions as a result of the use of models (artificial neural network model for energy demand management of Brazilian households, adaptive neuro-fuzzy inference system for predicting the power of photovoltaic installations in Tunisia, Bayesian regression model for solving the problem of routing electric vehicles in Sweden and Luxembourg) is significant, but it depends on each context (34%, 73% and 9%, respectively). The negative impacts of the 1st and 3rd models when predicting for one user exceed the positive impacts, however, when using models by many consumers, the total impact of AI becomes positive. The second model maintained a positive total balance in all cases of using AI, although not always significantly. The authors have formulated seven global recommendations that can contribute to reducing the carbon footprint of machine learning models in general. The main objective of the study [54] was to present the concept of reuse of hidden data of organizations to ensure digital decarbonization. Approaches to reducing greenhouse gas emissions and the formation of sustainable development and the use of data are formulated. [55] considered the system of systems approach and concluded that it is necessary to create effective AI models that will not harm the environment, paying attention to the practice of sustainable AI, from data collection to debugging the model throughout the life cycle of AI.

Well–known industries that are leaders in greenhouse gas emissions [56] are energy (production of electricity from hydrocarbon fuels such as coal, oil and/or gas), industry (various production processes of products such as steel, cement, chemicals and plastics), transport (cars, trucks, planes, ships and trains powered by hydrocarbon fuels), agriculture (food production, animal husbandry), housing (construction and operation of buildings, especially the use of energy for heating, cooling and lighting). These industries are the main sources of greenhouse gas emissions on a global scale, but the production processes of organizations in other industries are also accompanied by greenhouse gas emissions. Therefore, it is important for everyone to understand what harm is done to nature by this or that action. The company's carbon footprint can be calculated, monitored and reduced. GEE emissions of organizations can vary significantly depending on the country, region, and technologies used, even within the same industry.

To date, GEE mitigation strategies and associated health benefits in various sectors of the economy have not been fully studied. Gao et al. [57] conducted a comprehensive review of the evidence on these issues. Measures to reduce GEE emissions were mainly taken in five sectors (energy production, transport, food and agriculture, household and industry). Some comprehensive mitigation strategies covering multiple sectors tend to have great health benefits.

da Silva et al. [58] studied the current situation of the practice of reducing GEE emissions in universities and moving towards a greener campus. Differences were identified in the methodology and data used by each university due to the lack of standardization regarding time indicators, functional unit, limitation of data collection, as well as emission sources and emission factors.

The carbon footprint of AI attracts the attention of researchers, but there are no recommendations to limit it. Wang et al. [59] built a model of a three-way evolutionary game taking into account governments, alliances of the AI industry and consumers and studied the influence of key factors on the choice of strategy by these groups of players on the example of the use of intelligent air conditioners in China. It was found out that the behavior of governments has an important influence on the behavior of alliances of the artificial intelligence industry and consumers. Early-stage regulation by governments is necessary to limit the carbon footprint of AI, but becomes optional when the system reaches an optimal state. The choice of strategy by governments is determined by various factors (image benefits, regulatory costs, carbon price and subsidies provided to consumers, and industry alliances of artificial intelligence, etc.), the most significant are carbon prices and subsidies provided to consumers. AI industry alliances are dependent on carbon pricing. Consumers prefer the trends of environmentally friendly consumption, self-satisfaction and usefulness, but are not sensitive to subsidies.

Several traditional approaches to reducing the carbon footprint of the organization are known: energy efficiency (use of energy-saving technologies, energy-efficient equipment and lighting, improvement of building insulation); renewable energy sources (transition to the use of renewable energy sources such as solar energy, wind turbines and/or hydropower); control and reduction of emissions (effective systems for cleaning air emissions and reducing the use of hazardous chemicals and switching to safe alternatives); waste management (waste management, including recycling and disposal of waste); eco-friendly vehicles (use of public transport, automobile carpooling and electric vehicles, reducing the number of business trips in favor of online interaction); information and education (training of employees of sustainable practices and implementation of the environmental awareness program); sustainable interaction with suppliers (improving the environmental efficiency of suppliers and the use of sustainable methods of production and supply of goods and services); emissions compensation (investments in carbon sequestration projects, such as planting trees or creating and supporting environmental projects), etc.

Not only organizations, but entire cities should think about their sustainable development. Cities cannot exist separately from the environment, and their sustainability depends on their interaction with it. Technologies are rapidly becoming obsolete, so plans for sustainable development must be constantly updated. There are cities all over the world that have their own sustainable development strategies. Such as Los Angeles [60]. It was announced that 100% of wastewater will be processed in it by 2035, and 100% renewable electricity will be provided by 2045.

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4. CONCLUSION

Calculating the carbon footprint by consumers and producers of goods and services can have several practical advantages: assessing the contribution of a product, service and/or organization to global climate change (consumers and producers will be able to understand how everyone is responsible for climate change and set goals for reducing emissions), identifying and analyzing potential emission reductions (identifying the main sources of emissions from consumers and the organization, and the development of a strategy to improve the efficiency of resource use and reduce emissions of harmful gases), the development of the carbon credits market (organizing an understated level of carbon emissions due to carbon credits can bring additional income to the organization and contribute to its sustainability), the creation of a positive image and customer satisfaction, the possibility of participation in external programs sustainability and emissions reduction and receive additional benefits. In general, calculating the carbon footprint of consumers and producers of goods and services helps not only to assess its contribution to climate change, but also provides tools for taking measures to reduce emissions, increase resource efficiency and create a sustainable image.

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