2023 International Research Conference of Sri Lanka Technology Campus
Colombo, Sri Lanka. 14th-15th December 2023

Carbon Footprint Analysis with Simplified Emission Estimation Methodologies

R.D.T.D. Ranasinghe
Department of Computer Systems Engineering
Sri Lanka Institute of Information Technology
Colombo, Sri Lanka
tharusha.dinithma@gmail.com

W.O.A. Peiris
Department of Computer Systems Engineering
Sri Lanka Institute of Information Technology
Colombo, Sri Lanka
oshidhie@gmail.com

P.C.Y. Pitawela
Department of Computer Systems Engineering
Sri Lanka Institute of Information Technology
Colombo, Sri Lanka
ypitawela@gmail.com

A.M.U.S.B. Abeykoon
Department of Computer Systems Engineering
Sri Lanka Institute of Information Technology
Colombo, Sri Lanka
uvinduabeykoon123@gmail.com

Samantha Rajapaksha
Department of Information Technology
Sri Lanka Institute of Information Technology
Colombo, Sri Lanka
samantha.r@sliit.lk

Jenny Krishara
Information Technology
Sri Lanka Institute of Information Technology
Colombo, Sri Lanka
jenny.k@sliit.lk

***Abstract*—The global average temperature on July 4, 2023, reached an all-time high of 62.92 degrees Fahrenheit (17.18 degrees Celsius), making it the hottest day on Earth since at least 1979. [1]. This is a great reminder of why people should care about the environment. Being busy with day to today life, people don't have time or motivation to consider their personal carbon footprint. Harder to keep track of daily work and over-complicated carbon footprint calculators cause people to lose track of their carbon emissions. Lack of knowledge about carbon footprints and their impact on the earth's future is another main reason why people don't care about it. Many people believe that climate change is government propaganda, and some believe personal carbon footprint doesn't have an impact on the world since it is very minimal compared to Earth's scale. This research paper proposes a novel approach to calculating carbon footprints using a simple algorithm and interface that eliminates the need for users to remember numerical values. The study presents a methodology to determine personal carbon footprint using predefined values and using simple algorithms to analyze them. The research primarily concentrates on three main components, namely transportation, energy consumption, and food consumption. Each of these components is further subdivided into smaller components to simplify the algorithms. Transportation is categorized into four subcomponents: auto-mobile, aquatic, railway, and aviation. Energy consumption is divided into electricity, gas, and water consumption. Dietary emissions are categorized into food and beverages. Various algorithms will be employed in different subsections, ensuring a loosely coupled structure that enhances accuracy.**

Keywords*—Carbon Emission, Carbon Footprint, Emission Factor, Layered Architecture

I. INTRODUCTION

Carbon footprint is a metric that measures the amount of greenhouse gases emitted by an individual, organization, or community. It is expressed in metric tons of carbon dioxide equivalent (MT CO2e), which is a measure of the global warming potential of different greenhouse gases [7]. Carbon footprint can be used to track progress in reducing greenhouse gas emissions and to identify areas where emissions can be reduced. However, since this study considers smaller personal carbon emissions other than industrial level kilograms of carbon dioxide (CO2KG) is used as the standard unit [7]. It is important to understand the impact of individual carbon emissions and why it matters. The carbon footprint is an indicator of the amount of greenhouse gases emitted from an activity.

The earth needs warmth for its life to survive. During the daytime, the earth gets its warmth from the sun. While the earth absorbs the heat from the sun up to some extent it reflects most of it. According to the studies that have been carried out, the nighttime should be very cold without the heat from the sun making it very hard for the living species to survive. So, what is stopping the earth from becoming cold at night, the answer is the greenhouse effect. The greenhouse effect is a natural process that occurs in the Earth's atmosphere. This greenhouse gas layer has a significant impact on the earth. It is one of the reasons why the earth is suitable for life. The primary energy source of the earth is the sun. Without it, it is not possible to have life on the earth. but the sun emits different types of harmful solar radiation and heat radiation as well. Greenhouse gases absorb or reflect these unsuitable radiations preventing them from entering the earth. It acts as an invisible filter. Other than filtering the radiation, greenhouse gases act as a cover that traps heat from the sun in the earth's atmosphere preventing the earth from becoming very cold at night. It plays a major role in filtering solar radiation and maintaining the temperature.

Even though a greenhouse is a very significant and necessary phenomenon increased thickness of this layer can introduce a whole new set of problems. The solar heat cannot escape from the ticker greenhouse layer resulting in increased global temperature. Global warming has its own consequences such as ice melting, rising sea level and coastal floods, extreme weather conditions, disruption of ecosystems, food and water insecurity, health impacts, etc. these problems link one to another, so it is necessary to find the root cause of these issues and find a solution. Climate risks of 0.5-degree change in global temperature are illustrated in figure 1. Even though 0.5 Celsius seems like a very little value it is clear how it affects living species.

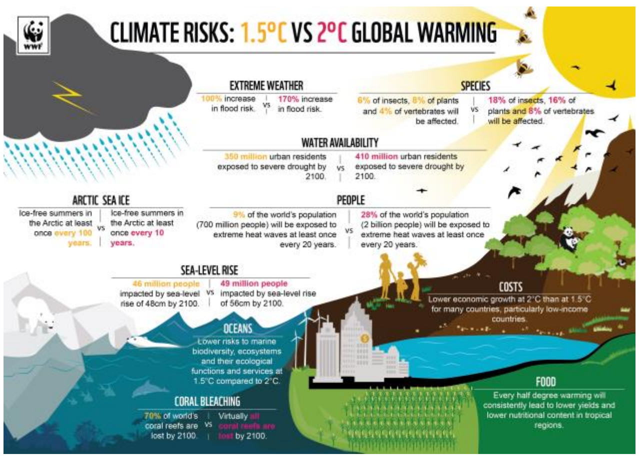

Fig. 1. Climate risks of global warming source: [10]

Being a sub-component of wider research of implementing a technological solution for climate resilience and disaster preparedness, this research component focuses on awaking people about personal carbon emissions and their impact while developing a simple and easier way to calculate personal carbon emissions motivating them to adhere to a low-carbon lifestyle.

II. Literature Review

A. History of Carbon Footprint

The carbon footprint concept is a newer version of the ecological footprint concept, which was developed in the early 1990s by Canadian ecologist William Rees and Swiss-born regional planner Mathis Wackernagel at the University of British Columbia. The carbon footprint concept focuses specifically on the emissions of greenhouse gases, while the ecological footprint concept takes into account a wider range of environmental impacts. [2]

Since the early 20th century, scientists and researchers have been studying how greenhouse gases influenced the Earth's atmosphere. However, it was not until the latter half of the 20th century that the phrase" carbon footprint" became well-known. As concerns over climate change increased and the necessity to measure individual and public carbon emissions became clear, the phrase gained popularity in the early 2000s. The concept was first applied to determine how human activity affected the environment, especially regarding energy usage, transportation, and industrial operations. Governments, corporations, and people began using carbon footprint analysis as a technique to analyze and minimize their contributions to greenhouse gas emissions when climate change became a major worldwide concern. Since then, the carbon footprint has transitioned from a phrase used mainly by scientists and environmentalists to one generally accepted as an essential statistic for analyzing sustainability and encouraging environmentally friendly behavior in a wide range of industries.

B. Problems with Existing Solutions

As climate change becomes a main topic in social media as well as governments and large-scale companies trying to reduce their carbon footprint, a timely solution to educate people and calculate their carbon footprint is necessary. Even though many platforms allow users to keep track of their carbon footprint, there are common missing key features on most of them.

One of the main missing key features can be identified as a lack of guidance. Most existing carbon footprint calculator platforms don't provide users with enough information to help reduce their carbon footprint because they are limited to only calculating carbon emissions. Researchers and developers put so much time and effort into building an accurate carbon footprint calculator, but the results of that process are meaningless if the platform doesn't guide and motivate users to reduce carbon emissions.

Another major flaw of existing carbon footprint calculators can be identified as overly completed calculation processes and not user-friendly designs. Considering the calculations used in existing carbon footprint calculators, it is clear that only simple multiplications, divisions, and additions are used to calculate them. In the standard approach, the users are expected to enter various values, and those inputs are applied to standard equations to get the output. The problem with this approach is that users are expected to memorize the exact numerical values such as liters of petrol burnt. Realistically humans are not naturally programmed to memorize such values, so they have to make an effort to either memorize or note down those values which is not a convenient or user-friendly method to do such tasks.

Although directly depending on the users to enter exact numerical values leads to an accurate result in calculating the carbon footprint it is worth compromising the accuracy to develop an algorithm to predict those values considering the massive positive change it makes on the user experience and convenience. With the advancement of information technology, it is necessary to apply modern technologies to make a positive impact on the planet.

C. Main Objectives of This Research

This research component focuses on those two main goals, educating individuals about climate change and developing a comprehensive solution to replace the existing complicated carbon footprint calculating process. Combining these two main goals, two in one solution can be introduced as a web or mobile application where users will have the convenience of a modern application and modern technologies such as artificial intelligence, image processing, and deep learning can be used.

III. Methodology

A. Conventional Carbon Footprint Calculation Methods

Several methodologies can be used to calculate the greenhouse gas emission associated with human activities. These techniques include both individual and industrial scales. And consider various factors with different accuracy and complexity levels. The "Emission inventory" method is a common carbon footprint calculation method that can be calculated by collecting data on energy consumption, transportation, industrial activities, and waste management and converting it into CO2 equivalent using emission factors. The emissions factor is a value of how much CO2 will be emitted into the atmosphere by a single unit of its category, for example Burning 1 L of gasoline produces approximately 2.3 kg of CO2 into the atmosphere. The value 2.3 is the emission factor of burning gasoline. Furthermore, the total CO2 emitted canbe calculated using the following equation "(1)". [3]

$$E_x = EF_x \cdot Q \tag{1}$$

- Ex = Emissions of pollutants x
- EFx = Emission factor of pollutant x
- Q = Activity or production rate.

There are several other methods to calculate carbon emission such as the "input-output analysis" method which considers the flow of products and services to estimate their carbon emission throughout the economy. The" life cycle assessment"method considers the entire life cycle of products and services including their production, use, and disposal stages to estimatethe overall carbon emission through their life cycle. The usageof these methods depends on the situation and the scope ofthe calculation process. Each method has its limitations and accuracy levels. So, it is important to have a common ideaof these methods and apply the most suitable method to a particular scenario based on the limitations, and requirements.

B. Challenges with Conventional Approaches

The main methods for determining carbon footprints, from individual to industrial contexts, have been traditional approaches for decades. These traditional methods are still widely used, yet they still have a lot of problems that might make them less useful and effective.

One of the key drawbacks comes from their heavy reliance on numerical values. When the right data is supplied, this can result in great accuracy, but it also presents a challenge because individuals frequently have trouble properly recalling complicated numerical inputs. This makes human mistakes more likely, regardless of how accurate the equation is. The problem, however, mostly is caused by the way that most programs are developed, which strongly relies on user inputs and applies them directly to the equation, eventually reducing user-friendliness. A more relevant strategy would be to streamline data entry while still taking into consideration a wide variety of variables affecting carbon footprints in order to improve these estimations.

C. Design and Development of a Less Numerical Solution

There are several ways to increase the user experience by reducing the exact numerical inputs required by the user. The simplest approach Is to estimate the values without changing the equation itself. As an example, if a user traveled 10 kilometers by car, we could calculate the emission of that commute by multiplying the volume of fuel burned by the emission factor of the fuel type.

Carbon Emission = fuel burned(liter) * emission factor (CO2 per liter)

$$C = V \cdot E \tag{2}$$

- C = CO2 Emission (kg)
- V = Volume of fuel burned (l)
- E = Emission Factor (kgl^{-1})

In this equation, the emission factor is a constant, and the fuel volume is the value that the user should enter to calculate the emission of the commute. Normally the user is required to know the value but practically it's harder to keep track of such variables all the time. Even though there is no need to change the equation it is necessary to find a more user-friendly way to get this value from the user. Instead of directly asking for the value it is more convenient to estimate it even though there will be a compromise in accuracy. Several methods can be used to estimate these values such as questioners chat-bots, IoT devices, etc. This research is focused on estimating the variables using a simple guided questionnaire. In this approach, the overall total carbon emission is divided into sub-categories such as transportation energy consumption, food, and industrial to use separate logic to estimate carbon emission. Transportation can be further classified into four main modes: road, rail, air, and sea. This categorization allows for a more optimized analysis of the transportation system itself to get more accurate output.

D. System Architecture

The proposed system will be developed using a three-tier architecture, which separates the presentation layer, application layer, and data layer. This architecture will allow for the system to be developed and maintained more easily, as wellas for it to be more scalable and secure.

The three-tier architecture of the system will consist of a presentation layer, an application layer, and a data layer. The presentation layer will be responsible for interacting with the user and displaying the system's interface. It will be implemented using HTML, CSS, and JavaScript. The application layer will be responsible for processing user requests and interacting with the data layer. It will be implemented using Python. The data layer will be responsible for storing and retrieving data from a database. It will be implemented using MongoDB.

The system will be developed as a progressive web application (PWA), which will allow users to access it using a variety of devices, including smartphones, tablets, and computers.PWAs are web applications that are installed on the user's device and can be used offline. This makes them ideal for use in environments where there is limited or unreliable internet connectivity.

The system will be developed using the Model-View-Controller (MVC) architectural pattern. This pattern divides the application into three components: the model, the view, and the controller. The model is responsible for storing and managing the application's data. The view is responsible for displaying the data to the user. The controller is responsible for receiving user input and updating the model. This pattern makes the application more modular and easier to maintain. It also offers several other advantages, such as increased scalability, security, portability, and reusability.

Overall, the three-tier architecture and MVC pattern are well-suited for the development of the proposed system. They will allow for the system to be developed and maintained more easily, as well as for it to be more scalable and secure.

E. Algorithm Design and Implementation

The algorithm takes as input the distance traveled, and the vehicle type. It then uses this information to estimate the fuel efficiency of the vehicle, fuel type, the total fuel burnt, and the emission factor. The algorithm can be modified to include other factors that affect fuel efficiency and emission factors, such as road conditions, weather, and driver behavior. The algorithm is a significant improvement over previous methods for calculating carbon emissions from transportation, and it is more reliable, and user-friendly. This algorithm will make it easier for people to calculate their carbon emissions from transportation and make more sustainable transportation choices. the user interaction flow and the sample logic are illustrated in figure 2

F. User Experience

Comparatively higher user satisfaction is expected from this research compared to the conventional approach. The proposed system is expected to provide a number of features that will improve user satisfaction compared to the conventional approach. These features include:

- A question-based user interface (UI) that is easy to use and understand.
- The ability to generate reports and see real-time statistics of carbon emissions over time.
- Personalized carbon reduction guidelines based on user results.

The question-based UI is expected to be more user-friendly than the conventional approach, which often requires users to input complex data. The question-based UI will allow users to simply answer a series of questions about their lifestyle and habits, and the system will automatically calculate their carbon footprint.

The ability to generate reports and see real-time statistics of carbon emissions over time is expected to be a valuable feature for users who want to track their progress and make informed decisions about reducing their carbon footprint. The reports will provide users with a detailed breakdown of their emissions, and the real-time statistics will allow users to see how their emissions change over time. The dashboard UI is illustrated in Figure 3.

The personalized carbon reduction guidelines are expected to be a helpful tool for users who want to make changes to their lifestyle in order to reduce their carbon footprint. The guidelines will be tailored to each user's individual needs and circumstances, and they will provide users with specific suggestions for how they can reduce their emissions.

Overall, the proposed system is expected to provide a number of features that will improve user satisfaction compared to the conventional approach. These features are expected to make the system more user-friendly, informative, and helpful for users who are interested in reducing their carbon footprint.

G. User Interaction Flow

The carbon emissions calculator component is part of a larger research project that aims to provide an all-in-one solution for climate resilience and disaster preparedness. The calculator can be accessed from the home page or navigation bar.

The first user interface (UI) that users interact with is the dashboard, which is illustrated in Figure 3. The dashboard provides users with a summary of their carbon emissions, as well as tips and tricks on how to reduce them. Users can also choose to calculate their carbon emissions or visit the tips and tricks page from the dashboard.

When users choose to calculate their carbon emissions, they are first asked to choose one of three methods: quick, average, or advanced. Each method considers different areas of a user's lifestyle and takes a different amount of time to complete. A comparison of the three methods is given in Table I.

TABLE I
COMPARISON OF CARBON EMISSIONS CALCULATOR METHODS

Method	Area considered	Estimated time to complete
Quick	Transportation, energy consumption	5 minutes
Average	Transportation, energy consumption, diet	10 minutes
Advanced	Transportation, energy consumption, diet, travel, waste, lifestyle choices	30 minutes

After choosing a method, users are asked to answer a series of questions about their lifestyle and habits. The system then uses the answers to these questions to calculate the user's carbon emissions. The results are displayed in a user-friendly format that allows users to see where their emissions are coming from and how they can reduce them.

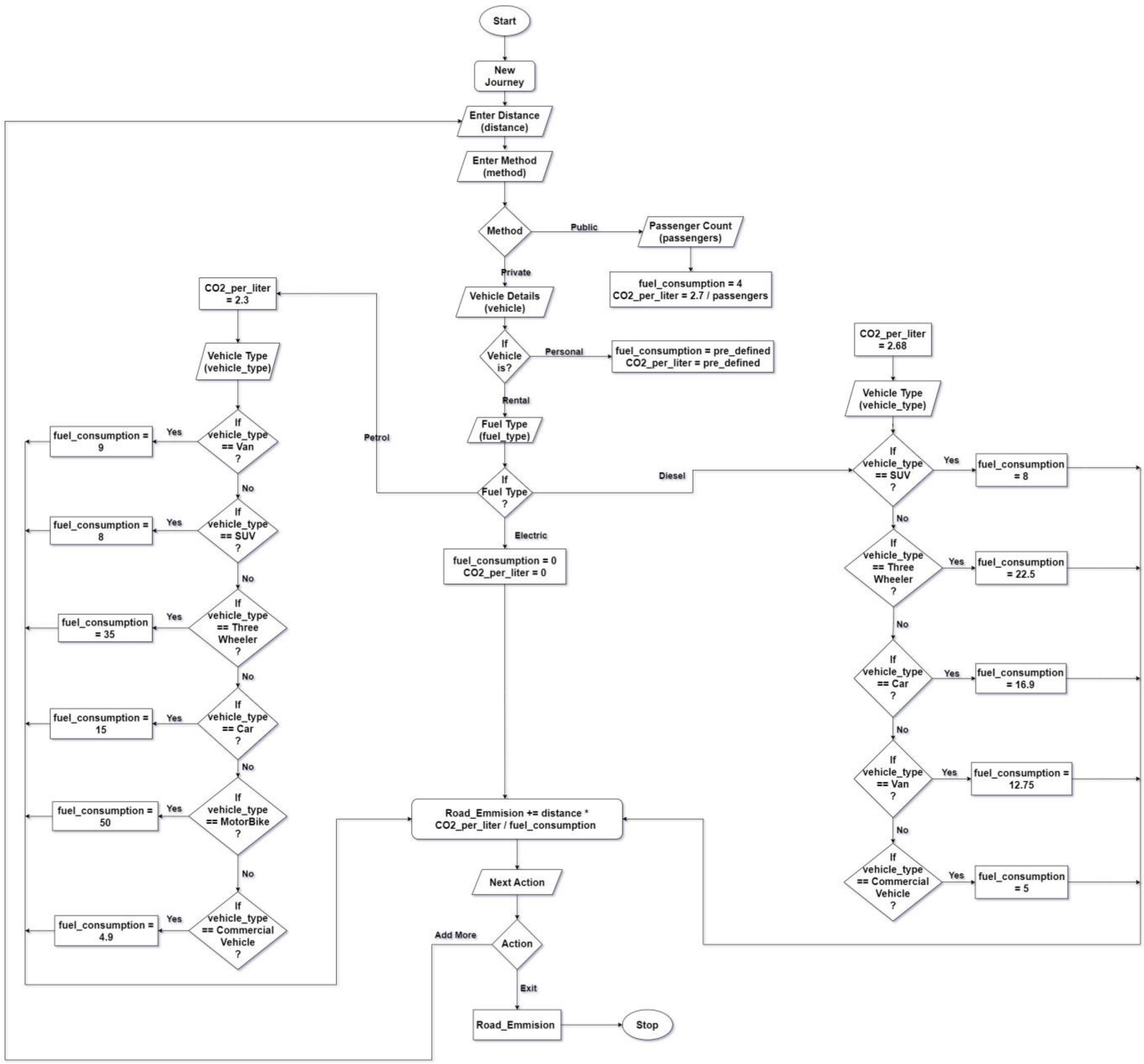

Fig. 2. Estimation logic

IV. Results and Discussions

A. Comparison with Conventional Methods

The proposed algorithm is a good compromise between accuracy and convenience. It is more accurate than previous methods that require users to know the fuel efficiency of their vehicle. However, it is not as accurate as the conventional method, which requires users to manually enter the fuel efficiency. The proposed algorithm is more convenient and user-friendly, which will lead to more people using it and therefore more accurate estimates of carbon emissions overall.

The slight loss of accuracy is manageable because carbon footprint calculation is not a critical calculation. Carbon footprint is not used to make decisions that could have life-or-death consequences. Therefore, a slight error in carbon footprint calculation is not a major concern.

a comparison between known value and estimation is illustrated below.

Actual Value (Known Values):

- Vehicle Type = Car
- Fuel Type = Petrol
- Distance = 10 km
- Fuel Consumption = 12 kmpl
- Emission Factor of Petrol = 2.3 CO_2 per Liter
- Emission (Actual) = 1.91 CO_2

Estimation:

- Vehicle Type = Car (Selection)
- Fuel Type = Petrol (Selection)
- Distance = 10 km (Input)
- Fuel Consumption = 15 kmpl (Estimation)
- Emission Factor of Petrol = 2.3 CO_2 per Liter (Estimation)
- Emission (Estimated) = 1.53 CO_2

$$\text{Accuracy} = (1.53 / 1.91)\ \% = 80\%$$

B. Limitations and Future Directions

Trending technologies like IoT and machine learning can significantly boost the precision of carbon emission calculations. IoT sensors capture real-time vehicle data, allowing ma- chine learning algorithms to predict emissions and offer personalized guidance. For example, the algorithm might suggest a more efficient route if it anticipates a user running late for work. GPS location data helps accurately calculate commutes, minimizing emissions by recommending less congested routes. These enhancements extend to areas like diet, energy consumption, and waste management. IoT sensors monitor food and energy usage, with machine learning identifying patterns for emission reduction. The algorithm may highlight high- carbon-footprint foods and propose eco-friendly alternatives. Similarly, for energy-intensive appliances, it suggests more efficient usage. Refining carbon emission calculations through IoT and machine learning empowers individuals to make informed lifestyle decisions, reducing their carbon footprint. Future research can explore advanced concepts for further enhancement.

V. Conclusion

This research paper addresses the challenge of calculating individual carbon footprints through a user-friendly algorithm that eliminates the need for precise numerical inputs. In the context of escalating environmental concerns, the proposed solution prioritizes user experience by offering a streamlined, question-based interface, real-time statistics, and personalized reduction guidelines. The research emphasizes the importance of understanding carbon emissions' impact on climate change and the need for accessible tools to motivate sustainable lifestyle choices. While the proposed method may entail a slight compromise in accuracy, its convenience is expected to foster greater user engagement and behavior change. The paper also suggests the future integration of emerging technologies like IoT and machine learning to enhance accuracy and broaden the scope of carbon reduction efforts. In sum, this research contributes to encouraging a low-carbon lifestyle by combining technology, user experience, and environmental awareness.

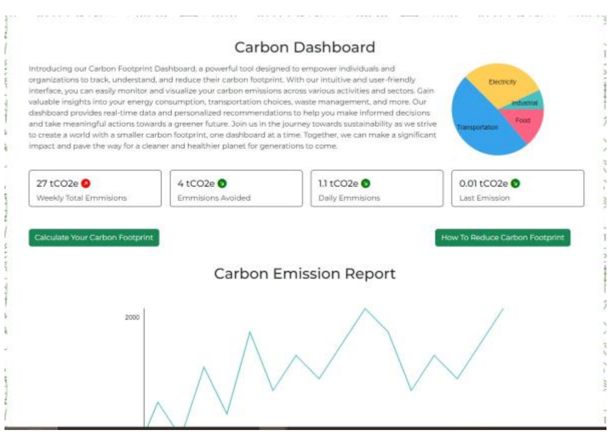

Fig. 3. Carbon emission dashboard

Acknowledgment

The researchers extend heartfelt appreciation to Dr. Samantha Rajapaksha, their esteemed project supervisor, for in- valuable guidance and motivation. Ms. Jenny Krishara, the co-supervisor, receives thanks for crucial insights during the research planning phase. The CDAP panel's guidance significantly shaped the project. A special thanks goes to research project leader Peiris W.O.A and fellow group members for their contributions. This collective effort led to the successful completion of the research. The researchers express gratitude to all, acknowledging the collaborative spirit and shared commitment that enriched the overall experience.

References

[1] Sands, L. (2023) This July 4 was hot. Earth's hottest day on record, in fact., The Washington Post. Available at: https://www.washingtonpost.com/climate-environment/2023/07/05/hottest-day-ever-recorded/ (Accessed: 18 July 2023).

[2] Carbon footprint (2023) Encyclopædia Britannica. Available at: https://www.britannica.com/science/carbon-footprint (Accessed: 20 July 2023).

[3] N. P. Cheremisinoff, "Pollution Management and Responsible Care," Waste: A Handbook for Management, pp. 487–502, Jan. 2011, doi: 10.1016/B978-0-12-381475-3.10031-2.

[4] S. Shi and J. Yin, "Global research on carbon footprint: A scientometric review," Environ Impact Assess Rev, vol. 89, p. 106571, Jul. 2021, doi: 10.1016/J.EIAR.2021.106571.

[5] M. C. Jones, M. J. Scott, and D. J. Reiner, "Carbon Footprint Calculators: A Review of the Literature," Environmental Science and Technology, vol. 50, no. 11, pp. 5731-5743, 2016.

[6] H. Ritchie, M. Roser, and P. Sola-Olmo, "Assessing the Accuracy and Usability of Carbon Footprint Calculators," Environmental Research Letters, vol. 11, no. 12, p. 124002, 2016.

[7] S. E. West, S. A. Myhre, and T. Dietz, "Developing a User-Friendly Carbon Footprint Calculator for Individuals," Environmental Science and Technology, vol. 52, no. 20, pp. 10111-10119, 2018.

[8] D. J. Reiner, M. C. Jones, and M. J. Scott, "The Carbon Footprint Calculator Landscape: A Review of Existing Tools and Recommendations for Future Development," Environmental Science ans Technology, vol. 54, no. 24, pp. 13288-13299, 2020.

[9] H. Ritchie, M. Roser, and P. Sola-Olmo, "Assessing the Impact of Carbon Footprint Calculators on Individual Behavior," Nature Climate Change, vol. 10, no. 12, pp. 1124-1128, 2020.

[10] "Why we need to rethink geo-economics to beat climate change," World Economic Forum, Dec. 12, 2019. https://www.weforum.org/agenda/2019/12/climate-change-and-international-relations-economics/ (accessed Nov. 27, 2023).