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Original Article

Development of a Mobile Application with a Virtual Assistant for Sustainability and Carbon Footprint Reduction

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Abstract - *Sustainability and carbon footprint reduction are crucial challenges. According to the IPCC, reducing these emissions by at least 45% is essential to keep global warming within a safe limit of 1.5°C and avoid an increase of up to 2.7°C by the end of the century. In response to this issue, the Sustainable Development Goals have been adopted, especially SDG 13, which promotes urgent action on climate change. This research presents a prototype mobile application that integrates Artificial Intelligence (AI)-based virtual assistants, playing a key role in promoting sustainable practices, raising awareness of environmental impact, and managing CO_2 emissions. Through emerging technologies and real-time data analysis tools, the application allows users to assess their carbon footprint and implement effective mitigation strategies. The app was implemen ted using the Mobile-D agile methodology, focusing on technical efficiency and user satisfaction. The evaluation results revealed averages of 4.04 and 4.07, respectively, indicating satisfactory performance in its objective.*

Keywords - *Mobile application, Sustainability, Carbon footprint, Artificial Intelligence, Efficiency.*

1. Introduction

The planet is facing different changes caused by climate change, which manifests itself in extreme phenomena such as heat waves, floods and droughts, causing serious impacts on ecosystems and human life [1]. According to the Intergovernmental Panel on Climate Change (IPCC), the planet is heading for a temperature increase of at least 2.7 degrees Celsius by the end of this century if significant measures are not implemented [2]. This problem is driven by the increased CO_2 emissions recorded in the last two years.

According to the Global Carbon Project report, 36.8 billion tonnes of CO_2 will be reported in 2023, representing an increase of 1.1% compared to emissions in 2022 [3]. In addition, the United Nations Environment Programme (UNEP) reports that 2021 Global Greenhouse Gas (GHG) emissions were 60% above 1990 levels [4] . This increase is alarming, as the IPCC points out that these emissions need to be reduced by at least 45% to keep global warming within a safe limit of 1.5°C [5] Carbon dioxide (CO_2) is recognized as the main greenhouse gas resulting from human activities, which has increased by 50% in less than 200 years [6]. Although it is part of the Earth's natural carbon cycle, human interventions have significantly increased its presence in the atmosphere. This hurts the capacity of natural sinks to capture and store this gas [7]. This increase in CO2 has been remarkable since the Industrial Revolution, upsetting the balance of the carbon cycle. The global average carbon footprint is estimated at 4.8 tonnes of CO2 per person per year, while in developed countries this Figure can be as high as 12.3 tonnes per individual [8]. The World Resources Institute states that 76% of CO2 emissions come from countries such as China, Indonesia, the European Union, India, Russia, Japan, Iran, South Korea, Brazil, the United States, and the United Kingdom [9].

As a result, the World Health Organisation (WHO) indicates that 37% of deaths are attributed to climate change-related problems, which are largely caused by human activities [10]. Human activities have been identified as key drivers of climate change, as most global warming results from increased anthropogenic emissions of greenhouse gases [11]. People contribute to greenhouse gas emissions through their daily routines, mainly CO2. Despite numerous awareness campaigns and government efforts, there is a significant gap in the availability of customized, interactive and accessible digital tools to help people understand and reduce their carbon footprint [12]. Most existing tools are static calculators or educational resources that are not tailored to users' behavioral patterns or preferences. This reveals a critical gap in research on integrating mobile technology with Artificial Intelligence (AI) to personalize environmental guidance and encourage sustainable habits in real time [13].

Therefore, for individuals to effectively reduce CO2 emissions from their actions and improve their relationship with the environment, effective technologies and tools have been developed. A clear example is the study [14], which developed carbon footprint calculators that aim to estimate each person's carbon dioxide emissions so that they can take responsibility for mitigating them. The "Mau Carbon Footprint" proposal offers recommendations to improve environmental impact.

To achieve this goal, a usability study based on Nielsen principles was carried out, obtaining an overall average score of 3.98 for the usability of the proposed calculator. In addition, the research [15] developed a mobile application to raise awareness and reduce environmental impact, using the Cascada methodology. The results showed that 89% of users believe that the APP can help, and experts validated its features with an average of 81%. It is concluded that environmental education is key and should be a priority from childhood to university. On the other hand, recent research [16] highlights recycling as a key strategy to reduce environmental pollution.

The purpose was to develop a mobile application that would improve waste management in recycling companies. With the Mobile-D methodology, significant progress was achieved: a 114.29% increase in customer loyalty, a 39.92% reduction in response times, and an 86.86% increase in the volume of waste recycled. It was concluded that the implementation of the mobile app generated a favorable impact on the efficiency of industrial recycling. However, the study [17] developed the playful application DoItRight, aimed at children from 5 to 13 years old, to encourage environmentally friendly behavior.

The System Usability Scale (SUS) methodology was applied to measure the usability of the application. The results of this evaluation revealed a score of 93.25, demonstrating its high usability and its ability to raise awareness among children about responsible waste management. This led to the conclusion that the app is effective and can play an important role in raising environmental awareness among children. Similarly, the research [18] is primarily focused on the development of a mobile application that promotes environmental awareness and provides solutions for energy, pollution, and waste management in Bangladesh. The app includes features such as environmental blogs, event alerts, and a sustainable behavior verification system. The proposal managed to satisfy at least 74% of users in terms of usability and quality. This tool has the potential to empower the population to address environmental challenges and encourage the habit. However, none of these studies incorporated intelligent virtual assistants capable of dynamically interacting with users through natural language and real-time feedback. Moreover, few of them provide longitudinal tracking of behavioral improvements or personalized AI-based interventions [19]. Thus, the novelty of this research lies in the integration of a mobile application with an AI-based virtual assistant, which provides personalized recommendations, daily environmental tips, motivational cues, and user footprint tracking. This innovation addresses the current lack of mobile environmental tools by merging usability, personalization and real-time communication, with the aim of reinforcing the population's capacity to act in a sustainable way.

In that sense, this research aims to create a prototype mobile application that includes a chatbot based on artificial intelligence, oriented towards sustainability and carbon footprint reduction. To raise awareness, provide recommendations, and motivate the population to take action to address environmental problems. In addition, it aims to assess the impact of this technology on experts and users as a tool to mitigate current and future environmental consequences. By combining mobile development methodologies, machine learning techniques and environmental data integration, this study hopes to contribute significantly to sustainable digital technologies and behavioral change.

This article is organized into four main sections: the first is the introduction, followed by a detailed description of the methodology used, covering the fundamental concepts, the design of the software, and the identification of the target population. The third section highlights the application development process's architecture and functionalities. Finally, the results obtained, as well as the discussions and conclusions of the study, are presented.

2. Methodology

The Mobile-D methodology is presented as an agile approach designed for mobile application development in small teams. It is based on iterative cycles that include five phases: exploration, initialization, development, stabilization, and testing [20].

This methodology enables the delivery of functional products in less than ten years by integrating effective development practices in a collaborative environment [21]. Figure 1. details the phases that make up this composite methodology.

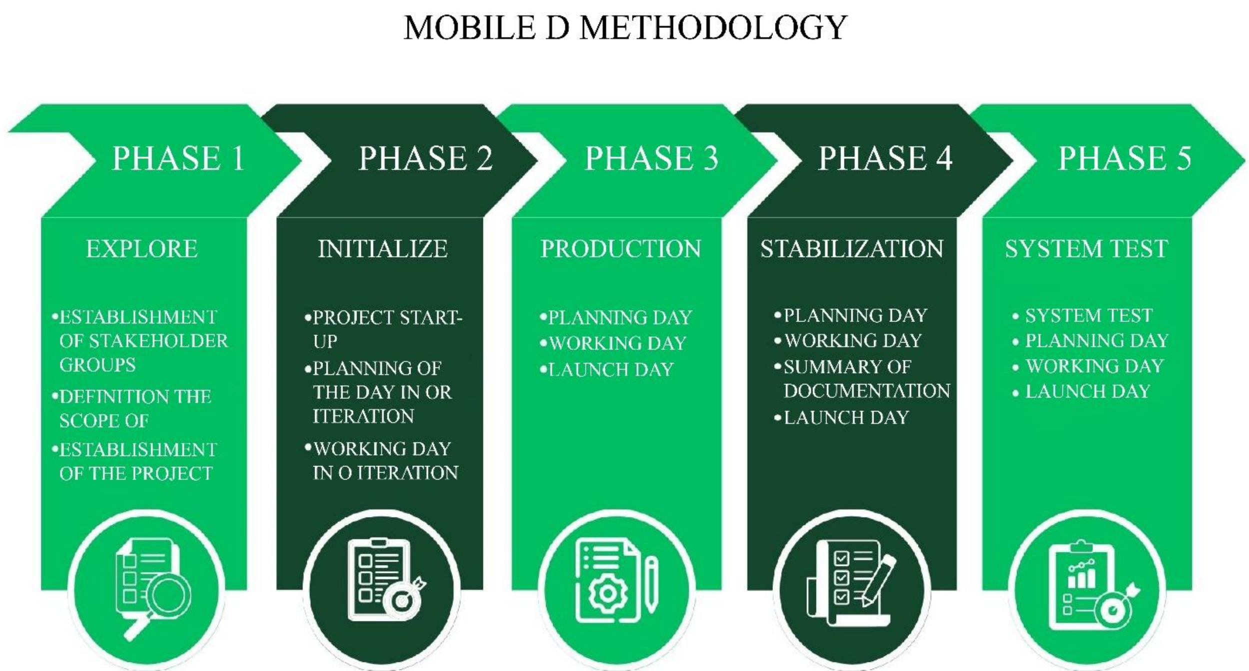


Fig. 1 Phases of the mobile-D methodology

2.1. Exploration

This phase involves generating an initial plan to identify stakeholders, define the scope of the project, and establish key processes, ensuring effective planning for the development of the project [22].

2.2.1. Stakeholders Include

- Target group: Manufacturing companies, government agencies, investors and sponsors.
- Application users: Small and medium-sized manufacturing companies.
- Developers: Technical project team

2.2. Initialisation

The initialization phase in the Mobile-D methodology focuses on guaranteeing the success of the subsequent phases of the project by preparing the necessary physical, technical, and human resources. It includes the establishment of the project and a clear initial planning, ensuring a solid basis for its development [23].

2.2.1. Hardware

- Laptop: Intel i5/Ryzen 5+ Processor
- Mobile devices: Android and iOS with 64 GB storage.

2.2.2. Software

- Wasapi. - It is a platform that optimizes the WhatsApp API with Artificial Intelligence to automate and personalize business communications [24].
- Chatgpt. – It is a conversational artificial intelligence model designed to answer questions, admit errors, question assumptions, and follow detailed instructions, optimized for improvement through user feedback [25].
- Firebase. - Facilitates the development of modern applications with AI tools, trusted by millions of enterprises globally [26].
- PostgreSQL. - It is an open-source relational database system, renowned for its reliability, performance, and robustness in data management [27].
- Flutter. - It is a Google SDK for building cross-platform mobile, web, and desktop applications with native performance. It stands out for its flexibility in interfaces, speed of development, and direct compilation capacity for Android and iOS [28].
- Python. - It is a versatile and easy-to-learn programming language, widely used in web development, software, data science, and machine learning. It is free, compatible with multiple platforms, and facilitates agile and efficient development [29].

2.3. Production

The architecture is presented in Figure 2. illustrates the design of the mobile application developed as a virtual assistant for sustainability and carbon footprint reduction in the industry.

The architecture presented for developing a mobile application with a virtual assistant is based on Flutter as the main framework to ensure a cross-platform and flexible design. Firebase is used as a backend to manage real-time data, authentication, and analytics, while Python integrates advanced functions, such as sustainability-related calculations.

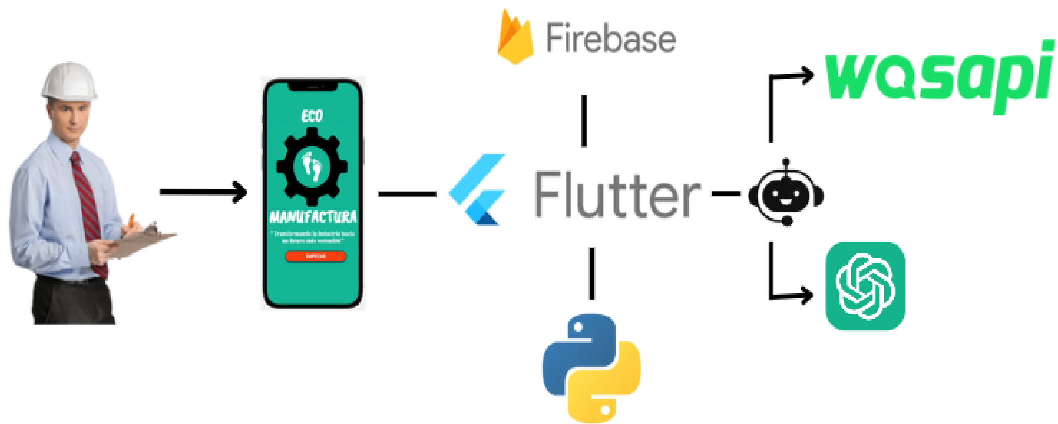


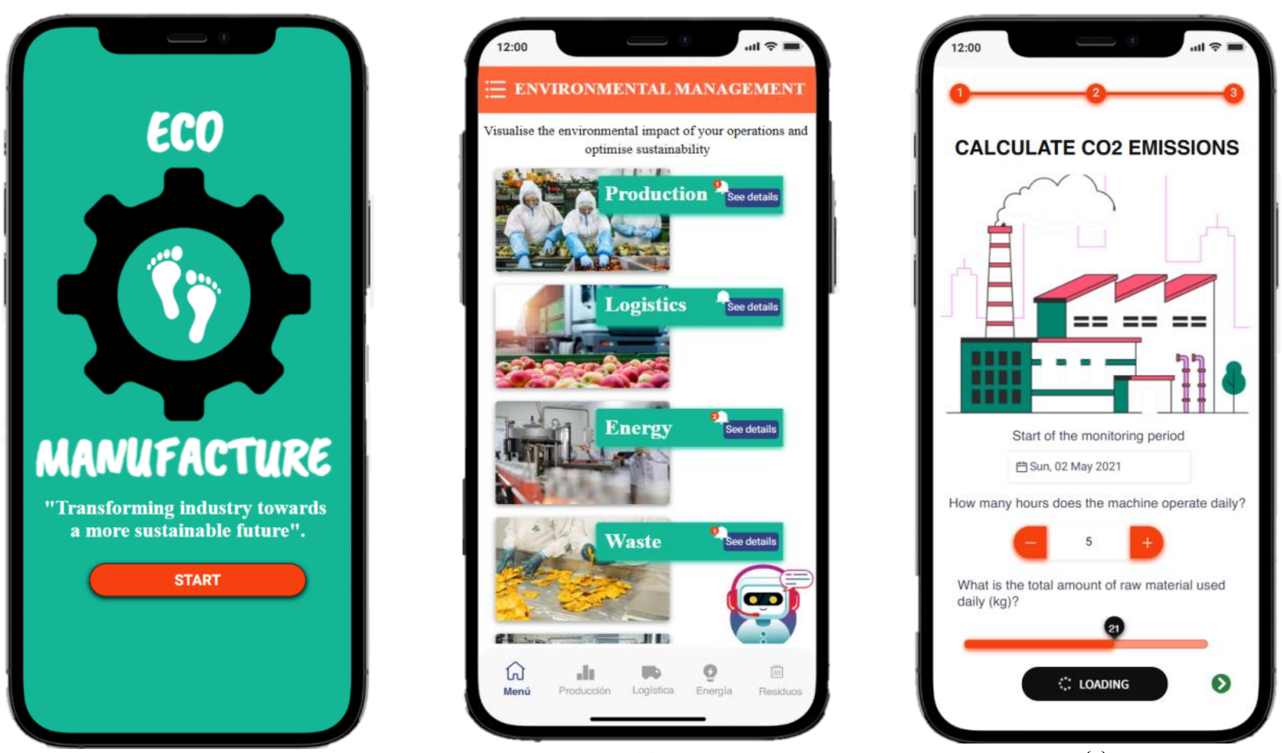
Fig. 2 Project architecture

In addition, the virtual assistant, powered by OpenAI (ChatGPT), interacts with users by providing personalized recommendations to reduce the carbon footprint. Finally, WASAPI connects to the system to provide relevant external data, such as environmental information, complementing the application's functions to encourage sustainable practices.

2.4. Stabilisation

The interfaces of the application are visualized below.

The interfaces presented reflect a holistic approach towards sustainability in the manufacturing industry. Figure 3 shows the user interfaces for green management in manufacturing. Figure 3 (a) is the login screen, which includes a motivational design with a symbolic logo and a sentence highlighting the importance of responsible practices, inviting the user to get started. Figure 3 (b) is the main menu that organizes the company's key areas, such as production, logistics, energy, and waste, allowing intuitive navigation and access to an interactive chatbot for real-time support. Finally, the CO_2 emissions calculation screen visualized in Figure 3 (c) offers a practical tool to measure the environmental impact of operations through input data, combining an educational visual design with interactive functionality.

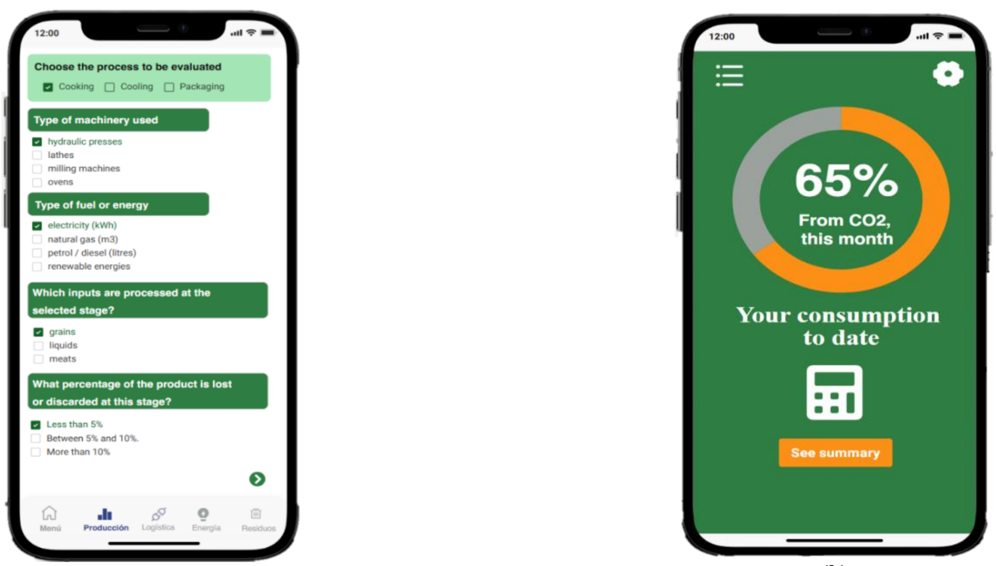


(a) (b) (c)

Fig. 3 Green management in manufacturing: (a) Welcome screen, (b) Green management main menu, and (c) CO_2 emissions calculation tool.

In Figure 4, the interfaces for the monitoring and evaluation of environmental impacts in industrial processes are shown. Figure 4(a) presents an interface for selecting and evaluating specific processes within manufacturing, such as cooking, cooling, or packaging. It includes detailed options on the type of machinery used, the source of energy or fuel, the inputs processed, and the percentage of product loss or waste at each stage. On the other hand, Figure. 4(b) shows a visual summary of the environmental impact, specifically the percentage of CO_2 emissions accumulated in the month, accompanied by a pie chart that facilitates a quick understanding of the Consumption.

It also includes a button to access a detailed summary, oriented towards sustainable decision-making. Figure 5 visualizes the user's conversation with the chatbot. In Figure 5(a), the chatbot identifies key areas to work on sustainability and suggests actions such as preventive maintenance and automation. Figure 5(b), analyses energy data and presents a breakdown in a graph, offering specific recommendations to reduce Consumption. Figure 5(c), analyses an archive of historical data, highlights key findings, proposes solutions such as solar panels, and shows the impact on emissions and costs, providing links to further information.



(a) (b)

Fig. 4 Environmental impact monitoring and assessment: (a) Process assessment, and (b) Environmental impact summar.

(a) (b) (c)

Fig. 5 Chat with the chatbot: (a) Selection of areas, (b) Energy diagnosis, and (c) Optimisation plan.

2.5. System Testing

For the application's evaluation, 10 experts from various universities in Peru and 20 users who play roles as managers, supervisors, or managers in manufacturing companies participated, to improve sustainability in their organizations. It was carried out through a Likert scale addressed to experts and users, respectively; the evaluated criteria are shown in Tables 1 and 2.

Table 1 details the evaluation criteria for experts, grouped into Design, Security, and Innovation. These criteria address aspects such as visual consistency, clarity, data control, reliability, and innovative functionalities related to sustainability. Table 2 presents the questions addressed to users, evaluating aspects related to the criteria of efficiency, functionality, and usability, with the aim of analyzing their experience and perception of the use of the application.

Table 1. Expert assessment criteria

Criteria	Aspects
Design	Is the visual interface intuitive and consistent throughout the application?
	Are the design elements (buttons, menus, icons) organized in a logical and accessible way?
	Do typography, colors, and design styles support clarity and legibility?
Security	Does the application allow you to control what data you share and how it is used?
	Do you consider the connections between the app and the servers to be secure and reliable?
	Do you feel the app will notify you quickly in case of a security problem?
Innovation	Does the app motivate you to take actions that positively impact sustainability?
	Do you find the chatbot provides useful and relevant answers to your sustainability queries?
	Do you consider the app's functions to be unique or different from other sustainability-related apps?

Table 2. Evaluation criteria by users

Criteria	Aspects
Efficiency	Does the application load the sections and functions you use quickly?
	Do you feel the application runs smoothly on your device without interruptions or crashes?
	Does the application respond quickly to any action?
Functionality	Do you find the features available in the app useful for your sustainability-related goals?
	Do you feel the application covers all your needs to carry out sustainable actions?
	Did all the functions you used within the application work correctly?
Usability	Do you find it easy to understand how to use the tools and sections of the application?
	Does the layout of buttons, menus, and options make the application easy to navigate?
	Do you consider the application's visual design (colors, typography, icons) to be pleasant and easy to understand?

3. Results

This phase presents the findings obtained during the validation process, which aimed to ensure that the design and functionality of the application met the standards of usability, accessibility, and end-user satisfaction. The validation was carried out through expert and user evaluation, using quantitative tools such as Likert scales and qualitative analysis based on observations. The results obtained from the validation with experts are detailed below.

3.1. Expert Validation

Validation by 10 experts yielded an average score of 4.04 on a Likert scale, indicating a positive rating of the design and organization of the application. The results confirm that the design complies with usability principles, although opportunities for improvement were identified, such as greater customization of the interactive elements. Figure 6 shows an overall positive assessment of the app in three key categories: Design, Security, and Innovation. The table shows that security scored the highest, with an average of 4.40 in the perception of trust, standing out as the strongest aspect.

In contrast, with an average of 3.50, innovation presents greater variability and opportunity for improvement, especially in the differentiation of its functions. The three-dimensional graph reinforces this perception, showing that most of the evaluations are concentrated at high levels ("high" and "very high"), although with room for optimization in specific areas such as design organization and innovative utility. Overall, the app meets the expected standards but still has room for improvement in terms of functionality and originality.

Table 3. Validation by expert judgement

Criteria	Aspects	Media	D.E	Quality
Design	Is the visual interface intuitive and consistent throughout the application?	3.90	0.99	High
	Are the design elements (buttons, menus, icons) organized in a logical and accessible way?	3.80	0.92	High
	Do typography, colors, and design styles support clarity and legibility?	4.30	0.82	Very high
Security	Does the application allow you to control what data you share and how it is used?	4.40	0.52	Very high
	Do you consider the connections between the app and the servers to be secure and reliable?	3.90	0.57	High
	Do you feel the app will notify you quickly in case of a security problem?	4.00	0.94	Very high
Innovation	Does the app motivate you to take actions that positively impact sustainability?	4.50	0.71	Very high
	Do you find the chatbot provides useful and relevant answers to your sustainability queries?	3.80	0.42	High
	Do you consider the app's functions to be unique or different from other sustainability-related apps?	3.80	0.63	High
Total		**4.04**	**0.72**	**Very high**

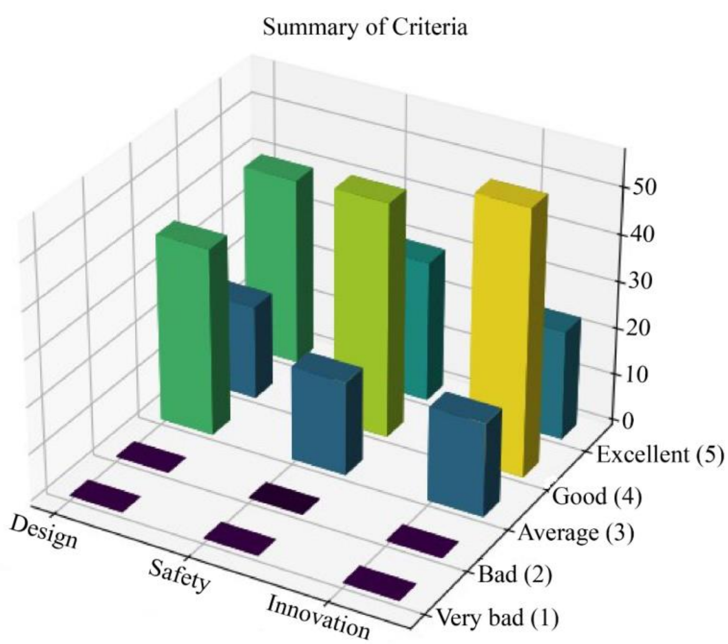


Fig. 6 Expert evaluation

3.2. User Validation

20 users were considered, including managers, supervisors, and managers in charge of reducing the carbon footprint in manufacturing companies, considering the criteria of efficiency, functionality, and usability. A total average of 4.07 was obtained, which means that it is of high quality.

Figure 7 shows that the majority of user evaluations are concentrated in the "good" and "excellent" levels, especially in the functionality and usability categories, which stand out as the highest rated. This indicates that users perceive that the application meets their needs and facilitates a pleasant and efficient user experience.

The efficiency category also shows a positive rating, albeit with a slight variability, suggesting opportunities for improvement in areas such as loading speed and fluidity on devices.

Overall, the results reflect a favorable perception of the application, with solid performance in functionality and usability, but with specific areas for improvement.

Table 4. Validation by users

Criteria	Aspects	Media	D.E	Quality
Efficiency	Does the application load the sections and functions you use quickly?	4.00	0.92	High
	Do you feel the application runs smoothly on your device without interruptions or crashes?	4.00	0.97	High
	Does the application respond quickly to any action?	4.20	0.89	Very high
Functionality	Do you find the features available in the app useful for your sustainability-related goals?	4.10	1.02	Very high
	Do you feel the application covers all your needs to carry out sustainable actions?	4.00	1.03	Very high
	Did all the functions you used within the application work correctly?	4.15	0.88	Very high
Usability	Do you find it easy to understand how to use the tools and sections of the application?	4.05	0.76	Very high
	Does the layout of buttons, menus, and options make the application easy to navigate?	4.10	0.97	Very high
	Do you consider the visual design of the application (colors, typography, icons) to be pleasant and easy to understand?	4.00	0.79	High
Total		**4.07**	**0.91**	**Very high**

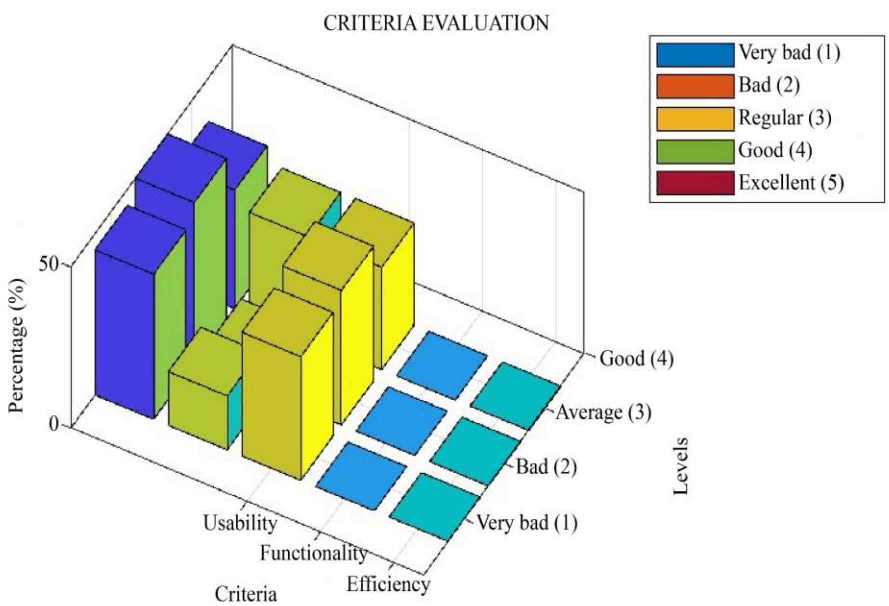


Fig. 7 User evaluation

4. Simulation of Environmental Impact

To estimate the potential environmental impact of the proposed application, a simulation was carried out using realistic energy consumption data from a medium-sized manufacturing company located in the city of Lima (Peru). The company selected for the simulation operates five days a week in a facility with an average monthly energy consumption of 15,000 kWh, distributed in three main areas: production (55%), air conditioning (25%) and lighting (20%). National energy mix data shows that each kilowatt-hour consumed emits approximately 0.33 kg of CO_2, resulting in an average monthly emission of 4.95 tons of CO_2.

Table 5. Initial conditions

Area	Monthly Consumption (kWh)	Emission Factor (kg CO_2/kWh)	Monthly Emissions (tonnes CO_2)
Production	8,250	0.33	2.72
Air Conditioning	3,750	0.33	1.24
Lighting	3,000	0.33	0.99
Total	15,000		4.95

4.1. Optimizations Recommended by the Wizard

Using the wizard, the following energy-saving strategies were simulated based on user interaction:

- Solar panels are installed to supply up to 30% of total energy consumption.
- Automation of production systems to reduce machinery energy consumption by 12%.
- Replacement of traditional lighting with LED systems reduces lighting energy by 40%.
- Preventive maintenance scheduling to reduce air conditioning inefficiency by 15%.

4.2. Expected Reductions

This reduction translates into a 48.34% decrease in monthly CO_2 emissions, reducing the company's footprint from 4.95 tons to 2.56 tons per month. Extrapolated to one year, this translates to 28.7 tons of CO_2 saved, which is equivalent to the carbon sequestration of approximately 1,310 mature trees per year, according to the U.S. Environmental Protection Agency (EPA).

Table 6. Monthly energy and CO_2 savings

Strategy	Area Affected	Estimated Energy Savings (kWh)	CO_2 Savings (kg)
Solar panel integration (30%)	General	4,500	1,485
Production automation (12%)	Production	990	327
LED lighting (40%)	Lighting	1,200	396
AC efficiency improvements (15%)	Air Conditioning	562.5	185
Total	—	7,252.50	2,393 kg

4.3. Economic and Sustainability Co-Benefits

In addition to reducing environmental impact, these measures also lead to cost savings. For example, by replacing all lighting with LEDs, the company can save about 480 soles per month, while automation and preventive maintenance reduce downtime and equipment breakdown costs. Moreover, the integration of solar panels, while requiring an initial investment, leads to long-term energy independence and resilience to energy price fluctuations.

5. Discussion

This study develops a mobile application with a virtual assistant to reduce the carbon footprint by improving user interaction with personalised recommendations. Unlike previous studies, such as that of [14], which created a carbon footprint calculator, this work moves forward by integrating a virtual assistant that interacts with users, providing personalised recommendations and enhancing the user experience.

The study by [15] also developed a mobile application for environmental awareness, but used the waterfall methodology. In contrast, the use of Mobile-D in this study allowed for greater flexibility and improved user loyalty. Research such as [16, 17] shows how mobile applications can promote sustainability, which is also achieved here through recommendations on recycling and environmental education. In summary, this study stands out for its innovative approach by integrating a virtual assistant that educates and guides the user in real-time, applying the Mobile D methodology.

6. Conclusion

The evaluation of experts and users shows that the mobile application developed meets the established objectives, standing out for its functionality, accessibility, and ease of use. The Mobile-D methodology allowed an agile adaptation to the user's needs, which contributed to the high acceptance of the application.

However, a limitation in conducting this research was the lack of a larger sample of users, and the lack of real-time data on users' behaviour in their everyday environment limits the impact of the application on reducing the carbon footprint. It is suggested that future research should incorporate more users to assess the long-term impact. Furthermore, pilot testing will be vital to obtain more specific information and explore the use of innovative technologies to optimise carbon footprint management and sustainability.

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