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## Original Articles



## Systematic Review / Bibliometric Articles

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# Study of Equations for the Non-Invasive Calculation of Hemoglobin Levels

**Noemi Araújo Esquivel da Silva[1*], Ciro Oliveira Fialho[1], Gabriel Barreto Teles Fonseca[1], Wendy Barbosa Conceição[1], André Ali Mere[2], Everton José Buzzo[2], Paulo Ali Mere[3]**

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**In many medical contexts, hemoglobin measurement is a routine procedure. However, the standard test for this parameter is invasive, which may cause discomfort and increase the risk of infection. Consequently, numerous studies have been conducted to develop non-invasive methods for hemoglobin measurement. This study aims to assess the performance of two equations that utilize optical signal data to estimate hemoglobin levels. The average error between the hemoglobin values calculated by these equations and reference values from the literature was analyzed. The equations yielded average errors of 23% and 4%, achieved by incorporating a correction factor into the second equation. These findings suggest that non-invasive hemoglobin estimation is promising, and including correction factors enhances accuracy.**

**Keywords: Hemoglobin Levels. Equations. Accuracy.**

According to the World Health Organization (WHO), anemia is a condition in which hemoglobin levels in the blood fall below average due to various pathological factors. In Brazil, anemia testing is mandatory when donating blood. However, this test typically involves invasive methods, requiring the extraction of a blood sample for laboratory analysis, which can cause discomfort and pose infection risks for the patient. This has led to a search for non-invasive techniques to measure hemoglobin levels. Photoplethysmography (PPG) is a non-invasive optical technique that uses light sources and detectors to capture variations in light reflection or transmission caused by pulsatile blood flow. Several studies in the literature have employed PPG for hemoglobin measurement. For instance, Jeon and colleagues (2002) [1] proposed a method for measuring hemoglobin using PPG with five wavelengths (569, 660, 805, 940, and 975 nm), achieving a prediction error of 8.5%. Similarly, Pinto, Parab, and Naik (2020) [2] developed a prototype that estimates hemoglobin levels using five LEDs (670, 770, 810, 850, and 950 nm) and a single photodetector. This study explores a system of equations that uses the optical response of PPG to calculate hemoglobin levels to make anemia detection faster and more practical. This approach could facilitate the development of devices that support this technique, making the blood donation process more efficient and reducing the risk of contamination for patients.

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## Materials and Methods

According to the Beer-Lambert law, the light absorption of a solution is directly related to its concentration. Additionally, the absorptivity of a substance depends on the wavelength of the emitted light. Based on this principle, Pinto, Parab, and Naik (2020) [2] developed a system of equations that relates the ratio of optical responses in pulsatile and non-pulsatile blood to a PPG signal with the concentrations of oxygenated and deoxygenated hemoglobin. This system is represented in Equation 1, where $C_{HbO2}$ and $C_{HB}$ correspond to oxygenated and deoxygenated hemoglobin concentrations, respectively; $R\lambda$ represents the ratio of the optical signal response between pulsatile and non-pulsatile blood at each wavelength, and $\epsilon_{HbO2}$ and $\epsilon_{Hbr}$ represent the absorptivity coefficients of oxygenated and deoxygenated hemoglobin, respectively, at each wavelength.

Robles, Chowdhury, and Wax (2010) [3] introduced a correction factor related to the thickness of the absorber in a system of equations used to calculate hemoglobin via the transmission method (Equation 2). In this equation, LLL represents the correction factor, while rrr is a factor related to light reflection.Using the systems presented in Equations 1 and 2, blood hemoglobin levels can be calculated by summing the concentrations of oxygenated and deoxygenated hemoglobin.

## Results and Discussion

To evaluate the performance of the equations, we used PPG signal data (both pulsatile and non-pulsatile optical responses, from which the R, body mass index (BMI), and hemoglobin data from the study by Chen and colleagues (2023) [4] involving ten individuals. Table 1 presents the values for the absorptivity coefficients of oxygenated and deoxygenated hemoglobin at different wavelengths.

**Equation 1.** Equation for calculating hemoglobin by Pinto, Parab, and Naik (2020).

$$\begin{cases} \epsilon_{HbO2}(\lambda_1) * C_{HbO2} + \epsilon_{Hbr}(\lambda_1) * C_{Hbr} = R_{\lambda_1} \\ \epsilon_{HbO2}(\lambda_2) * C_{HbO2} + \epsilon_{Hbr}(\lambda_2) * C_{Hbr} = R_{\lambda_2} \\ \epsilon_{HbO2}(\lambda_3) * C_{HbO2} + \epsilon_{Hbr}(\lambda_3) * C_{Hbr} = R_{\lambda_3} \\ \epsilon_{HbO2}(\lambda_4) * C_{HbO2} + \epsilon_{Hbr}(\lambda_4) * C_{Hbr} = R_{\lambda_4} \end{cases}$$

Figure 1 presents the results obtained using the equation proposed by Pinto, Parab, and Naik (2020) [2]. Figure 2 shows the hemoglobin calculations using the same dataset but applying the system developed by Robles, Chowdhury, and Wax (2010) [3]. The average error using Equation 1 was 23% (3.3 g/dL), whereas Equation 2 showed an average error of 4% (0.5 g/dL), indicating that adding the correction factor in Equation 2 significantly improved accuracy. However, the correction factor is influenced by skin tone, blood perfusion, and other physiological parameters, which were not addressed in this study. Despite this, the results demonstrate that PPG data can accurately calculate hemoglobin levels. Further research on these influencing factors is necessary to achieve even greater precision in hemoglobin calculations.

## Conclusion

The evaluation of hemoglobin calculation using the proposed systems of equations yielded

**Equation 2.** Equation for calculating hemoglobin proposed by Robles, Chowdhury, and Wax (2010).

$$\begin{cases} \epsilon_{HbO2}(\lambda_1) * C_{HbO2} + \epsilon_{Hbr}(\lambda_1) * C_{Hbr} - \frac{1}{L} * \ln(r) = -\frac{1}{L}\ln(R_{\lambda_1}) \\ \epsilon_{HbO2}(\lambda_2) * C_{HbO2} + \epsilon_{Hbr}(\lambda_2) * C_{Hbr} - \frac{1}{L} * \ln(r) = -\frac{1}{L}\ln(R_{\lambda_2}) \\ \epsilon_{HbO2}(\lambda_3) * C_{HbO2} + \epsilon_{Hbr}(\lambda_3) * C_{Hbr} - \frac{1}{L} * \ln(r) = -\frac{1}{L}\ln(R_{\lambda_3}) \\ \epsilon_{HbO2}(\lambda_4) * C_{HbO2} + \epsilon_{Hbr}(\lambda_4) * C_{Hbr} - \frac{1}{L} * \ln(r) = -\frac{1}{L}\ln(R_{\lambda_4}) \end{cases}$$

**Table 1.** Absorptivity coefficients of oxygenated and deoxygenated hemoglobin at various wavelengths.

| Wavelength | $\epsilon_{HbO2}$ cm$^{-1}$/M | $\epsilon_{Hbr}$ cm$^{-1}$/M |
|---|---|---|
| 660 | 319.60 | 3,226.56 |
| 740 | 446.00 | 1,115.88 |
| 850 | 1,058.00 | 691.32 |
| 940 | 1,214,80 | 708.16 |

**Figure 1.** Comparison between actual and calculated hemoglobin using the equation by Pinto, Parab, and Naik (2020).

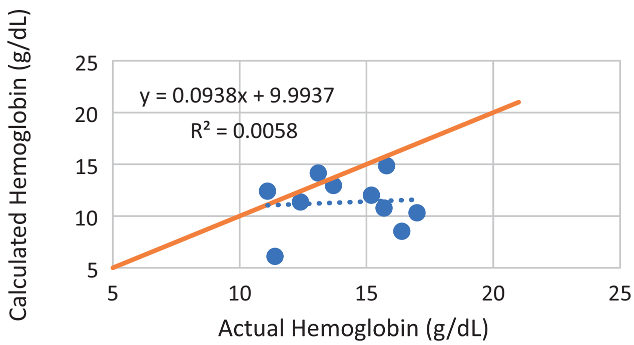
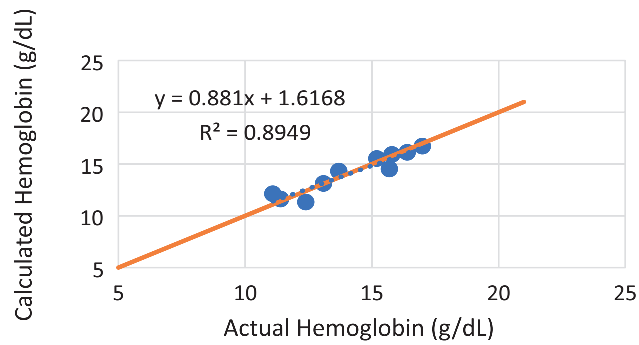



**Figure 2.** Comparison between actual and calculated hemoglobin using the equation by Robles, Chowdhury, and Wax (2010) [3].




promising results, particularly with the inclusion of correction factors. A more comprehensive investigation of these factors is recommended to improve the accuracy of hemoglobin estimation further. Chen and colleagues (2023) [4] conducted a similar study, comparing results from logistic regression and machine learning models, and reported deviations of 0.762 g/L. Future studies should investigate comparing different methods and equations for calculating hemoglobin using optical techniques, considering variables such as skin tone, blood perfusion, and temperature. These factors are crucial, as they directly influence the optical signal received during measurement.

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# Challenges of Operationalizing a Mobile Computerized Tomography Unit: Experience Report from the ProPulmão Project

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**The ProPulmão pilot project, launched in 2023, aimed to screen and analyze the epidemiological profile of lung cancer in remote communities across Bahia, Brazil, where access to imaging exams is limited. Recognizing the critical role of low-dose computed tomography (CT) in reducing lung cancer mortality, the project employed a mobile unit equipped with a 16-channel CT scanner and the necessary medical infrastructure to screen asymptomatic smokers and ex-smokers who had quit smoking up to 15 years ago. While the initiative proved effective, it encountered significant logistical challenges, particularly with internet connectivity and power supply—both essential for the consistent operation of the CT unit and the transmission and storage of medical images. Despite these obstacles, the project successfully facilitated early detection of lung cancer cases, underscoring the importance of such screening programs. The challenges led to refining work protocols, including improved image storage techniques, a deeper understanding of managing medical image servers, and enhanced communication between the technical and medical teams. These experiences contributed to the ProPulmão project's success. They provided valuable insights for implementing similar initiatives in other states across Brazil, thereby promoting greater accessibility and early detection in underserved areas.**
**Keywords: Lung Cancer. Screening. Computed Tomography. Accessibility.**

Lung cancer, as highlighted by the Global Cancer Observatory (2022) [1], is the most prevalent malignancy worldwide, accounting for approximately 2.5 million new cases, which represents 12.4% of all cancer incidences.

A study by Lima Costa and colleagues (2020) [2] reveals a notable reduction in lung cancer mortality rates among men, dropping from 19.72 (2001-2005) to 12.62 (2026-2030). However, among women, the mortality rate is expected to increase from 7.62 (2001-2005) to 9.61 (2026-2030), with the southern region of Brazil showing the highest mortality rates.

The effectiveness of annual low-dose computed tomography (CT) screening in reducing lung cancer mortality by up to 20% was demonstrated by the National Lung Screening Trial (NLST) in 2011 [3]. This underscores the importance of three-dimensional imaging diagnostics for early detection of calcified nodules and lesions, particularly in vulnerable populations such as smokers and ex-smokers. Japan was among the first countries to implement a mobile CT unit for lung cancer screening in 1998 [4], and a similar initiative was developed in Barretos, São Paulo, Brazil, as described by Chiarantano and colleagues (2022) [5].

In Bahia, an epidemiological profile study by Chaves and colleagues (2022) [6] revealed that between 2018 and 2021, the state ranked 8$^{th}$ in the number of diagnoses of bronchial and lung cancer, with 1,620 cases, 1,097 of which were in the capital, Salvador. In this context, the ProPulmão pilot project was launched to develop a mobile CT unit to screen for lung cancer among vulnerable populations in remote areas of Bahia with limited access to diagnostic imaging. This initiative is crucial for transforming the landscape of lung cancer diagnosis and treatment in Brazil. However, operating such a mobile unit presents several challenges that must be addressed to ensure its success.

## Materials and Methods

This study is a descriptive, qualitative experience report that emerged from the initiative to address the various challenges of operationalizing a mobile tomography unit and exploring possible

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solutions to optimize workflow. The project utilized a heavy transport vehicle equipped to carry a 16-channel Access Tomography model with technical parameters of 100 kV, 50 mAs, 92 mA, and a slice thickness of 2.00 mm. The vehicle was also adapted with the necessary medical infrastructure to ensure safe patient care and to perform lung tomography scans using minimal radiation doses while maintaining high-quality imaging (Figure 1).

## Results and Discussion

The experience gained from the ProPulmão Pilot Project, particularly in the areas of image transmission, storage, and interpretation in each city across Bahia, highlighted several crucial and recurring challenges (Table 1).

These impacts highlight the critical need for reliable internet connectivity and robust data management protocols in mobile CT units, mainly when serving remote or underserved populations. The challenges experienced underscore the importance of addressing these technical issues to ensure that mobile health initiatives like ProPulmão can achieve their full potential in improving public health outcomes.

The internet connection has proven to be a critical factor in the success of the ProPulmão Pilot Project, as it is essential for the seamless sending, storage, and viewing of medical images. However, the connection's instability and unpredictability have posed significant challenges. We recommend the following solutions to address these issues:

**External Support System:** Implement an external storage system to complement the CT scanner's limited internal memory. This will prevent memory overload, which can impair the scanner's functionality, ensure continuous operation, and safeguard against data loss.

**Protocol Development and Adaptation:** Develop and adapt protocols that allow for comprehensive monitoring of the image transmission process from the mobile tomography unit to the server. This will help to ensure that images are correctly and promptly uploaded, minimizing the risk of data loss.

**Figure 1.** Service flow.

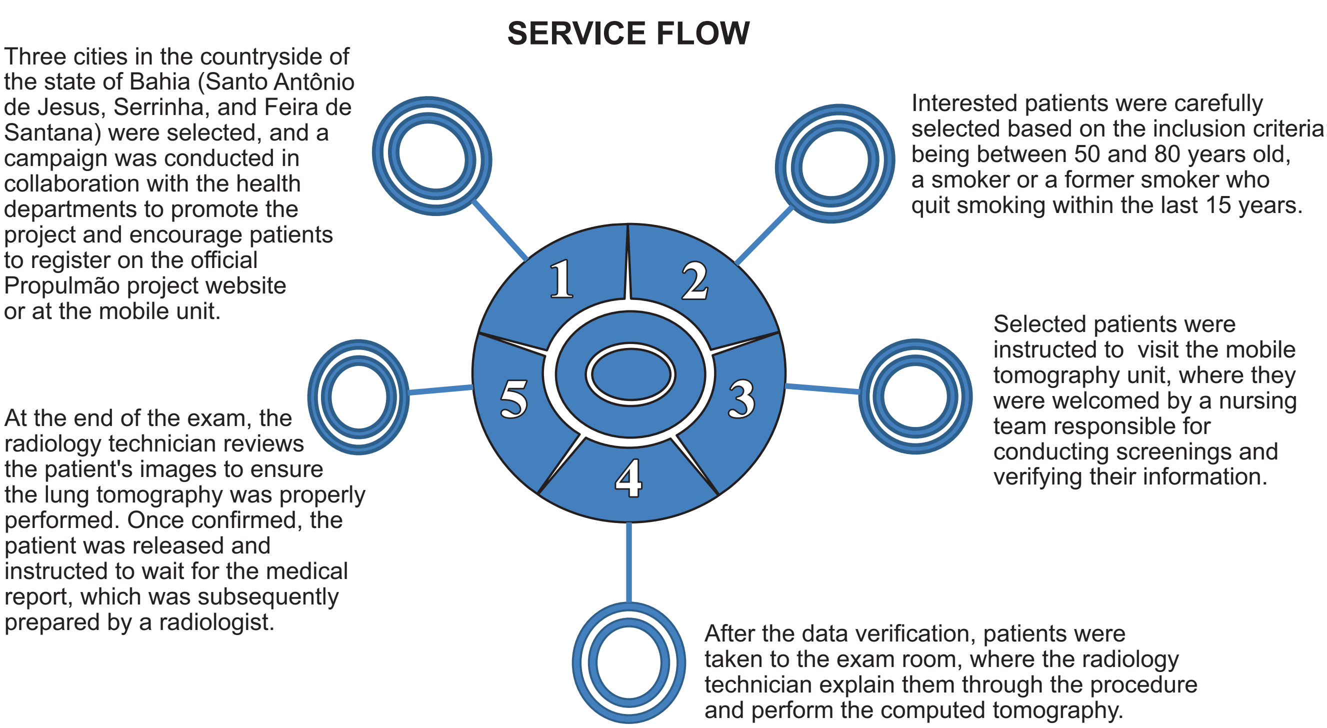

**Table 1.** Chanllenges and impacts the ProPulmão pilot project.

| Challenges | Impacts |
|---|---|
| **Patient Recruitment and Adherence**<br>Despite an active publicity campaign in collaboration with municipal and social organizations, patient recruitment in some interior cities of Bahia fell below expectations. This shortfall can be attributed to difficulties in patient transportation, limited internet access, and challenges in maintaining communication via mobile phone. | **Lack of Lung Lesions**<br>The lack Detecting lung lesions in vulnerable populations prevents the accurate assessment of the profile of malignant lung disease in these communities. |
| **Internet Connection Instability**<br>Unstable internet connections, particularly in remote areas, frequently impair the functioning of the server used for sending, storing, and viewing images. This instability posed significant challenges to maintaining the continuity and reliability of the imaging services provided by the mobile unit. | **Missed Diagnoses**<br>Some exam images failed to upload to the server due to inadequate internet connectivity. This prevented radiologists from evaluating the images and releasing diagnostic reports. In the worst-case scenario, the loss of patient exams meant that crucial diagnostic opportunities were missed, potentially leaving lung lesions undetected. |
| **Manual Data Entry Errors**<br>On days when the server was unavailable, manual scanning of patient data became necessary. However, this process was prone to errors, further complicating the workflow and potentially impacting the accuracy of patient records. | **Data Entry Errors**<br>The CT scanner is the source of ionizing radiation and the system where patient data is registered. Under normal conditions, Wdata is automatically populated by typing a unique access code for each patient. However, on days when the internet connection was unstable, data had to be entered manually, leading to errors. These errors included mismatches in patient names on exam records, which could result in a medical report being issued under the wrong name, compromising patient safety and the accuracy of medical records. |
| **Limited Internal Storage in the CT Scanner in the Mobile Unit**<br>The imited internal storage capacity poses a significant challenge. Once the storage reaches its maximum capacity, new exams can be performed, and older exams can be deleted to free up space. This limitation necessitates the regular management of stored data, which includes the timely transfer of completed exams to an external storage system or cloud-based server, ensuring that the CT unit can continue to operate efficiently without interruptions. | **Image Loss and Delays**<br>Internet instability also caused delays in transmitting exams to the server. In some cases, exams that had not yet been uploaded were inadvertently erased from the CT scanner's internal storage, resulting in the permanent loss of images. These exams had to be redone, leading to delays in patient care and additional radiation exposure. |

**Regular Server Checks:** Implement routine checks of patient images on the server to detect errors in patient data, prevent image duplication, and ensure no patient images are missing. This proactive approach will help maintain data integrity and reduce the likelihood of operational errors.

**Enhanced Multidisciplinary Communication:** Strengthen communication between the technical team and medical professionals. Improved collaboration will help identify and address operational issues quickly, significantly reducing potential errors and ensuring a smoother workflow.

Addressing these critical areas can significantly improve the operational efficiency of the mobile CT unit, ultimately leading to better patient outcomes and more reliable diagnostic processes.

## Conclusion

The ProPulmão project, like any pilot initiative, faced unexpected challenges that required adaptive solutions. In instances where issues were not immediately resolved or detected, the project's development benefitted from these challenges by fostering the creation of more efficient work protocols. This process involved holding regular meetings with the development team, training the involved professionals to identify server instabilities quickly, and forming dedicated teams to verify patient data. Additionally, the project improved techniques for the optional storage of patient images to mitigate data loss in case of technical difficulties. In conclusion, the ProPulmão project has provided valuable insights into the epidemiological profile of lung cancer in remote cities of Bahia. The lessons learned from this experience will serve as a solid foundation for future projects with similar objectives, contributing to the scientific community and raising public awareness about the importance of early diagnosis and the dangers posed by lung lesions.

## Acknowledgments

Special thanks are extended to Senai Cimatec for enabling the development of the ProPulmão Pilot Project and offering the opportunity to participate in this transformative experience. We deeply thank Gabriel Barreto, Gesse Oliveira, Rodrigo Tutu, and João Bartolomeu.

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# Survey of Smart Technologies for Application in Home Elderly Care

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**This project addresses the increasing demands of an aging population and the need to adapt social structures to accommodate elderly individuals better in specialized care settings. As the number of elderly individuals grows, there is a pressing need for practical solutions to enhance their quality of life and ensure their well-being. The methodology employed in this project includes a comprehensive survey of care environments' characteristics and a thorough analysis of available intelligent technologies. These technologies encompass various communication options such as RFID, Bluetooth Low Energy (BLE), LoRaWAN, ZigBee, and Ultra Wideband, as well as a range of sensors designed to monitor sleep, physical activity, and nutrition among the elderly. Implementing these intelligent technologies aims to facilitate the early identification of potential health risks and provide continuous monitoring of the elderly's overall quality of life and health. Preliminary tests have indicated the necessity for further investigation into additional resources to enhance the effectiveness and coverage of these sensors.**
**Keywords: Smart Technologies, Monitoring. Nursing Home. Quality of Life.**

The aging population has led to an increasing demand for solutions that address the specific needs of elderly individuals, particularly in specialized care environments such as nursing homes. In this context, integrating innovative technologies is crucial for enhancing the quality of life and ensuring the safety of these individuals.

A primary concern in these environments is the safety of residents. Sensory technologies can address this issue by improving safety and preventing accidents. Sensors can detect movements, falls, and other events that may jeopardize the health and well-being of the elderly. Preventative measures can be taken with such data, such as alerting caregivers or family members responsible for the resident's safety. Additionally, sensory technologies can offer other benefits, including monitoring sleep quality, physical activity, and nutrition, thereby contributing to improved health and quality of life for the elderly.

In the project's initial phase, conducted in 2022, various indoor location and monitoring communication technologies were evaluated, including RFID, Bluetooth Low Energy (BLE), LoRaWAN, ZigBee, and Ultra Wideband. Each technology exhibited distinct advantages and disadvantages regarding range, cost, power consumption, and compatibility with other devices. After a thorough comparison, the most suitable technologies were selected for specific applications within the project.To monitor the sleep of elderly individuals, several sensor options available on the market were considered in the first phase of the project, including motion sensors, pressure sensors, and ultrasonic sensors.

A well-evaluated solution for the project was using ultrasonic sensors capable of detecting the chest and abdomen movement during breathing. This allows caregivers to monitor the frequency and quality of patients' breathing. Additionally, the data collected can be analyzed to identify possible anomalies or patterns that could indicate respiratory problems, enabling preventive actions to provide more effective care for the elderly, thus increasing quality of life and reducing health risks [1-3].

Among the communication technologies assessed, preliminary evaluations highlighted that BLE (Bluetooth Low Energy) technology, while promising in aspects such as low energy consumption and high compatibility with other devices, faced significant challenges. Subsequently, tests and experiments were carried out with RFID (Radio-Frequency Identification) technology, chosen for its feasibility of implementing Arduino

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and the MFRC522 module, widely used for contactless communication. This project proposes to continue evaluating and implementing the selected technological solutions for monitoring in a nursing home setting.

## Materials and Methods

The method adopted for this project involved evaluating two main options: beacons (BLE) and RFID. Initially, beacons were considered due to their ability to provide indoor location tracking, enabling real-time monitoring of elderly individuals' movements and locations. Their low energy consumption would allow for their installation in various locations within the home, facilitating caregiver oversight. However, after encountering issues with BLE devices, such as communication problems and high import costs, RFID technology was selected for further testing and experimentation. The MFRC522 RFID reader module, based on the NXP chip, was chosen due to its affordability, ease of implementation, and widespread availability. This module operates at a frequency of 13.56 MHz and supports contactless communication, allowing it to read and write on cards adhering to the Mifare standard.

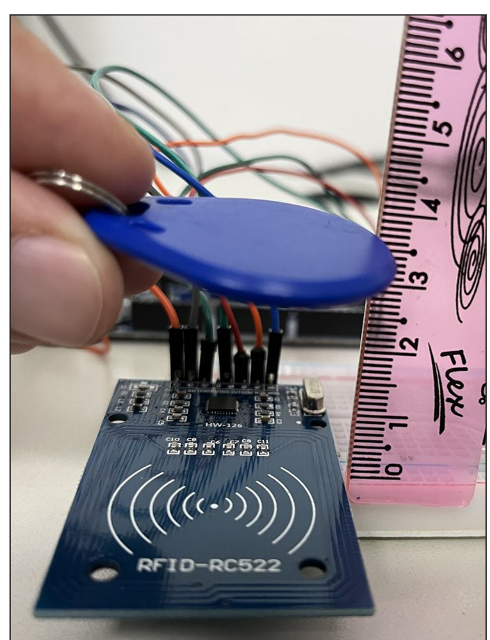
A code was developed for Arduino using the Arduino IDE software to test the viability of RFID technology. The experiments included jumpers, a breadboard for connecting components, an Arduino Mega 2560 microcontroller, and a computer. A simple code was created to test the RFID module's functionality and determine the distance at which the sensor can detect RFID tags, assessing the feasibility of this technology for the project.

The system was designed to collect data by positioning the RFID reader at various locations, such as doors, and attaching RFID tags to patients' clothing. This setup aimed to monitor specific metrics, such as the number of trips and the average time each person spent in the bathrooms. The code checks for nearby RFID tags, and when detected, it reads their serial numbers and displays them on the serial port. This setup evaluated the average distance at which the RFID module can read the tags. The tags were gradually removed from the reader, and detection and instances of reading failures were noted. Measurements were taken with a ruler to determine the effective range of the RFID module.

## Results and Discussion

Figure 1 shows the measurements taken with a ruler. The results showed that the maximum range of the RFID reader, with repeatability tested 20 times, was approximately 48 mm. This range is insufficient for meeting the application's specific needs, as a typical door has dimensions of approximately 210 cm x 80 cm. Therefore, the sensor's range is inadequate for detecting a tag on a patient's clothing from such a distance. The tests demonstrated the need for additional investigations to improve BLE and RFID technologies, focusing on enhancing the ability to provide indoor patient location for monitoring bathroom visits and assessing the cost-benefit of implementation. Other communication technology options are still being considered for the project's implementation

**Figure 1.** Tests for measuring the sensor's average detection distance.



of intelligent solutions in the nursing home. Technologies such as LoRaWAN and ZigBee are under evaluation, and other technologies that still need to be addressed could be studied and evaluated.

## Conclusion

This study investigated intelligent technologies to improve the care and safety of older adults in specialized homes. Innovative technologies can offer numerous benefits to nursing homes, enhancing patients' safety, comfort, and overall well-being. Various communication technologies and sensor options, including motion, pressure, and ultrasonic sensors, were meticulously evaluated. However, the tests revealed a need for further investigation to enhance the selected solutions, particularly concerning the range and effectiveness of these sensors.

Moreover, trained professionals must use these technologies appropriately to ensure that elderly individuals receive comprehensive and high-quality care at home. Despite the challenges, using intelligent technologies presents a promising option for improving the quality of life for the elderly and providing more effective care. Therefore, continued exploration and refinement of available technologies are essential to advancing the well-being and safety of older individuals in specialized care settings.

## Acknowledgments

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# Assistive Technologies in Aphasia Rehabilitation: Prototyping for the Task of Object Naming

**Évila Maria de Souza Carneiro[1*], Claudia Simões Pinto da Cunha Lima[1]**
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**Aphasia is a language disorder caused by brain injuries, often as a result of a stroke. This condition significantly impairs communication and profoundly affects the lives of patients. Rehabilitation is critical in improving outcomes and may include tasks such as object naming, where patients identify presented images. This process can be enhanced through the use of assistive technologies. This exploratory study was conducted in three stages: a systematic review, developing and validating a preliminary prototype, and creating the final version. The systematic review revealed that integrating technology into treatment provides immediate and long-term benefits. However, a notable gap was identified: the lack of designed software for this purpose. To address this need, the study proposes developing a prototype application to support aphasia rehabilitation, with a primary focus on object-naming exercises.**
**Keywords: Aphasia. Rehabilitation. Applications. Naming.**

Aphasia is a language disorder caused by an injury to the brain region responsible for communication skills such as reading, speaking, and writing [1-3]. The injuries can be caused by neurodegenerative diseases, trauma, tumors, and infections, with stroke being the most common [1]. Symptoms vary according to the type and degree of aphasia, but generally, they manifest as a loss of the ability to assimilate, process, and express oral and written language.

An aphasic person may have their professional and personal life affected, directly impacting their well-being and quality of life, because communication difficulties contribute to a feeling of non-belonging. One way to encourage social inclusion is through language. Language is fundamental in this process because it represents a group that shares a culture and communication rules. The use of language, besides generating a sense of belonging, is also an important means of self-expression, ensuring autonomy and freedom for the speaker.

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Legislation that makes the inclusion of different languages aimed at accessibility, such as LIBRAS and braille, mandatory in shows, theater, and schools is an example of the importance of language in the inclusion process. According to Silvia Lane, language acts within groups to generalize and transmit practices for survival, which is essential for transmitting knowledge acquired over time through socialization [4].

Thus, aphasic people are vulnerable in terms of participation in social groups. Besides being made invisible because of their disorder, they cannot communicate clearly through language.

Rehabilitation is crucial for recovering the patient's language skills and contributing to their reintegration into society.

Aphasia rehabilitation can be performed through various tasks. This study focuses on object naming, which involves presenting a physical object or a picture of the object to the aphasic person, who needs to identify it. A speech therapist or a family member can assist with this task by providing hints to help with naming.

Different methods can be used to perform the naming task. One example is "Look, Listen, Repeat," in which a series of photos of objects are presented to the patient, followed by the graphic and phonetic presentation of the object's name, which the patient needs to repeat aloud [4]. This method can be efficient in recovery, as naming difficulty arises from the blockage of lexical-semantic association, contributing to problems with attention, fixation, and memory caused by brain damage [2].

Constant repetition and reinforcement of rehabilitation tasks contribute to improving the difficulties presented [2]. As part of the treatment, the family member accompanying the aphasic patient needs to reproduce the activities practiced in the clinic at home. This is an important part of recovery because it complements the work done with the speech therapist and facilitates the repetition of training in the comfort of home.

The increasingly widespread use of gamified technological resources in treating different medical conditions has proven effective [5]. The association of games with treatment offers a more engaging and motivating environment for the patient, who participates more actively in recovery. Additionally, using technology in conjunction with treatment offers a broader range of possibilities, such as including games in this process [1,5,6].

In the context of aphasia rehabilitation, technology can act as an ally in systems that help facilitate patient communication. The studies found address applications that assist aphasic individuals in forming sentences, such as the Jellow App, an Augmentative and Alternative Communication application developed by Alam and colleagues designed to compensate for impaired language skills [5]. While they support stimulus therapy, these programs are not designed with a focus on treatment but rather on immediate communication.

During the systematic review conducted for this study, only one project with this proposal was found, the Thai naming application for clients with aphasia [5]. The study selected 5 pairs of caregivers and aphasic patients who underwent treatment together with the application for 12 weeks, showing improvement and stability in word naming. Patients also reported improved quality of life and self-esteem after using the application, showing that assistive technologies can be an effective and accessible tool in the recovery of aphasia patients [7].

However, the application is only available in Thai, limiting its use to speakers of the language. From this, a potential lack of assistive software for aphasia rehabilitation that uses the naming task and can be used by patients with professional guidance was identified.

Other possibilities not identified include software aimed at medium and long-term maintenance of acquired skills, the chance to transfer the battery of tasks performed by the speech professional to the digital environment, recording patient progress, adapting treatment to patient individualities, and a program in Portuguese that meets these requirements.

In this context, this study aims to develop a prototype application to support aphasia rehabilitation, focusing on object naming in a way that can complement the actions of health professionals. Hopefully, the developed system can encourage aphasic recovery and autonomy, positively impacting their rehabilitation process.

## Materials and Methods

This exploratory study, conducted between November 2023 and May 2024, comprised four key stages: a systematic review, prototyping of a preliminary version, validation of the preliminary prototype, and development of the final prototype.

### Systematic Review

The systematic review explored the state-of-the-art application of assistive technologies in object-naming tasks for aphasia rehabilitation. Conducted using the Scopus platform and CAPES Journals, the review identified 21 articles, of which seven were deemed relevant to the project based on their focus and methodologies.

### Preliminary Prototype Development

The preliminary prototype was created using Figma, a free vector graphic editing and prototyping tool. Figma's features enable the creation of interactive user screens and diverse user flows, making it an ideal platform for developing distinct application interfaces. The prototype adopted the "Look, Listen, Repeat" method [4], presenting an object alongside its written name for the patient to recognize and repeat while omitting the auditory component visually.

Key features included:

**Reward System:** Users earned a coin for each correct naming attempt. Incorrect answers were not penalized to avoid discouragement.

**Hint Options:** Two hint mechanisms were incorporated to assist users:
- The first displayed the word spelling incrementally, letter by letter, allowing users to identify the word progressively.
- The second provided the image and complete spelling of a related object to aid associative recognition.

Validation of the Preliminary Prototype

The prototype was presented to a speech therapist specializing in aphasia rehabilitation in Bahia. The therapist evaluated the prototype based on clinical knowledge and practical experience, suggesting adjustments to enhance its relevance and functionality. These insights informed the next stage of prototype refinement.

Final Prototype Development

Feedback from the validation stage was implemented in the final development phase. Additional refinements focused on enhancing the application's usability and patient engagement.

## Results and Discussion

Systematic Review Insights

The systematic review highlighted the relevance of object-naming tasks across different aphasia contexts, demonstrating their efficacy in facilitating word retrieval. Combining traditional speech therapy with technological tools enhanced patients' naming and communication abilities.

The research uncovered a gap in domestic contributions to this field, with only one article originating from Brazil. This underscores the need to promote the development of aphasia-specific technologies tailored to the Portuguese language and Brazilian accessibility requirements.

Furthermore, only 3.2% of the reviewed articles were linked to engineering or computer science, revealing a significant opportunity for interdisciplinary exploration in assistive technology applications for aphasia treatment.

Key Findings

Seven of the 21 articles analyzed were selected for their detailed focus on object-naming tasks and the application of assistive technologies. Table 1 summarized the findings, which outlines the main points of each study, emphasizing approaches to object naming and their outcomes.

Implications for Development

The analysis confirmed that object-naming tasks effectively contribute to aphasia rehabilitation when integrated with assistive technologies. However, the limited presence of Brazilian research and engineering contributions suggests untapped innovation potential. This study addresses this gap by proposing a technology-driven solution tailored to local needs and contexts.

This work demonstrates that leveraging assistive technologies can complement clinical efforts, improving the recovery experience for aphasia patients while fostering inclusivity and autonomy.

Summary of Findings

The reviewed studies demonstrated positive outcomes in recovering naming abilities and

**Table 1.** Sistematic review results.

| Reference | Relevant Topics |
|---|---|
| Menke R et al, 2009 [8] | Patients received computer-assisted naming training over the course of two weeks. The training involved associative language learning to strengthen the semantic associations between object images and auditory and graphic cues.<br>The training was structured into five levels of difficulty, where the cues provided to the patients were progressively reduced, culminating in the free naming of the object without phonological or graphic cues.<br>The training was supervised by an experienced speech and language therapist, who evaluated the patients' responses and provided feedback after each training block. |
| Savage SA et al, 2023 [9] | The naming task was applied using photographs of target objects presented in random order through a computer program. The method used was "Look, Listen, Repeat."Slides were created for each item on the training lists, including an image of the target object, followed by the same image with the written label and an audio presentation of the corresponding word.<br>Naming performance improved after each intervention block, with maintenance over time and generalization to naming objects in natural environments. |
| Alam N et al, 2021 [1] | The study group showed greater improvement in spontaneous speech, naming, and communication. The use of the Jellow app facilitated the effective expression of patients' skills, indicating that the application is a useful complement to stimulation therapy.<br>These findings suggest that integrating technology with traditional therapy can enhance treatment outcomes, providing patients with additional tools to aid their rehabilitation journey. |
| Barca L et al, 2009 [10] | Visual naming is thought to occur through the interaction of vision, semantics, and language, with visual and functional attributes of objects stored in separate locations, requiring successive access to these locations for effective naming. The studied patient exhibited a more pronounced visual naming deficit when objects were presented visually compared to other sensory modalities.<br>This suggests that the visual processing pathway may be particularly affected, impacting the ability to access the semantic and linguistic information needed for naming.<br>The patient did not show selective difficulties with specific categories of objects, indicating that the naming deficit encompassed a variety of object categories.<br>This broad impact suggests a general impairment in the pathways or processes involved in accessing and integrating visual, semantic, and linguistic information. The patient demonstrated complex performance in object naming tests, with errors that included visually and semantically related errors, unrelated responses, and non-responses.<br>These errors reflect the challenges in accessing or processing the necessary information for accurate naming and suggest a need for targeted therapeutic strategies to address these specific types of errors. |
| Middleton CQE, Mirman D, 2019 [2] | Identifying omission errors as a failure to attempt naming the object contrasts with commission errors, which involve producing incorrect or non-existent words. Understanding the neurocognitive basis of omission errors is crucial for personalizing treatment and evaluating outcomes. Research into the relationship between the location of brain lesions and the occurrence of omission errors in figure naming can provide insights into which areas of the brain are critical for the different stages of the naming process. This information can help clinicians tailor interventions based on the specific areas of impairment. The use of a computational model of figure naming can be valuable in assessing whether the degradation of lexical-semantic or lexical-phonological connections contributes to omission error rates. By simulating these connections, researchers can explore how disruptions in these pathways might lead to difficulties in accessing the necessary information for naming. Such models can help predict which types of errors are likely based on the nature and location of the brain lesion, allowing for more targeted therapeutic approaches that address the specific deficits contributing to the omission errors. |

(continuing)

| | |
|---|---|
| Trevittaya T, Piyawat K, Chinchal S, 2023 [11] | The categorization of twelve verbs and 58 nouns into two groups involved associating each word with an image, pronunciation, and six different types of cues to aid naming. These cues included semantic hints, the first letter, written words, sentence completion, phonological cues, and spoken words. The content validity of each item, such as words, images, and cues used in the application, was evaluated by three qualified speech therapists using the Item Objective Congruence (IOC) index. This ensured that the items adequately covered the proposed content. A naming rehabilitation app was developed and tested, then reviewed by experts to ensure its validity. The app was subsequently used in a study with five caregivers and five clients with aphasia.<br>The use of the naming app in Thai was positive for the treatment of clients with aphasia. The results demonstrated that the protocol facilitated improvements in naming skills and enhanced the quality of non-verbal communication.<br>The app proved effective in improving the ability of clients with word-finding difficulties to retrieve words and enhance their capacity for spontaneous naming. This indicates that such tools can be valuable in supporting language rehabilitation efforts, offering structured and diverse approaches to word retrieval practice. |
| Alam N, Kumar R, 2014 [12] | The evaluation of a 50-year-old patient diagnosed with Broca's aphasia was conducted using the first part of the Western Aphasia Battery (WAB). The assessment revealed severe impairments in spontaneous speech, repetition, and naming, although the patient showed better auditory comprehension.<br>The patient was able to name 3 items without any cues and 9 items with tactile and phonemic cues. This suggests that while there is a significant naming impairment, certain strategies or prompts can aid in word retrieval.<br>In the word fluency task, the patient was unable to name three animals within a given minute. This further highlights the challenges in verbal fluency and the ability to generate words spontaneously.<br>For the sentence completion and responsive speech tasks, the patient completed 3 out of 5 items. This indicates some ability to engage in structured language tasks, but with notable limitations.<br>The total score obtained for naming was 29, which indicates significant difficulties in object naming and verbal fluency. These results emphasize the need for targeted therapeutic interventions to address these specific areas of impairment, potentially incorporating strategies that leverage the patient's relatively better auditory comprehension to support language production. |

maintaining skills over short- and long-term periods. However, none of the software solutions identified offered gamified, customizable treatment tailored for patients to practice and sustain these skills independently. Additionally, there was no software available in Portuguese to serve this purpose. While existing solutions addressed some individual requirements, none encompassed them simultaneously. This gap highlights the potential for developing software with enhanced functionality, broader applicability, and features that address these unmet needs.

In summary, the studies showed good results in patients' recovery of names and in maintaining skills in the short and long term. However, no gamified and customizable treatment software was identified that is available for patients to train and maintain the skills acquired, based on professional guidance, and available in Portuguese. The studies found meet some of the requirements, but not simultaneously, leaving room for the development of software with more possibilities that expand the applicability of this resource and address the identified gaps.

## Prototype

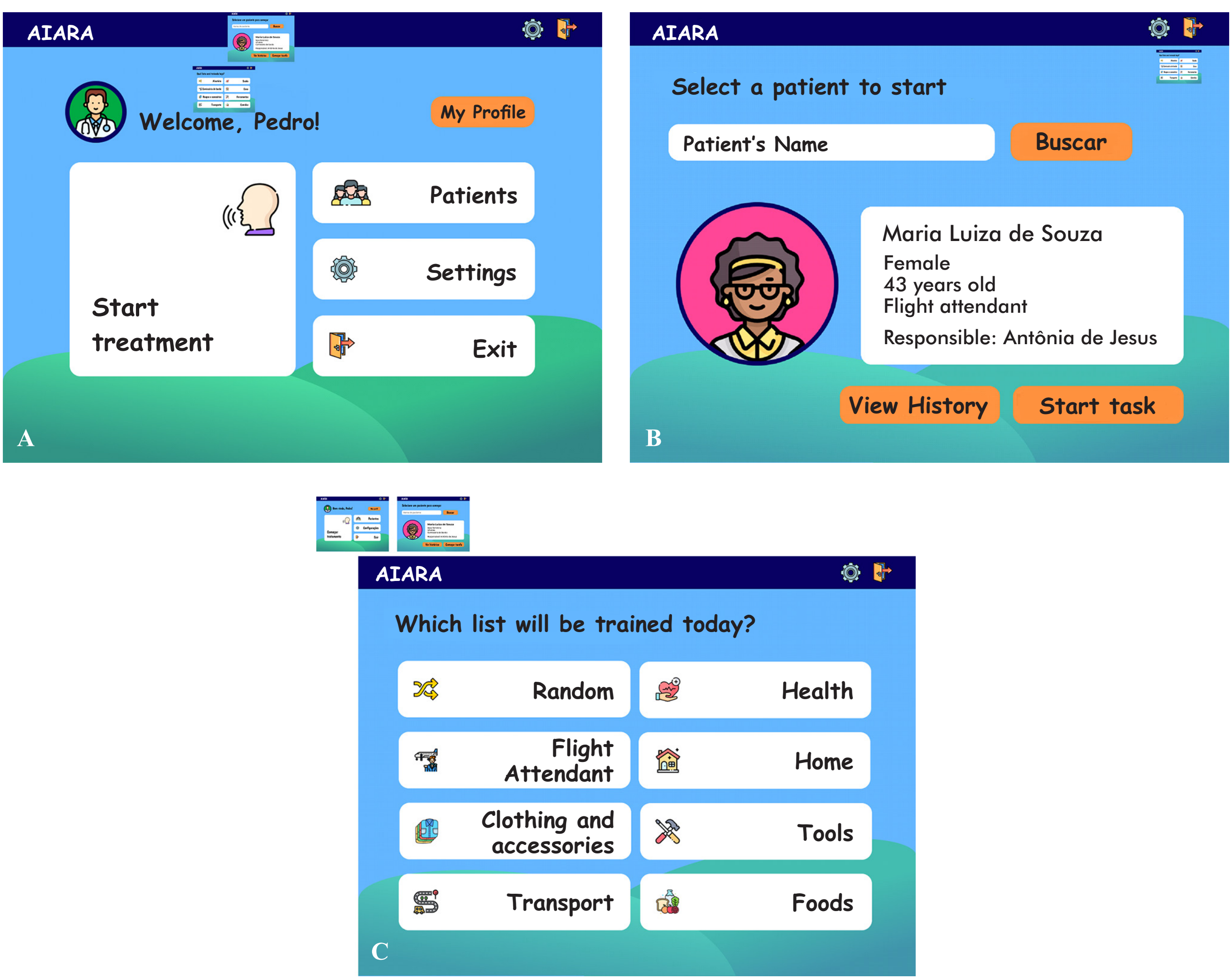
The first version of the functional prototype for the object naming task was developed based on the insights gained from reading the articles. The first step was to catalog the positive aspects identified in the methodology of the articles reviewed. Next, the perceived gaps and implementation possibilities to address these resource deficiencies were cataloged.

After presenting the preliminary version to a specialized professional, they implemented the suggested adaptations. The prototype development was carried out by integrating these aspects. Two primary interfaces were created, one accessed by the speech therapist and the other by the patient. The goal is to create a unified environment that can be used in the clinic and at the aphasic individual's home. This way, the patient will be more familiar with repeating exercises at home, providing a more efficient way to transfer the word list.

Two distinct flows were created to allow and restrict the speech therapist's ability to customize the aphasic person's treatment. Viewing the patient list and editing the boards or word lists is only permitted for the speech therapist. With these functions, the professional can tailor the treatment for each patient according to their specific needs. The word lists are thematic and associated with patients as needed.

Upon accessing the app, the screen illustrated in Figure 1A is presented. The "Patient" button displays the list of registered patients, allowing users to view their medical information and history. The "Settings" button leads to a screen for customizing text size, buttons, and contrast and allows the word list to be edited. Pressing the "Logout" button logs the user out of their profile. This functionality can also be executed by the button in the upper right corner and the settings, and it works the same for the aphasic individual. When accessing the "Start Treatment" button, the

**Figure 1A.** A. Speech therapist interface. B. Patients search interface. C. List selection interface



speech therapist needs to select the patient they are attending to through the database search (Figure 1B). Upon selecting the patient, the word list options are presented for the therapist to select which one needs to be trained during the session (Figure 1C). The speech therapist could use the platform for treatment and indicate to the patient which lists should be practiced at home. However, the patient interface functions are limited and operate differently from the speech therapist's interface.

The patient is not permitted to create, alter, or delete lists. Furthermore, the training will be limited to the list indicated by the speech therapist responsible for their treatment, and they cannot choose autonomously.

Upon logging into the application, the user is presented with the screen illustrated in Figure 2A. The "Logout" and "Settings" buttons function like the speech therapist's interface. Clicking the button to start training presents the theme selected by the speech therapist (Figure 2B) for that particular training, which begins by pressing the "Start Task" button. Both interfaces allow for app customization to ensure accessibility. Users can adjust contrast, font size, and sound volume. The buttons are designed in sizes that allow the patient to handle the app independently, which is important as many patients have impaired motor skills due to their injuries. The interfaces contain only the necessary information to avoid user confusion and errors. The texts are designed to be large enough for comfortable reading, avoiding excessive text on the screens. Care was taken to select colors that facilitate visibility and differentiation between buttons, text, and other elements. The treatment execution has the same interface regardless of the user type. After completing the necessary steps and starting the training, a screen is displayed with the image of the object (Figure 3). The screen also includes four buttons at the bottom: two for navigating between words, indicated by the letter A (previous and next); one to count correct answers (B); and another for the patient to try again (C). The list being trained is indicated at the top.

Additionally, the screen includes three more buttons in the designated area. One of the buttons expands the screen (D), allowing the patient to view the object more clearly if necessary (Figure 4). The other two buttons are related to hint options. The button indicated by the letter E activates the semantic hint, where an object associated with the object that needs to be identified is displayed on the screen (Figure 5). The button indicated by the letter F activates the spelling hint, where the word is presented one letter at a time.

A reward system was also added to encourage the patient to participate in treatment. The player earns a coin for each correctly named object in this system. This reward is an incentive, as the patient undergoing treatment aims to name the words correctly to earn more coins or rewards.

**Figure 2.** A. Patient interface. B. Start task patient interface.

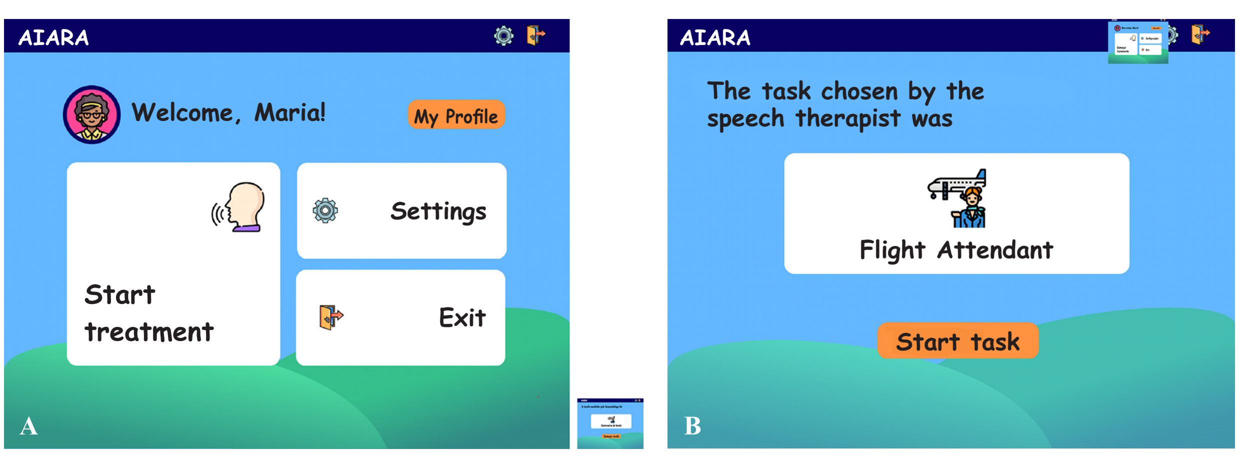


**Figure 3.** Training page.

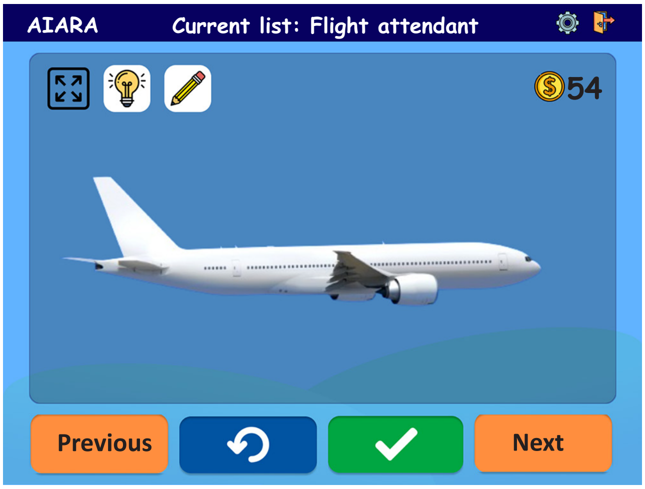



**Figure 4.** Image with zoom-in.


**Figure 5.** Semantics tip.

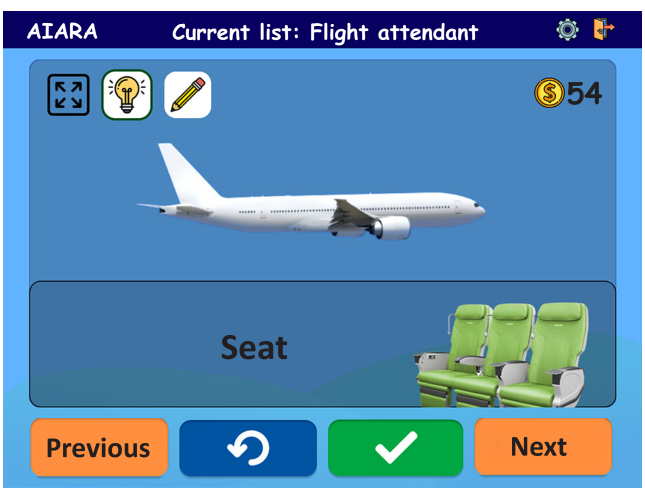
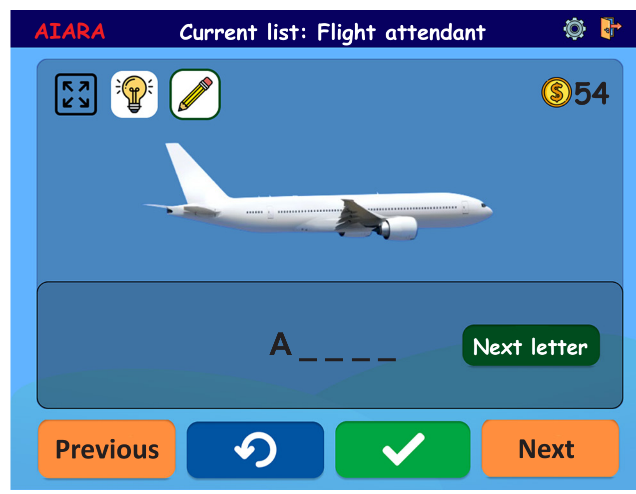



**Figure 6.** Spelling tip.




There is no deduction of coins for incorrect identifications, as implementing such a rule could have the opposite effect on the reward system's objective. However, errors are recorded with each new attempt, along with correct identifications, for logging in to the patient's profile. These records serve as a way to track progress and allow the speech therapist to analyze more precisely which adaptations are necessary and need to be made throughout the rehabilitation process.

## Conclusion

With the development of the functional prototype of an application that can support aphasia rehabilitation through the task of object naming, it was possible to verify that this tool could be an important resource in the treatment. The intention is to model the application based on the developed prototype so that it can be implemented and made accessible to speech therapists and aphasic patients.

Moreover, using additional resources can contribute to word recovery and improve patient communication and quality of life. Tasks such as object naming, especially when assisted by gamified technologies, are practical in various contexts, emphasizing the need for personalized and adaptable treatments.

The prototype can aid in the development of the application and contribute positively to aphasia treatment, helping recover the patient's communication skills and promoting a better quality of life and autonomy.

The next research phase, which aims to develop and implement the application, is also expected to fill the gaps found in similar services identified during the systematic review by offering an interactive naming system that encourages recovery and autonomy for aphasic individuals.

The prototype can promote the continuation of treatment outside the clinical environment by considering the creation of user-friendly and accessible interfaces for speech therapists and patients. This is essential for consolidating acquired skills through repetition and reinforcement. A reward system and auxiliary hints can enhance patient engagement, making the rehabilitation process more motivating and effective.

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# Building Citizens: The Educational Role of the 'New Ekinata' Project in Obtaining Documents by Young People

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**The 'New Ekinata' project introduces an innovative approach to civic education for young Brazilians by focusing on acquiring essential documents for citizenship. The project proposes the development of a mobile game designed to educate and engage youth in obtaining documents, understanding their requirements, and appreciating their significance in societal life. This initiative addresses the information gap many young people face, empowering them to understand and exercise their rights and duties. The game seeks to make learning more engaging and practical, with a detailed analysis planned at the project's conclusion to assess its development, impact on civic awareness, and contribution to facilitating access to essential documents.**
**Keywords: Young People. Documents. Game. Citizenship.**

In the Brazilian context, obtaining essential documents for citizenship can be challenging, particularly for young people. There is a pressing need for initiatives that raise awareness and facilitate access to information on this crucial topic. In response to this need, the "New Ekinata" project introduces an innovative approach to civic education by developing a mobile game. The primary objective of this game is to provide a didactic and engaging method for explaining the document acquisition process, detailing its requirements, and emphasizing its significance for active participation in society. This initiative aims to enhance civic awareness and facilitate document access among young Brazilians, highlighting the project's purpose and potential positive impact on the target audience.

## Materials and Methods

The methodology adopted for the "New Ekinata" project involved a focused study and development process centered around creating a mobile game for civic education. Over a year, the project was primarily conducted domestically, utilizing team members' machines. Remote collaboration, facilitated through online communication and file-sharing tools, was crucial to the project's progress.

Although the game's target audience included college students and individuals interested in civic education, there was no requirement to collect specific field data from this population. Data analysis was primarily conducted at college events, where user feedback was gathered at various project stages.

Quantitative and qualitative analyses assessed the game's effectiveness and user engagement. Ethical standards were upheld throughout the project, including obtaining informed consent from participants when applicable and ensuring their privacy was respected during all phases of the research.

Using games for learning is widely recognized as both practical and engaging. According to Gee (2003) [1], games provide unique opportunities for learning by encouraging problem-solving, critical thinking, and collaboration among players. Thus, educational games like the one developed in the "New Ekinata" project can significantly enhance civic education and improve user engagement.

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## Results and Discussion

Analysis of the "New Ekinata" reception reveals predominantly positive feedback among users who tried the game. In particular, there was a strong appreciation for the artistic elements employed, highlighting the game's visual quality and aesthetic appeal. The game's dynamics were also well-received, with users noting their ability to keep players engaged and entertained throughout the experience. However, some observations were made regarding the game's complexity. Multiple users expressed difficulties with certain aspects, considering them somewhat complex. This perception may have impacted the game's accessibility and overall user experience. In response to this feedback, changes and adjustments were implemented in the game after Computing Week to make it more intuitive and accessible to a broader range of users.

## Results and Discussion

These insights highlight the importance of involving users in the game development process. The ability to adapt and adjust the game based on user feedback and experiences is crucial for ensuring its effectiveness and relevance. The initial positive feedback, combined with the modifications made, suggests the promising potential for "New Ekinata" as both an educational tool and a means of civic awareness.

## Conclusion

The "New Ekinata" project represented an enriching journey in game development, offering a valuable opportunity to gain knowledge in various areas. The extensive research on game design, applications in Unity, and the use of the C# language significantly contributed to a deeper understanding of the game creation process. Additionally, the project provided in-depth learning about the procedures for obtaining documents in Brazil, emphasizing each document's importance in society. Combining these elements, "New Ekinata" provides entertainment, educates, and raises awareness among players about essential civic issues. This project reflects a commitment to innovation, continuous learning, and the desire to positively impact society through technology and education.

## Acknowledgments

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# Use of Artificial Intelligence and Sizing and Simulation Software in Photovoltaic Plants

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**This academic study investigates the application of sizing and simulation software, such as PV*SOL and PVSYST, to analyze actual data collected from solar plants in Petrolina (PE), Messias (AL), and Piranhas (AL), comparing it with meteorological data from nearby stations. The study's objective is to assess the accuracy and effectiveness of these tools in implementing, testing, and monitoring solar plants. Essential factors in photovoltaic project design include meteorological data, site shading, module orientation, geographic location, temperature-induced losses, electrical components, equipment, and climate change considerations. The analysis covers January to December 2023, using hourly data from reliable meteorological inputs. These software tools aid in system sizing by incorporating multiple factors and estimating energy output, which is crucial to closely matching predicted energy production with actual performance. The quality of meteorological databases and mathematical models impacts software performance, necessitating efforts to filter, qualify, and catalog data sources. Production results indicated an annual output of 3,796 MWh for the Petrolina plant and 1,027 MWh for the Messias II plant, with measured data showing a 5% to 12% variation from estimated figures. Furthermore, the study incorporates Neural Designer, a machine learning-based neural network software, to conduct additional comparative analyses. The findings provide insights into site selection, equipment, plant characteristics, operational practices, and alignment of energy production with software predictions, offering recommendations for improvements and identifying potential locations for future solar farms.**
**Keywords: AI. Photovoltaic Plants. Brazil.**

Photovoltaic generation (PVG) is marked by the inherent intermittency of solar resources, requiring careful management to ensure a stable electricity supply to the grid. Accurate PVG predictions can reduce the net cost of generation and contribute to grid security [1]. Solar forecasting minimizes the need for backup resources in energy imbalance markets, helping balance energy supply and demand [2].

Solar forecasting methods analyze the behavior of solar resources or PVG time series, using historical data from the series or other influencing factors to make predictions [3]. Solar forecasting techniques are classified into statistical, machine learning, physical, and hybrid approaches [4]. Machine learning models have gained prominence for hourly solar forecasting in recent years, and numerous studies have validated their effectiveness [5].

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Photovoltaic plants experience predictable operational losses that impact performance, including ohmic losses in cabling [6], dust accumulation, light-induced degradation (LID) [7], and degradation over the module's lifespan, typically less than 1% per year [8]. Additional energy losses occur during the conversion from direct current (DC) to alternating current (AC) in the inverter [6].

Therefore, monitoring photovoltaic installations' energy output is essential to detect efficiency reductions caused by anticipated losses or environmental factors. For instance, a rainy year could reduce energy production due to diminished sunlight exposure rather than increased losses. Several parameters, including solar radiation on PV modules and ambient temperature, influence the energy output of a PV system [9]. Accurate, local data collection near the installation site is critical for making reliable predictions and ensuring an optimal return on investment [10].

Recognizing the need for metrics to improve efficiency and predictability in solar plants, this study utilizes artificial intelligence and statistical and computational comparison methods to optimize renewable energy production and forecast performance. Integrating actual data with estimated results creates a database with diverse scenarios and plant types. This custom-architected software analyzes data through neural networks, aiding in predictive modeling. Over one year, the study provides insights that can help identify which locations will yield higher productivity, which months will generate the most energy, and much more, ultimately guiding investors and consumers on the optimal timing and location for installing solar power systems.

The photovoltaic cell operates based on the photovoltaic effect, utilizing semiconductor material, which has properties between a conductor and an insulator. Silicon, which visually resembles sand, is the primary semiconductor in the solar panels studied here. Pure silicon crystals lack free electrons, making them poor conductors. However, adding small amounts of other elements, a process known as doping enhances conductivity. When silicon is doped with phosphorus, the resulting material gains negatively charged free electrons, creating N-type silicon. Alternatively, doping with boron produces P-type silicon with positive charges. When N-type and P-type silicon are layered together (Figure 1), they form an electric field upon exposure to light, creating the environment necessary for the photovoltaic effect to occur. This effect enables the conversion of solar energy into electrical energy.

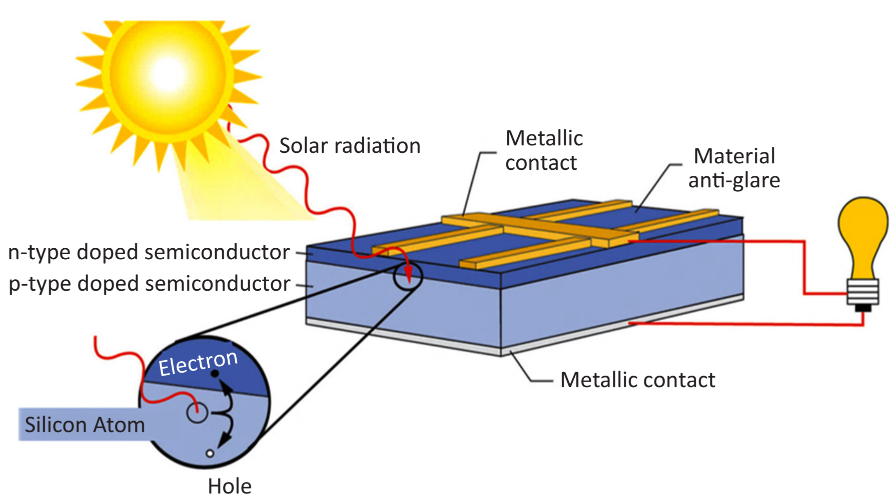
**Types of Photovoltaic Panels**

**Monocrystalline Silicon (mono-Si) Cells**: These cells use older technology but are highly efficient. They convert 14%–21% of sunlight into electricity. Their high efficiency allows for more energy generation per unit area, requiring less space than polycrystalline or thin-film cells.

**Polycrystalline Silicon (poly-Si) Cells**: Made from the same raw material as monocrystalline cells, poly-Si cells differ in crystal formation. They are produced by casting silicon into a block, making multiple crystals visible in each slice. This structure gives polycrystalline cells an efficiency of 13%–17%, slightly lower than monocrystalline cells.

**Thin-Film Cells**: Thin-film technology involves applying a layer of material, such as cadmium telluride (CdTe), copper indium gallium selenide (CIGS), or amorphous silicon (a-Si), to a flexible or irregular surface. Although their efficiency is lower (7–13%), they are more cost-effective and offer greater application flexibility.

**Figure 1.** Schematic of the photovoltaic effect on the silicon atom.



### Components of a Solar Plant

**Solar Panels**: The core components that convert solar radiation into direct current (DC).

**Charge Controllers**: They regulate the charge in batteries, preventing overcharging or deep discharges and thus extending battery life.

**Inverters**: Often considered the "brain" of the system, inverters convert DC to alternating current (AC) and can raise voltage levels (e.g., from 12V to 127V). In some setups, inverters may connect to other generators or the grid.

**Batteries**: Acting as the system's "lungs," batteries store electricity for use when solar power is unavailable, such as during the night or on cloudy days.

### Types of Photovoltaic Systems

**Grid-Tied Systems**: These systems connect to the electrical grid and can supply energy for general grid use. Unlike isolated systems, grid-tied systems do not require batteries or charge controllers, making them simpler and more efficient for a broad energy supply.

**Off-Grid Systems**: Isolated or autonomous, these systems are not connected to the grid. They directly power appliances and are generally designed for specific, local use.

**Hybrid Systems**: These systems combine photovoltaic energy with other power sources, such as wind turbines or diesel generators. Hybrid systems are versatile, as they can connect to the grid, operate in isolation, or be supported by the grid as needed.

### Solar Potential in Brazil

Brazil's vast land area and extensive rooftop space in residential and commercial buildings, combined with high solar irradiance, present substantial potential for centralized and distributed solar generation. The Brazilian Solar Energy Atlas, published in 2017 by the National Institute for Space Research (INPE), indicates that the Northeast region has the highest average annual solar irradiation values (5.52 kWh/m² per day) and the lowest interannual variability [15]. This high irradiance, coupled with low precipitation and minimal cloud cover, especially in semi-arid areas, makes the Northeast a priority for solar energy investments, as evidenced by public and private projects.

### Study Locations and Proposed Photovoltaic

Plant

This study analyzes three locations: Petrolina (PE), Messias (AL), and Piranhas (AL), with Piranhas as a potential future site for photovoltaic projects. The planned plant will be located near Petrolina in an area designated as a Solar Energy Research Platform. Located along the São Francisco River, approximately 722 km from Recife in Pernambuco, Petrolina is a notable center for tourism and agricultural exports, especially fruits and wines. It has robust air and road infrastructure (including access via highways BR-232, BR-110, PE-360, BR-316, BR-428, and BR-122), as well as proximity to the Neoenergia (Companhia Energética de Pernambuco) 13.8kV distribution line, which is less than 100 meters from the project site at coordinates 9.39416° S, 40.5096° W.

The photovoltaic plant is situated in the São Francisco Pernambucano backlands, which features a tropical semi-arid climate (BSh). The terrain is flat with gently undulating features and typical caatinga vegetation adapted to the arid conditions. The soil is stony, with limestone and clay deposits. Historical meteorological data for the area indicate an annual average of 7.8 hours of sunshine per day, yielding approximately 5.38 kWh/m²/day (or 19.38 MJ/m²/day) in solar irradiation, an annual ambient temperature averaging 26.34°C, and an average annual rainfall of 538.7 mm.

Messias, located in Alagoas, spans 113.8 km² with a population of 17,856. The population density is about 156.9 inhabitants per km². Positioned 12 km Northeast of Rio Largo, Messias is bordered by Rio Largo, Murici, and Flexeiras. At an elevation of 104 meters above sea level, Messias experiences a tropical, hot, and humid climate with an average annual temperature of 24°C and rainfall of around 2,200 mm. The precipitation pattern is seasonal, with May, June, and July being the wettest months, while December through February are the driest.

## Materials and Methods

Meteorological Data Collection Equipment (Table 1)

Critical for photovoltaic assessments, solar radiation data can be limited by location and measurement frequency. Solar radiation reaching the Earth's surface includes two primary components:

**Direct Radiation**: Sunlight that reaches the ground without deflection.

**Diffuse Radiation**: Sunlight scattered by atmospheric particles.

For precise solar resource assessment, both components are measured on inclined surfaces, such as photovoltaic (PV) modules. This data is gathered through specialized equipment, including pyranometers and pyrheliometers, which record solar radiation intensity. However, the cost of installing and maintaining these instruments at each distributed generation site is often prohibitively high (National Institute of Meteorology) [16]. These include:
**Heliograph**: Measures the duration of direct sunlight exposure (Figure 2A).
**Actinograph**: Continuously records solar energy reaching the area (Figure 2B).
**Pyranometer**: Accumulates the total solar energy incident throughout the day (Figure 3).

This advanced setup enables reliable data collection for energy modeling, ensuring that photovoltaic systems are accurately sized and capable of meeting their energy generation goals.

A pyrheliometer (Figure 3) measures direct solar irradiance. Sunlight enters the device through a window and is directed onto a thermopile, which converts the heat into an electrical signal. This signal's voltage is then processed using a specific formula to determine the irradiance in watts per square meter (W/m²) [11-14].

**Table 1.** Equipment present in the photovoltaic plant.

| Instrument | Quantity | Variable |
|---|---|---|
| Anemometer | 1 | Wind direction and speed |
| Pyranometer First Class | 2 | Global solar radiation |
| Humidity sensor and temperature | 1 | Humidity and temperature |

**Figure 2A/B.** Heliograph and Actinograph.


**Figure 3.** Pyranometer.

Climatological Stations at Solar Plants

Chef has established a climatological monitoring platform to improve data accuracy at the solar plants studied. This platform contains essential meteorological instruments for acquiring precise local data (Figure 4). The station complements government-run facilities by providing additional data and enabling a comprehensive regional analysis of solar resources. This setup assists in better understanding local climate patterns, ensuring a more accurate assessment of solar energy potential and operational efficiency at the plant locations.

The pyranometer (Figure 5) is a device used to measure solar radiation on a flat surface. It is designed to measure the density and solar radiation flux (W/m²) from the above hemisphere within a wavelength range of 0.3 µm to 3 µm.

**Figure 4.** Chesf climatological tower.

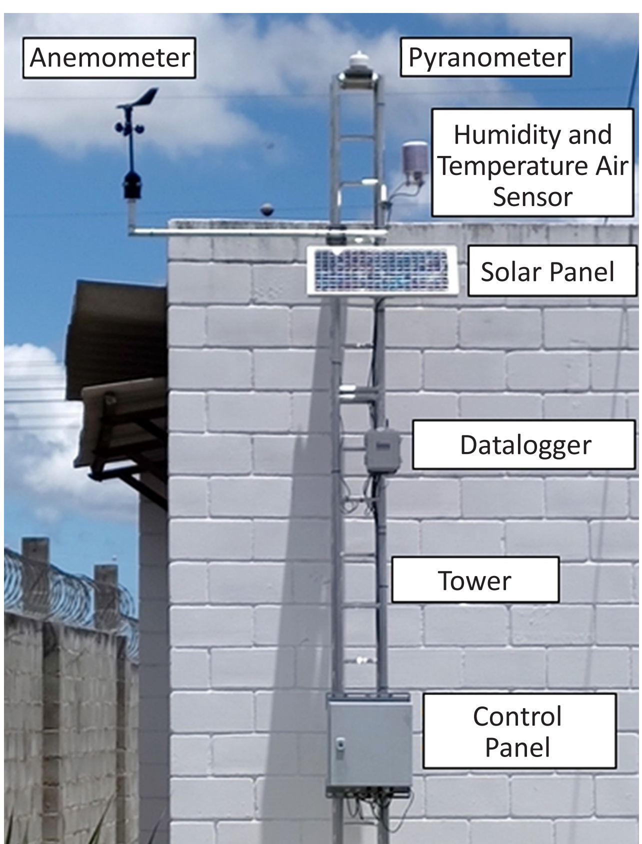



**Figure 5.** Pyranometer.

Other Data and Meteorological Sources

**INMET (Instituto Nacional de Meteorologia) [15] and Partner Institutions**: They provide access to meteorological products, allowing for the overlay of various data layers, such as satellite images, weather forecasting models, and severe weather alerts.

**LABMET (Meteorology Laboratory)**: LABMET, the meteorology laboratory affiliated with the Federal University of Vale do São Francisco (UNIVASF), was established to support undergraduate and postgraduate courses. The laboratory also plays a crucial role in supporting agricultural activities in the region and providing the public with reliable information on weather and climate conditions. To achieve this, a state-of-the-art infrastructure was set up to monitor weather and climate variables and conduct agrometeorological research in the semi-arid region.

**Global Solar Atlas (Solargis) [16]**: The primary goal of the Global Solar Atlas is to offer quick and easy access to solar resource data and photovoltaic energy potential worldwide. It includes GIS layers and poster maps that showcase the resource potential on global, regional, and national scales.

Other Researched and Utilized Sources

- Meteonorm (used in Pvsol and Pvsyst for comparison);

- Copernicus Climate Atlas (for data comparison);
- Brazilian Solar Energy Atlas (for studies and analysis);
- Virtuxsolar (for observation of polarimetric data by latitude and longitude);
- CAMS Forecasts;
- CRESESB - Reference Center for Solar and Wind
- Energy Sérgio Brito;
- SUNDATA (CRESBES);
- UNESP - Agrometeorology and Solar Radiometry Laboratory (to observe solar ephemerides);
- Labren/Sonda/Redesolpe (for comparison studies).

Dimensioning and Simulation Software: To size a photovoltaic (PV) project, several factors must be considered, including ohmic losses, shading, module tilt angles, solar trajectory alignment, geographic location, and temperature-related power losses, as well as other electrical and climatic factors. Many of these are difficult to predict without the aid of a reliable meteorological database [17].

Given the numerous variables, photovoltaic simulation software can assist in the system sizing process by factoring in the considerations mentioned above. Such software should produce accurate results, as it is crucial to have a tool capable of predicting energy generation that closely matches the actual energy produced by an installed system.

The performance of this software also depends on the quality of the meteorological database and the mathematical models it employs [18].

Some commonly used software for PV system sizing include PVSYST [19] and PV*SOL [20]. It is important to note that these are paid tools, and Neural Designer will also be used for machine learning and neural network-based analysis. These software packages require annual fees or fixed costs for each version. Studies such as those by Machado and colleagues [21] and Silva and colleagues [22] have already compared the performance of the software mentioned (excluding SAM) with actual energy generation data from photovoltaic systems at various Chesf (Eletrobras) facilities in Petrolina - PE, Messias - AL, and Piranhas - AL.

The present study aims to compare PV*SOL and PVSYST by comparing simulation results with the actual energy outputs of the respective photovoltaic installations. This will allow for assessing the software's accuracy in forecasting energy production relative to actual system outputs in solar plants and determining whether the results are within the limits proposed in existing literature. PVSYST is widely recognized in academic and commercial sectors, making it an essential reference for this study.

For statistical analysis, the percentage difference between measured and estimated power will be calculated based on basic power calculations and the estimates produced by each software program included in the study.

Cell Output Power

Various factors, such as cell temperature, time of year, wind speed, ambient temperature, and geographical position, complicate accurately determining the energy production of a photovoltaic cell. Additionally, the efficiency of the cell (ηcell) decreases with increasing cell temperature, which directly impacts the output power (Pcell). Using the Total Power of Continuous Energy (PTEC) method, energy production can be estimated by integrating instantaneous generation over time for the module area, applying the formulas in Equations 1 and 2.

$$P_{cell,i} = A_{cell}\,\eta_{cell,i} G_i \qquad \text{Eq. 1}$$

$$Q_{pv,i} = A_{pv}\, G_i\, \eta_{eff,i}\, 30 \qquad \text{Eq. 2}$$

Where:

- Apv or Acell = area of the PV plate (m²);
- ηcell, *i* = efficiency of the PV plate (%);
- *Gi* = solar radiation (W/m²);
- 30 = days of a month;
- i = number of months.

Period Analyzed, Qualification, and Data Filters

In this study, meteorological and radiation data were analyzed using data collected from both power generation and meteorological measurement equipment at Chesf (Eletrobras) solar plants involved in the research (Table 2).

The analyzed and proposed period is from 01/01/2023 to 12/31/2023, with hourly intervals of 01h (one hour), as made available by meteorological stations and downloaded from the INMET, LABMET system, and other meteorological data sources used in the study.

With a 13-hour analysis interval multiplied by 365 days for the year 2023, we will have 4745 data for each variant. Taking into account 7 to 8 variables studied, this totals a coverage of 33215 to 37960 items.

Another key aspect of the study was analyzing the locations of meteorological stations in relation to solar plants to enhance accuracy. Table 3 presents the respective distances.

Pre-treatment of Meteorological Data

It is recommended that the meteorological data selected undergo pre-treatment to ensure its quality and reliability. This process should include the following steps:

**Time Filter**: Select data from 05:00 to 18:00, corresponding to the solar cycle and the period of maximum usable radiation.

**Data Cleaning**: Filter out null, discrepant, and negative values within this time frame.

**Missing Data Estimation**: Apply the curve adjustment technique using averages for the specific period to estimate missing data.

**File Preparation**: Prepare CSV and TXT files for importing into the applications used in this study.

**Software Data Analysis**: Some tested software tools include interfaces that analyze the imported data.

**Literature Review**: Further investigation of related data and literature can help refine the analyzed

These tools generate logs and alert or error messages if null, discrepant, or erroneous data is detected. Sometimes, the software identifies the problematic

**Table 2.** Geoclimatic information on photovoltaic plants.

| Location | Altitude (m) | Cloudiness Annual Average (tenths) | Rains (mm) | Climate |
|---|---|---|---|---|
| Petrolina | 385 | 0.5 | 430 | Semiarid |
| Messias | 104 | 0.5 | 777 | Tropical Rainy |
| Piranhas | 88 | 0.5 | 492 | Tropical |

**Table 3.** Station identification and station distance photovoltaic plant.

| Location | Station Chosen | Distance from the Station by the Plant (Km) |
|---|---|---|
| Petrolina | LABMET/CHESF | 23 |
| Messias | INMET/UFAL/CHESF | 12 |
| Piranhas | INMET/UFAL | 4 |

data, prompting the user to review and correct it. meteorological data source.

Solar Plant Location Suggestion in Piranhas (AL)

For selecting the location of the solar plant within the Chesf (Eletrobras) facilities' territorial area, the following criteria were considered:

- **Proximity to Electrical Infrastructure**: The site should be close to existing electrical installations within the Chesf (Eletrobras) network.
- **Proximity to Meteorological Stations**: The location should be near a meteorological station or a research center focused on meteorology.
- **Radiation Levels and Feasibility**: The site should have favorable radiation rates to implement a photovoltaic system.
- **Accessibility**: The site should be easily accessible and ideally located near a medium-sized city, facilitating labor availability, construction, and commissioning.
- **Educational and Research Opportunities**: The presence of technical or higher education institutions nearby could provide qualified labor and allow the plant to serve as a reference for academic studies. Expanding knowledge areas and Chesf (Eletrobras) would benefit the educational institution by developing human capital and expertise.

Methodology for Location Selection

In addition to the factors outlined above, the Brazilian Solarimetric Atlas (Version 2000) – Cresesb was used, focusing on the areas of Piranhas (AL) and Canindé do São Francisco (SE), near the Chesf (Eletrobras) complex in Xingó.

Three potential points of interest were identified with the support of the Global Solar Atlas (Solargis) platform. These points were selected based on their distance to the local meteorological station and the Chesf facility (Substation SE Xingó 69 kV). They are referred to as Point 1, Point 2, and Point 3.

Another critical aspect of the research was investigating the nearby meteorological stations, assessing their data collection capabilities, and evaluating their operational status.

## Results and Discussion

During this work, the broad possibilities of using sizing, simulation, and neural network software for use in photovoltaic plants were emphasized, especially Cresp solar plants – Solar Energy Reference Center of Petrolina (PE), Messias II (AL) and as a suggestion, a possible design and implementation of a solar plant in the city of Piranhas (AL), as this location has Chesf (Eletrobras) facilities.

This section addresses the methodological procedures for comparing and evaluating the use of global solar irradiation (GHI) databases obtained through INMET, Labmet, and other meteorological sources and validating their use in solar energy systems.

The methodology continues to obtain global solar irradiation data from the two databases for the chosen cities and compare them using graphs and statistical indicators. These cities were selected because they have local meteorological stations and solar plants from Chesf (Eletrobras).

As sensors are susceptible to errors, some radiation or meteorological information may not be in the bank. Therefore, a broader data search is carried out.

Measurement Data

*Cresp Photovoltaic Plant – Petrolina (PE)*

Data from the Cresp Petrolina solar plant were collected, and an online database was downloaded from the SCADA WEG software platform (Table 4).

*Photovoltaic Plant – Messias (AL)*

In the Messias II plant, data from the GOODWE platform shows that the total output comes from seven inverters, each with a 25 kW capacity, though one inverter is currently offline, resulting in an active output of six inverters at 100 kW each. According to the project's descriptive memorandum and calculations (Resende [23]), technical specifications of the modules and inverters are outlined. Simulations run in PVSyst software (version 6.35) estimate an annual energy generation of 1.431 MWh for the designed system (Table 5).

Table 6 summarizes all the meteorological variables used in the study and in the three locations observed, considering their monthly average.

In Table 7, we can observe the GHI and LAT values for the studied locations. Below, we have the explanatory legend of these types of radiation. It is worth noting that in this present study, we focused on the two types of radiation due to their particularities and uses in the academic and project fields.

**Table 4.** Generated energy Petrolina (PE).

| | 2020 | 2021 | 2022 | 2023 |
|---|---|---|---|---|
| **Real Energy (MWh)** | 3428.77 | 3822.51 | 3467.34 | 3796.64 |

**Table 5.** Generated Energy Messias (AL).

| | 2020 | 2021 | 2022 | 2023 |
|---|---|---|---|---|
| **Real Energy (MWh)** | 122.67 | 72.51 | 107.08 | 118.19 |

**Table 6.** General table of meteorological data.

| | | Jan | Febr | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Petrolina** | **Temp. °C** | 28 | 28 | 28 | 27 | 27 | 25 | 25 | 25 | 27 | 28 | 29 | 28 |
| | **Rain mm** | 62,8 | 80.2 | 101.7 | 49.5 | 8 | 4.6 | 3 | 1.8 | 3.3 | 11.1 | 45.8 | 63.8 |
| | **KT Index** | 42.4 | 48.9 | 46.8 | 40.6 | 38.6 | 38.2 | 41.3 | 31.3 | 24.6 | 25.4 | 47.4 | 42.9 |
| | **Humidity %** | 58 | 63 | 67 | 70 | 64 | 61 | 60 | 53 | 48 | 48 | 50 | 54 |
| | **Wind Km/h** | 23.4 | 21.4 | 20.5 | 20.6 | 22.4 | 23.6 | 25.4 | 26.4 | 25.4 | 24.2 | 22 | 21 |
| **Messias** | **Temp. °C** | 26 | 27 | 27 | 26 | 25 | 24 | 23 | 23 | 24 | 25 | 26 | 26 |
| | **Rain mm** | 18.1 | 23.2 | 44.5 | 131.3 | 199.8 | 199.6 | 199.2 | 52.7 | 22.7 | 28.2 | 11.4 | 13.3 |
| | **KT Index** | 37.6 | 33 | 37.3 | 37.2 | 48.8 | 49.3 | 49.3 | 52.6 | 47.2 | 41.4 | 39.8 | 40 |
| | **Humidity %** | 75.9 | 70.4 | 66.9 | 78.5 | 84.9 | 75.4 | 65.1 | 75.8 | 83.6 | 82.1 | 79 | 78.7 |
| | **Wind Km/h** | 24.8 | 23.6 | 20.9 | 19.8 | 18.8 | 21 | 21.5 | 23.1 | 22.2 | 24.1 | 26.8 | 25.4 |
| **Piranhas** | **Temp. °C** | 29 | 29 | 29 | 28 | 26 | 25 | 24 | 24 | 26 | 28 | 29 | 29 |
| | **Rain mm** | 34.3 | 40.4 | 53.3 | 61.8 | 71.3 | 60.3 | 58 | 27.8 | 14.7 | 12.8 | 22.3 | 38.8 |
| | **KT Index** | 40.3 | 37.8 | 32.9 | 45.2 | 37.4 | 33.9 | 35.3 | 38.8 | 37.2 | 47.5 | 60.2 | 54.3 |
| | **Humidity %** | 53.1 | 52.1 | 57.8 | 66.9 | 76.2 | 78.6 | 78.5 | 72.5 | 67.8 | 61.7 | 64.5 | 62.6 |
| | **Wind Km/h** | 24.1 | 23.8 | 22.6 | 18.9 | 17.5 | 18.4 | 19.8 | 22.2 | 24.7 | 28.9 | 27.2 | 27.7 |

GHI: Global Horizontal Irradiation; LAT: Global irradiation at the tilt of the local latitude.

**Table 7.** GHI and LAT comparison in the 3 locations (kWh).

| | Petrolina | | Messias | | Piranhas | |
|---|---|---|---|---|---|---|
| **Irrad.** | **GHI** | **LAT** | **GHI** | **LAT** | **GHI** | **LAT** |
| **Anual** | 5.76 | 5.78 | 5.22 | 5.22 | 5.47 | 5.47 |
| **Jan** | 6.38 | 6.00 | 5.87 | 5.53 | 6.31 | 5.94 |
| **Feb** | 6.16 | 5.96 | 5.83 | 5.64 | 6.06 | 5.86 |
| **Mar** | 6.02 | 6.03 | 5.84 | 5.85 | 5.97 | 5.98 |
| **Apr** | 5.24 | 5.44 | 5.06 | 5.25 | 5.32 | 5.53 |
| **May** | 4.82 | 5.16 | 4.23 | 4.52 | 4.47 | 4.78 |
| **Jun** | 4.57 | 4.97 | 3.90 | 4.21 | 4.07 | 4.41 |
| **Jul** | 4.82 | 5.19 | 4.00 | 4.30 | 4.20 | 4.51 |
| **Aug** | 5.55 | 5.84 | 4.57 | 4.79 | 4.83 | 5.08 |
| **Sep** | 6.32 | 6.4 | 5.39 | 5.45 | 5.66 | 5.73 |
| **Oct** | 6.40 | 6.24 | 5.67 | 5.53 | 5.96 | 5.81 |
| **Nov** | 6.50 | 6.16 | 6.16 | 5.84 | 6.43 | 6.09 |
| **Dec** | 6.38 | 5.95 | 6.11 | 5.70 | 6.36 | 5.93 |

We cannot forget the chosen arrangement and the results obtained by the Neural Network using the Neural Designer software (Table 8).

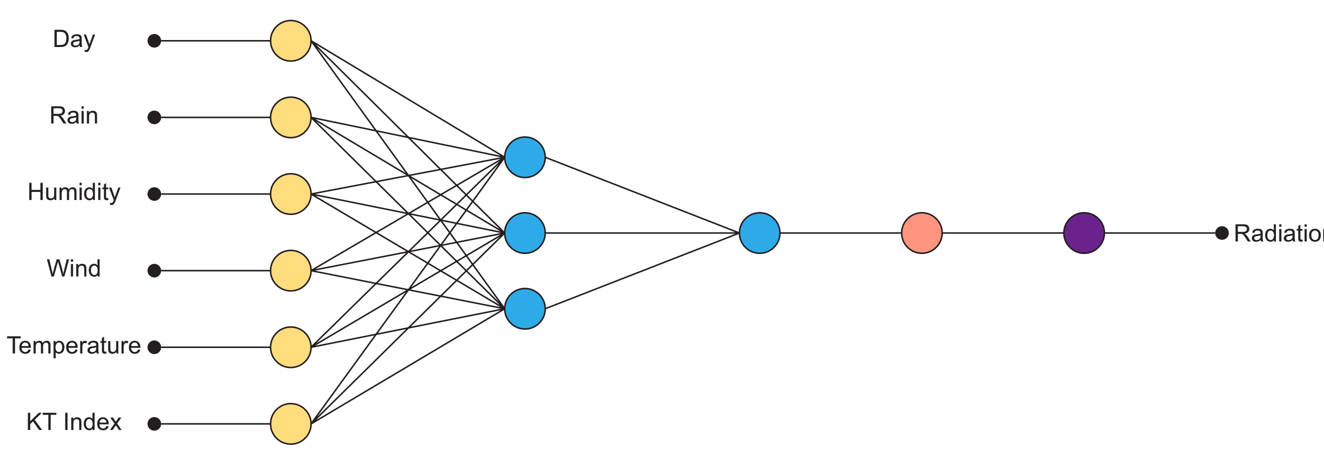
Figure 6 shows a graphical representation of the network architecture.

Although this paper focuses on comparisons between measured and estimated energy production, we have added a goodness-of-fit plot between the

**Table 8.** Perceptron framework.

| Perceptron Layer | Number of Entries | Number of Neurons | Activation Function |
|---|---|---|---|
| 1 | 6 | 3 | Hyperbolic Tangent |
| 2 | 3 | 1 | Linear |

**Figure 6.** Neural network model.




Scaling layer with 6 neurons (yellow; perceptron layer with 3 neurons (blue); perceptron layer with 1 neuron (blue; de-scaling layer with 1 neuron (red); bounding layer with 1 neuron (purple).

same variables to demonstrate how well a statistical model fits a set of observations. Goodness-of-fit measures are used to measure the discrepancy between observed values and expected values under a probability model (Figures 7 and 8).

Table 9 below shows the data arrangement, number of samples, and percentages of samples chosen for each stage of the neural network calculations.

Concerning the proposed location of a plant in the Piranhas region (Alagoas), results from the three observed points are presented as follows. Another key aspect of the research involved identifying nearby meteorological stations, assessing data availability at these sites, and evaluating their operational status. To support this, the Atlas Solar Global platform (Solargis) was utilized, enabling measurement and sizing on an embedded map. Using this platform, three specific points of interest were selected (Figures 9-11).

The website (Forensically Beta, 2024) facilitates uploading saved images for analysis. Once the image is uploaded, it appears on the main screen. By selecting the "Level Sweep" tab and applying the adjustments shown in the image below, the darkest points on the polarimetric map section are highlighted. This step helps identify areas with the highest irradiation levels (Figure 12).

Table 10 presents the results for the three points, with a particular emphasis on point 3, where the sample shows the best results aided by the Global Solar Atlas.

Tests were conducted using PVSYST, PVSOL, and Neural Designer software, with estimated radiation values calculated from both measured and projected data. Following this, the comparison

**Figure 7.** Estimated and measured radiation - Goodness of Fit Cresp Petrolina in kWh.

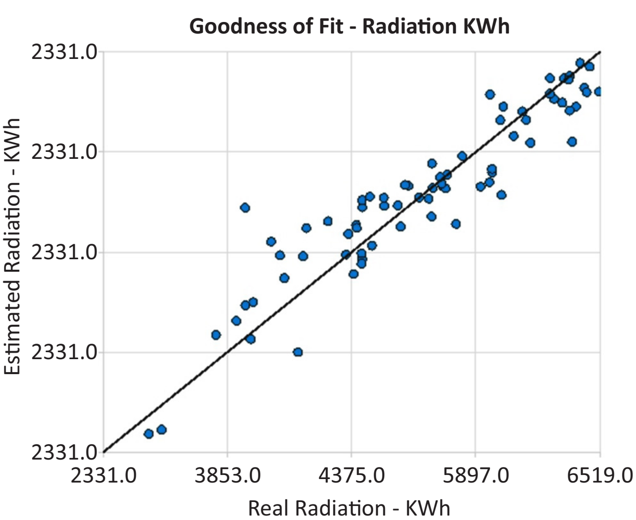



**Figure 8.** Estimated and measured radiation - Goodness of Fit Messias in kWh.

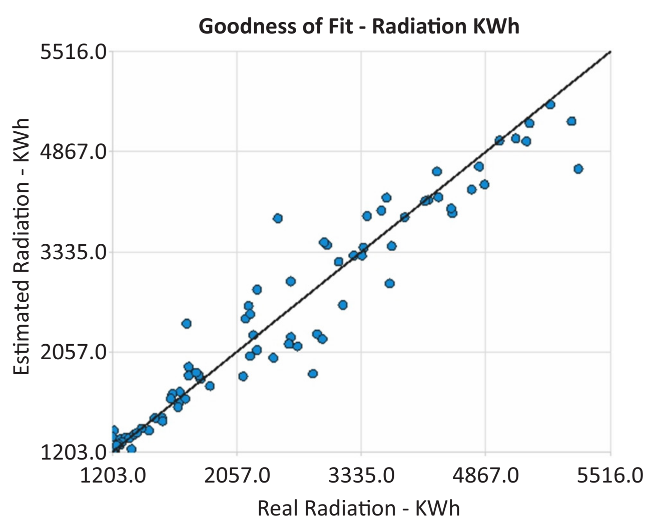
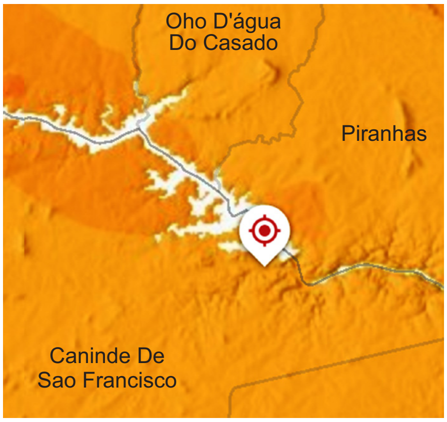



**Table 9.** Sample chart.

| | Petrolina | Messias | Piranhas | % Samples |
|---|---|---|---|---|
| **Training Samples** | 2697 | 2441 | 2248 | 60% |
| **Selection Samples** | 899 | 813 | 749 | 20% |
| **Test Samples** | 899 | 813 | 749 | 20% |
| **Unused samples** | 0 | 0 | 0 | 0% |

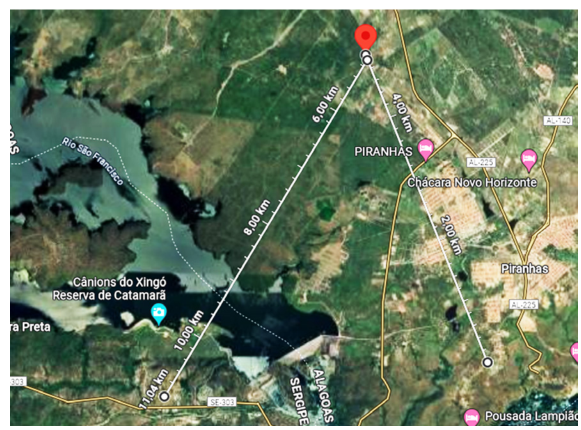
**Figure 9.** Point 1: Close to Canindé do São Francisco, next to the substation (SE Xingó 69 kV) - location: 9°37'37.1 "S 37°48'41.0".





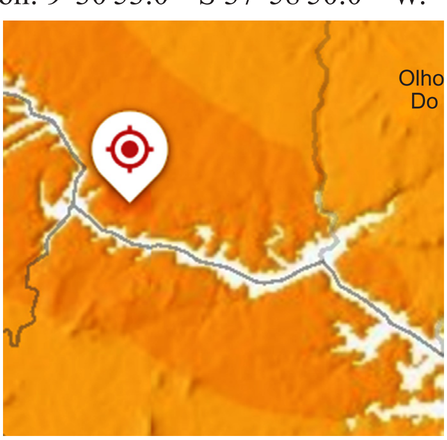
Distance from the fictitious photovoltaic plant Point 1, to the Inmet Piranhas A371 station, located next to UFAL Instituto Federal de Alagoas, Piranhas Campus: 4.90 Km.

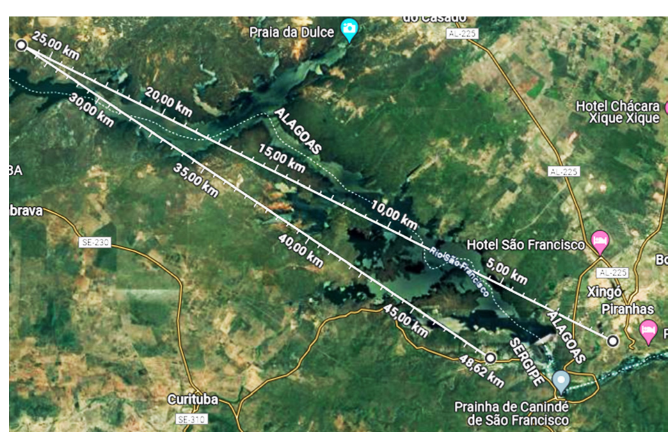
**Figure 10.** Point 2: Nearby Piranhas AL aerodrome - location: 09°34'48" s, 37°47'02 "w.


The distance to INMET PIRANHAS A371 station, located next to UFAL Instituto Federal de Alagoas, Piranhas Campus, is 5.00 km.Distance from the Ponto 2 photovoltaic plant to the SE Xingó 69kV Chesf substation (Eletrobras): 6.00 Km.

**Figures 11.** Point 3: Close to the Lameirão settlement in the municipality of Delmiro Golveia in Alagoas - location: 9°30'53.0 "S 37°58'50.0 "W.




The distance to INMET PIRANHAS A371 station, located next to UFAL Instituto Federal de Alagoas, Piranhas Campus, is 26.22 km. Distance from the Ponto 3 photovoltaic plant to the SE Xingó 69kV Chesf substation (Eletrobras): 22.4 Km.

**Figure 12.** Forensically beta site to search for points with the highest radiation.

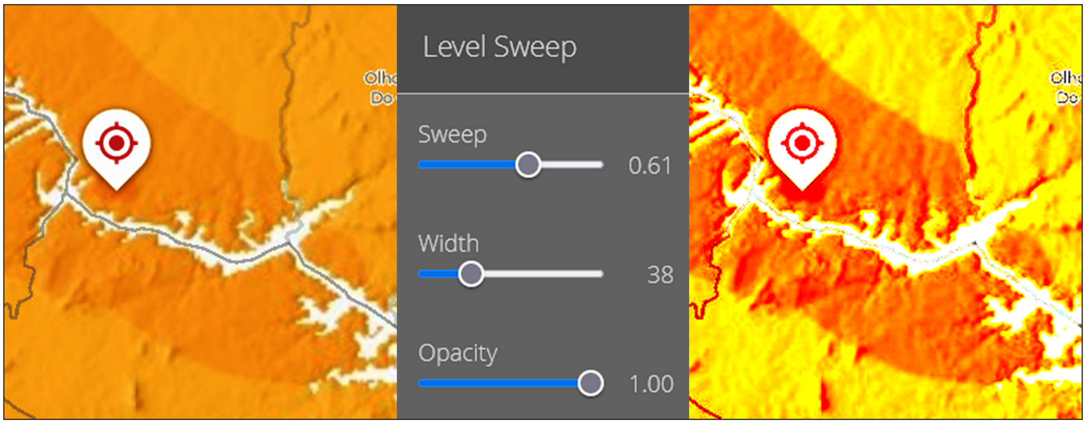



**Table 10.** Comparative data simulated by Atlas Solar Global in the 3 points.

| Index | Acronym | Point 1 | Point 2 | Point 3 | Unit. |
|---|---|---|---|---|---|
| Specific Photovoltaic Power | PVOUT | 4.352 | 4.397 | 4.535 | kWh/kWp day |
| Normal Direct Irradiation | DNI | 4.451 | 4.476 | 4.870 | kWh/m² day |
| Global Horizontal Irradiation | GHI | 5.543 | 5.559 | 5.749 | kWh/m² day |
| Diffuse Horizontal Irradiation | DIF | 2.356 | 2.364 | 2.247 | kWh/m² day |
| Global Irradiation Tilted at Optimal Angle | GTI_opta | 5.589 | 5.611 | 5.803 | kWh/m² |
| Air temperature | TEMP | 26,9 | 25.8 | 25.9 | °C |
| Optimal Tilt of Photovoltaic Modules | OPTA | 8 | 9 | 9 | ° degrees |
| Terrain Elevation | ELE | 69 | 249 | 221 | m |

percentages for the total radiation measured at the modules' inverter were determined. Tables 11, 12, and 13 display these comparisons for the locations of Petrolina (PE), Messias (AL), and the proposed plant site in Piranhas (AL). Note that Piranhas (AL) participates only in calculations using Neural Designer, as it is a suggested location without direct measurement data.

## Conclusion

The most significant challenge during this research was acquiring complete, cohesive, and high-quality data. However, success was achieved after an extensive review of multiple data sources, enabling the selection of the most reliable and comprehensive datasets. The data qualification and filtering stage followed, ensuring accuracy. Despite this, a lack of standardization, insufficient data, and inadequate meteorological stations remain significant issues. Many operational stations either do not provide all the necessary data or experience periods of inactivity. While Brazil boasts a network of meteorological stations, many regions still face gaps in monitoring coverage.

Three locations in the Northeast were analyzed, each exhibiting distinct climatic characteristics. For example, Messias (AL) experiences higher precipitation rates of 944 mm, almost double the averages of the other two locations: Petrolina (PE)

**Table 11.** Radiation results in software and their percentages for Petrolina in kWh.

| PETROLINA in kWh | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Estimated | Real | PVSYST | PVSOL | NEURAL | % PVSYST | % PVSOL | % Neural Network |
| Jan | 127.15 | 127.02 | 181.58 | 160.71 | 165.22 | 42.95 | 26.52 | 30.07 |
| Feb | 126.68 | 117.11 | 138.64 | 138.80 | 131.29 | 18.38 | 18.52 | 12.11 |
| Mar | 116.05 | 119.26 | 162.80 | 135.44 | 134.91 | 36.51 | 13.57 | 13.12 |
| Apr | 109.13 | 125.40 | 137.16 | 114.43 | 108.87 | 9.38 | -8.75 | -13.19 |
| May | 92.01 | 106.24 | 104.67 | 100.90 | 111.31 | -1.48 | -5.02 | 4.77 |
| Jun | 94.13 | 102.87 | 94.18 | 92.73 | 108.12 | -8.44 | -9.85 | 5.11 |
| Jul | 120.95 | 138.51 | 103.15 | 99.27 | 121.93 | -25.53 | -28.33 | -11.97 |
| Aug | 131.04 | 138.42 | 123.48 | 124.74 | 144.45 | -10.79 | -9.88 | 4.36 |
| Sep | 145.51 | 141.72 | 145.49 | 144.91 | 149.25 | 2.66 | 2.25 | 5.31 |
| Oct | 153.65 | 152.26 | 157.89 | 164.36 | 153.34 | 3.70 | 7.95 | 0.71 |
| Nov | 143.21 | 122.05 | 167.90 | 159.40 | 161.71 | 37.57 | 30.60 | 32.50 |
| Dec | 142.47 | 122.97 | 156.94 | 160.81 | 157.18 | 27.62 | 30.77 | 27.82 |
| Annual | 1501.98 | 1513.82 | 1673.88 | 1596.51 | 1647.59 | 10.57 | 5.46 | 8.84 |

**Table 12.** Radiation results in software and their percentages for Messias (AL) in kWh.

| MESSIAS II in kWh | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Estimated | Real | PVSYST | PVSOL | Neural | % PVSYST | % PVSOL | % Neural Network |
| Jan | 132.84 | 111.65 | 130.40 | 136.47 | 151.38 | 16.79 | 22.23 | 35.59 |
| Feb | 114.73 | 95.96 | 113.10 | 125.10 | 130.31 | 17.86 | 30.36 | 35.80 |
| Mar | 121.97 | 109.10 | 111.10 | 121.59 | 139.15 | 1.83 | 11.45 | 27.55 |
| Apr | 102.57 | 95.93 | 101.90 | 102.14 | 117.04 | 6.22 | 6.47 | 22.01 |
| May | 92.13 | 89.71 | 88.10 | 90.08 | 105.13 | -1.79 | 0.41 | 17.19 |
| Jun | 76.22 | 68.70 | 69.90 | 81.70 | 86.97 | 1.75 | 18.93 | 26.60 |
| Jul | 85.18 | 88.51 | 81.10 | 85.32 | 97.18 | -8.37 | -3.60 | 9.80 |
| Aug | 98.30 | 86.91 | 97.80 | 103.43 | 112.16 | 12.53 | 19.01 | 29.06 |
| Sep | 101.81 | 89.34 | 107.70 | 116.17 | 115.99 | 20.55 | 30.03 | 29.83 |
| Oct | 119.85 | 102.11 | 123.00 | 133.82 | 135.53 | 20.46 | 31.06 | 32.73 |
| Nov | 104.48 | 62.70 | 130.10 | 141.03 | 119.45 | 107.50 | 124.93 | 90.50 |
| Dec | 125.86 | 27.20 | 136.80 | 141.21 | 143.38 | 402.94 | 419.15 | 427.13 |
| Annual | 1275.94 | 1027.82 | 1291.00 | 1378.07 | 1453.69 | 25.61 | 34.08 | 41.43 |

**Table 13.** Estimated radiation percentage x neural designer radiation in Piranhas plant.

| | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec | Annual |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Estimated** | 168 | 150,7 | 153,5 | 142,3 | 115,1 | 105,6 | 150,2 | 152,2 | 174,2 | 162,9 | 168,06 | 154,2 | 1797 |
| **Neural** | 151,4 | 132,9 | 134,1 | 124,3 | 100,6 | 94,98 | 131,2 | 132,9 | 153,4 | 149,3 | 154,91 | 138,1 | 1598 |
| **% Neural Network** | -9,86 | -11,8 | -12,6 | -12,6 | -12,6 | -10,1 | -12,6 | -12,6 | -12 | -8,4 | -7,82 | -10,41 | -11,1 |

with 435 mm and Piranhas (AL) with 495 mm. The proximity of the São Francisco River in Piranhas may cause a microclimate, which could positively or negatively affect the data obtained.

As for temperature, the annual average remained consistent across all three cities, with Messias (AL) recording 25.16°C and Petrolina (PE) and Piranhas (AL) averaging around 27°C. The cloudiness index in Messias (AL) and Piranhas (AL) was similar at around 42%, whereas Petrolina had a slightly lower index of 39%. Regarding humidity, Messias (AL) had 76%, Petrolina (PE) 58%, and Piranhas (AL) 66%. The average wind speed across all locations was approximately 23 m/s. These data are crucial for a broader understanding of the plant's potential. Minor shading in the study areas was noted but did not affect the overall results.

As observed by Iea-Pvps [24], dirt and other loss factors were also considered in the calculations, leading to an annual loss of 3% to 4%, reaching up to 7% in some cases, by standards set by IEA-PVPS (International Energy Agency Photovoltaic Systems Programme). Regarding irradiation, higher values were observed at the Petrolina (PE) plant, with an annual average of 5.76 kWh, while Piranhas recorded 5.47 kWh and Messias 5.22 kWh. This variation in irradiation was reflected in energy production: Petrolina (PE) produced between 1501 and 1673 kWh/year per m², Piranhas (AL) between 1597 and 1796 kWh/year per m², and Messias (AL) between 1027 and 1453 kWh/year per m². When comparing measured energy production to estimated values, the results were positive and within acceptable tolerances. In Petrolina (PE), energy production was 5.46% higher than measured values in PVSOL, 8.84% higher in Neural Designer, and 10.57% higher in PVSYST.

The differences in Messias (AL) were more significant, with energy production in PVSYST being 25.61% higher, PVSOL 34% higher, and Neural Designer 41.43% higher. When accounting for the decrease in production during October, November, and December, replacing the lower values with historical averages, the percentage differences were reduced to 12.4% in PVSYST, 20.4% in PVSOL, and 26.7% in Neural Designer.

The proposed solar plant in Piranhas (AL) showed promising results, with three potential installation sites identified: Piranhas (AL), Delmiro Gouveia (AL), and Canindé do São Francisco (SE). These sites were selected for their proximity to a meteorological station, the Federal University of Alagoas (UFAL) advanced campus, and several Chesf (Eletrobras) facilities.

The difference between estimated and calculated energy production from the software was approximately 11%, with the potential for further reduction depending on the selected installation point. In evaluating the software, it became evident that each tool has strengths and unique features.

The results were generally consistent, with some software offering additional functions and a broader database, while others required a better understanding of data entry and technical aspects. PVSOL stands out for its 3D project visualization capabilities, whereas PVSYST focuses more on technical aspects and reporting. Both software options offer significant flexibility in input parameters, including a wide range of equipment manufacturers in the solar energy sector, which aids in obtaining accurate results. PVSYST and PVSOL allowed testing of different module tilt angles, concluding that the chosen angle for the project is the most efficient and cost-effective.

Neural Designer's application in the electrical sector shows promise, though it is more widely used in various commercial and industrial fields.

The Neural Designer yielded positive results in the tests conducted, though it required clean data with minimal discrepancies. Despite this initial challenge, the software demonstrated good performance, offering high customizability and the ability to predict various outputs and prognoses. This study provided valuable insights into the potential for photovoltaic energy production in the Northeast region of Brazil, and the findings have implications for future solar plant installations in the area.

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# Additive Manufacturing in the Oil Gas Industry: Strategies for Managing Powder Waste in Multi Jet Fusion Printing (MJF)

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**In the context of the Product Development Process (PDP), particularly during the development phase, there is growing recognition of the importance of waste management in producing components used in the industry. This increased awareness has led to a progressive interest in formulating approaches to understand and mitigate the possible resulting environmental impacts. Within this context, considering the substantial increase in the application of Additive Manufacturing techniques in the oil and gas industry, especially the deposition of polymeric layers, notably through the use of PA 12 and PP powder, it becomes imperative to thoroughly examine the production process in order to assess the feasibility of reincorporating discarded materials into the production chain of polymeric materials. In this context, this article proposes a detailed analysis of the manufacturing flow of a Multi Jet Fusion (MJF) Additive Manufacturing machine to assess the percentage of waste generated in small-scale prints by quantifying the mass of waste generated in the process, as well as pointing out alternatives for disposing of this waste. When the parts are produced, PA12 and PP powder waste is generated; in this deposition process, the powder is reused, returning to its production process. However, after the part has been made, it needs to be blasted with glass microspheres to remove all the powder residue that is trapped in the part. The waste generated during blasting is a mixture of PA12, PP, and glass microspheres, which, if not disposed of in an environmentally appropriate way, can have an environmental impact. Over 9 days, the results revealed an average of 12.15% waste from the component blasting process. It is suggested that this waste be used to manufacture filaments by extrusion and in additive manufacturing machines to deposit molten material. This material can produce other components for the oil and gas industry using FDM printers. It should be noted that bibliographical references identify viable techniques for reintegrating discarded materials into other manufacturing processes. Reducing PA12 and PP waste in additive manufacturing contributes to economic efficiency. It aligns with environmental and social goals, promoting sustainable practices and supporting the achievement of the Sustainable Development Goals in the oil and gas sector.**

**Keywords: Waste Reduction. Additive Manufacturing. Polymers. Oil and gas.**

Additive manufacturing, commonly called 3D printing, is a revolutionary process of fabricating objects by depositing materials in successive layers. Unlike traditional subtractive manufacturing methods, which involve removing material from a solid block, additive manufacturing constructs parts incrementally, layer by layer, until the final object is completed [1].

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Among the diverse range of additive manufacturing techniques, powder bed fusion methods are particularly notable. These methods create parts by fusing powdered materials. One prominent example is HP Multi Jet Fusion (MJF) technology, an advanced polymer-based additive manufacturing technique. MJF operates by selectively melting powdered material to form the desired part.

The process begins with the uniform spreading of a thin layer of polymeric powder across the printing bed. A fusing agent is then selectively jetted onto areas of the powder where fusion is intended. This agent defines the regions that will subsequently be exposed to infrared light. The infrared light causes the powder in the targeted areas to fuse, layer by layer, following the digital design until the part is fully formed [2].

Figure 1 illustrates this process, demonstrating the precision and efficiency of HP Multi Jet Fusion technology.

The efficiency and precision of HP Multi Jet Fusion (MJF) technology underscore its pivotal role in driving technological innovation and enhancing production processes.

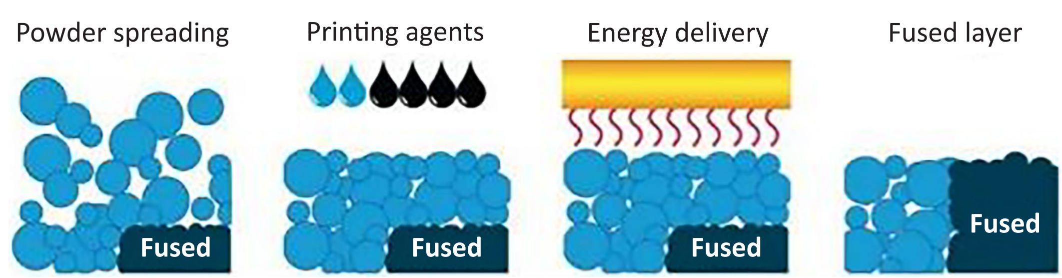
This method offers several significant advantages, including high production efficiency, minimal material waste, and the ability to produce intricate geometries without additional support structures.

These attributes make MJF particularly suitable for producing final-use parts, expanding its applicability across various industries.By enabling the creation of complex designs with ease, additive manufacturing fosters innovation and provides unparalleled flexibility in the design and production of components. Industries ranging from aerospace and automotive to healthcare and consumer goods increasingly leverage this technology to meet evolving demands and reduce manufacturing constraints [3].

Figure 2 illustrates a systematic representation of the MJF part manufacturing process, providing a detailed visualization of the steps involved in transforming a digital model into a tangible printed component.

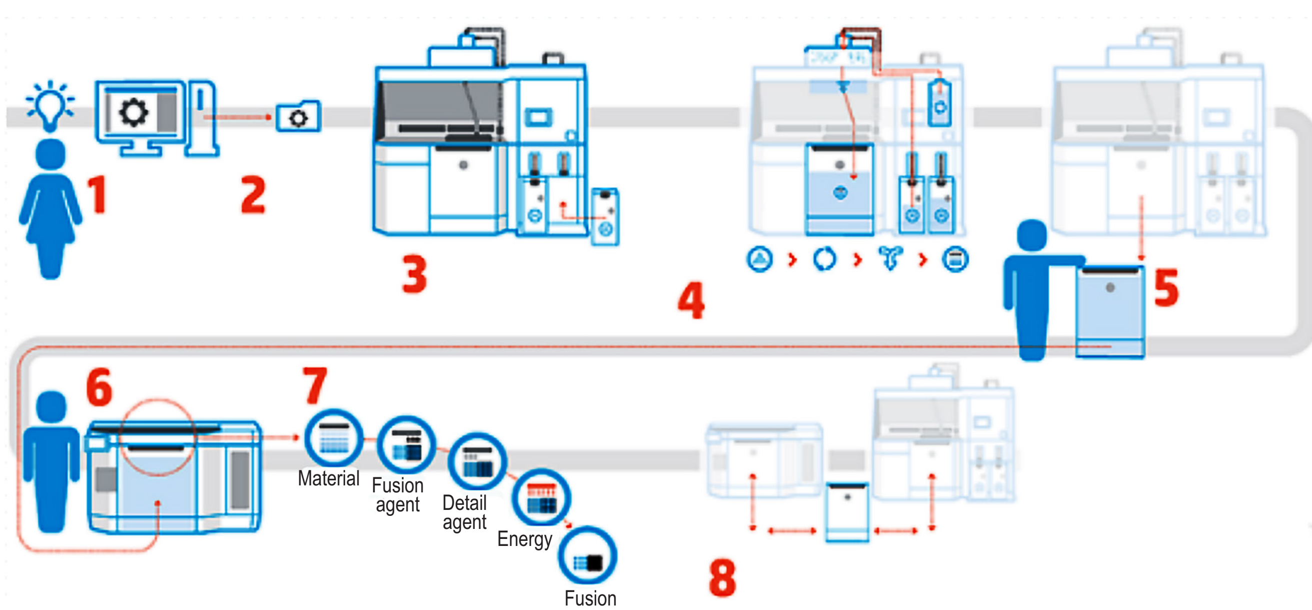
The workflow of HP Multi Jet Fusion (MJF) technology involves a systematic series of steps designed to ensure the efficient and precise production of parts. The process proceeds as follows:

**Figure 1.** Material fusion process.




Adapted from HP Multi Jet Fusion (2018) [4].

**Figure 2.** HP usability workflow.




Adapted from HP (2017) [5].

1. **Prepare the project for printing:** Finalize and configure the digital model for the printing parameters.
2. **Place the model into the printer:** Load the prepared digital model into the printer's system.
3. **Insert the material cartridge:** Add the material cartridge containing a virgin and recycled polymer blend.
4. **Fill the printing tank with material:** Load the required amount of polymer powder into the printing tank.
5. **Remove the tank filled with material:** Transfer the tank to the printer, ensuring it contains the quantity specified by the project.
6. **Power the development printer:** Turn on the printer and prepare it for printing.
7. **Start the material deposition process:** Initiate the layer-by-layer and fusing process, following the digital model specifications.
8. **Remove the vat with printed material:** After printing, remove the vat and allow the printed part to cool. Once cooled, return it to the processing printer for unpacking.

During the unpacking stage, unmelted powder is vacuumed back into the recycled material container for future use, highlighting the sustainable aspects of this technology. However, the printed part often retains significant amounts of polymer powder residue. This necessitates a post-processing stage, during which the part undergoes blasting to clean its surface and achieve the desired finish (Figure 3).

This workflow emphasizes efficiency and sustainability and showcases the attention to detail required to produce high-quality parts using MJF technology.

The CMV® machine plays a crucial role in the post-processing stage of Multi Jet Fusion (MJF) additive manufacturing by blasting the parts to remove surface residue. In this process, glass microspheres are used as the blasting material, effectively cleaning the surface of the printed parts. However, this procedure generates waste from a mixture of polymers and glass microspheres. This waste is directed to the disposal sector without being reused, presenting a missed opportunity for sustainability and resource optimization.

Disposing of such waste poses a significant environmental challenge due to the inherent environmental impacts of polymer and glass waste. Additionally, this practice results in losing valuable raw materials that could otherwise be recovered and repurposed [6].

The primary objective of the present study is to conduct a comprehensive analysis of the MJF manufacturing workflow, with a particular focus on the post-processing stage. This involves:

1. Mapping the post-processing process to identify areas where waste is generated.
2. Quantifying the percentage of waste produced during the blasting process.
3. Proposing a route for reusing the generated waste, specifically by extruding the polymer-glass composite to create polymeric filaments for additive manufacturing.

The study seeks to enhance the sustainability of MJF technology by integrating waste recovery into the manufacturing cycle. The extrusion of polymeric filaments addresses environmental concerns and reintroduces waste materials into the production chain, fostering a circular economy model within additive manufacturing.

**Figure 3.** Unpacking the part.

## Materials and Methods

Four distinct phases were implemented to thoroughly evaluate the disposal and potential reuse of waste generated in the Multi Jet Fusion (MJF) additive manufacturing process. This approach ensured a comprehensive understanding of waste management and its implications within the production process.

Analysis of Production Flow

In the initial phase, the printer's production flow was systematically analyzed to identify the specific stages at which waste was generated. This step aimed to pinpoint the primary sources of waste within the manufacturing process and establish a baseline for subsequent evaluations.

Defining Waste Collection Frequency

The second phase involved determining the frequency of waste collection. This was done by analyzing the current waste collection schedule to establish consistent intervals for waste data collection, ensuring an accurate representation of waste generation trends over time.

Waste Collection and Weighing

During this phase, the collected waste was systematically weighed to calculate the average weight of waste produced across multiple production cycles. This data provided a quantitative foundation for assessing waste volumes and their potential for reuse.

Waste Quantification

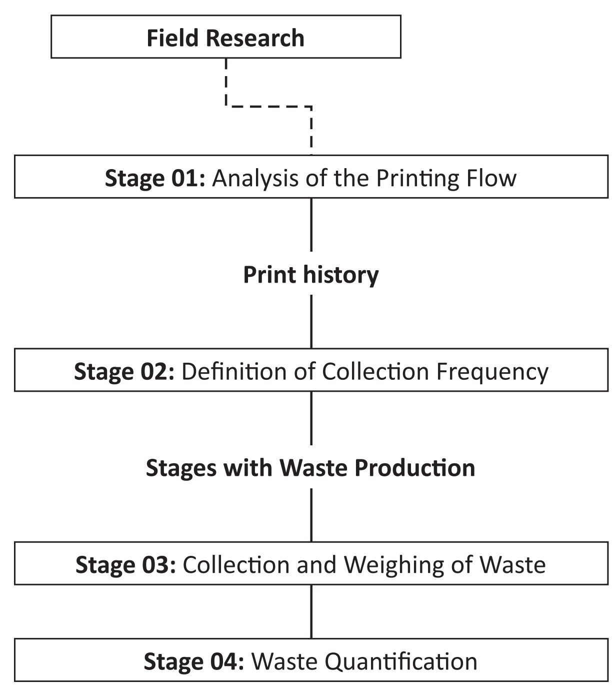
In the final phase, the percentage of waste generated about the total material used was calculated. A specific formula was defined to consistently quantify waste, allowing for comparative analysis and exploring reuse strategies. This methodological design offers a structured and comprehensive waste evaluation approach, emphasizing quantitative and qualitative insights. The results contribute to identifying opportunities for improved waste management practices, particularly in exploring the reuse of materials in the production process.

Figure 4 illustrates the schematic representation of the methodological flow, providing a visual overview of the sequential steps undertaken in this study.

Production Flow Analysis

A thorough examination of the Multi Jet Fusion (MJF) production flow and post-processing was conducted to map all activities from raw material input to the completion of finished products. This mapping process was instrumental in pinpointing critical stages where material waste occurs, enabling the identification of opportunities for implementing waste reduction or reuse measures. The volume of waste generated during production is directly tied to the filling capacity of the vats, which are the compartments where the parts are printed. This volume fluctuates depending on the printing material required for each production cycle. After

**Figure 4.** Methodological collection flow.



the printing stage, all parts undergo a mandatory post-processing procedure that involves blasting to remove residual material adhered to their surfaces.

In the blasting process, materials are handled collectively without segregating different polymer types. Production schedules dictate that some collections may include a mix of polypropylene (PP) and polyamide 12 (PA12), while others primarily consist of PA12, the predominant polymer in MJF production. This variability in waste composition underscores the importance of tailored waste management strategies, as the distinct properties of each polymer can significantly affect disposal and recycling processes.

It is vital to systematically measure and analyze all waste generated during the production flow to address these challenges. Accurate waste quantification is crucial for a deeper understanding of its composition and volume, which supports the development of more effective control, management, and potential reuse practices. This process enhances sustainability and aligns with the principles of resource optimization and environmental stewardship.

Definition of Collection Periodicity

The production cycle of the Multi Jet Fusion (MJF) system is dictated by the demand of ongoing projects, leading to fluctuations in production volume, with alternating periods of high and low activity. To establish the optimal periodicity for waste collection and analysis, we evaluated historical production data to determine the average duration required to achieve representative production volumes.

Based on this evaluation, a 15-day interval was identified as the ideal measurement period. This interval corresponds to the blasting machine's typical cleaning cycle, during which an average of 11 vats are produced. The data collection process effectively captured a representative sample of production activities by aligning the collection schedule with the cleaning cycle.

We planned five collection periods over consecutive cycles to ensure a robust and comprehensive analysis. This approach allowed for the integration of production history with variations in machine cleaning and project demand, offering a clear picture of waste generation across different scenarios.

Given the variability in project timelines, the number of vats produced during each collection period differed, reflecting the dynamic nature of production. Despite these variations, the 15-day interval ensured consistent and comparable data points for each collection.

With the periodicity defined, collections and measurements were conducted as planned (Table 1). This data forms the foundation for analyzing waste generation trends and identifying opportunities for improved waste management practices.

Collection, Weighing, and Quantification of Waste

The waste generated from the production and post-processing stages was collected and measured during the defined collection periods to assess its quantity and characteristics. The cleaning process, while straightforward, required manual handling to

**Table 1.** Collection period.

| Collection Number | Collection Date | Quantity of Vats |
|---|---|---|
| 1 | 12/26/2023 | 8 |
| 2 | 01/09/2024 | 7 |
| 3 | 01/23/2024 | 12 |
| 4 | 05/06/2024 | 11 |
| 5 | 05/20/2024 | 17 |

extract the accumulated dust from the equipment's reservoir.

The collection began by opening the reservoir valve located at the back of the equipment. Using an internal shovel, the accumulated dust was manually removed and transferred into plastic bags for storage and transportation. The waste was then prepared for weighing using a 300Kg IDR 7500 ABS Scale—RAMUZA-2012, ensuring accuracy in mass measurement.

Upon weighing, the collected waste was packed and transported to its destination—currently a specialized recycling company. This step highlights the importance of aligning waste management practices with environmental sustainability principles.

Quantification Process

The waste quantification was based on calculating the percentage of waste generated relative to the material initially processed in the vats. The total mass of waste was recorded for each collection, and the material usage per vat was determined. This calculation considered:

- The dimensions of the printing vat and
- The density of the powdered material, as specified by HP and BASF, the respective manufacturers of the materials.

The resulting values were used to derive the percentage of waste generated per vat during the process. Detailed data for material properties and densities are summarized in Table 2, providing a foundation for analyzing waste trends and identifying potential areas for optimization.

This methodology ensured a systematic approach to waste quantification, enabling a detailed understanding of material usage and disposal practices across the production cycle.

Figures 5 and 6 show the printing vat and a graphic representation of its internal dimensions, respectively.

The calculation of the mass of the polymer used for printing was performed using Equation (1), which assumes that the printing vat was filled with raw material during the printing process:

$$M = V.\rho \quad (1)$$

Where:
M: Mass of the polymer (in kilograms).
V: Volume of the printing vat (in cubic meters).
ρ: Density of the polymer powder (in kilograms per cubic meter).

This Equation accurately estimated the material's initial mass, which was crucial for quantifying waste generated during the production cycle. By knowing the exact mass of polymer used for printing, the proportion of material that transitioned into waste versus that which was effectively utilized in the final printed parts could be determined.

## Results and Discussion

Variations in waste results were evident across the different collections, primarily influenced by the sizing and geometric complexity of the printed parts. For instance, parts with features such as holes or lower density tended to retain more powdered material in specific regions, which led to a noticeable increase in the recorded waste amounts.The waste was separated into two bags during each collection cycle and weighed individually to ensure accurate data gathering. Using Equation (1), the mass of the material used in printing

**Table 2.** Printing vat dimensions.

| Material | Vat Dimensions | Material Density |
|---|---|---|
| Polypropylene (PP) | L = 380 mm, D = 284 mm, H = 370 mm | 0.87 g/cm³ |
| Polyamide 12 (PA12) | L = 380 mm, D = 284 mm, H = 380 mm | 1.01 g/cm³ |

**Figure 5.** Print vat.

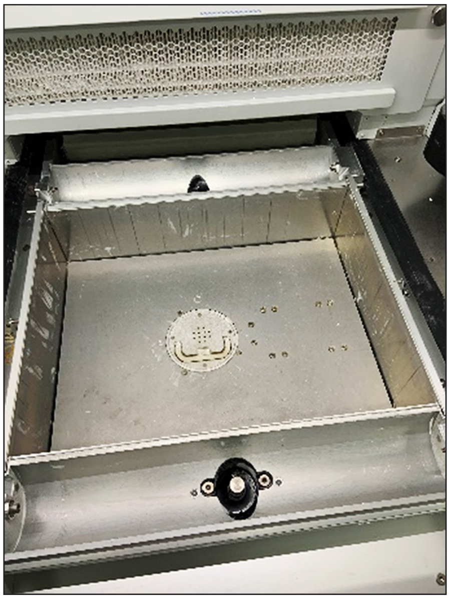
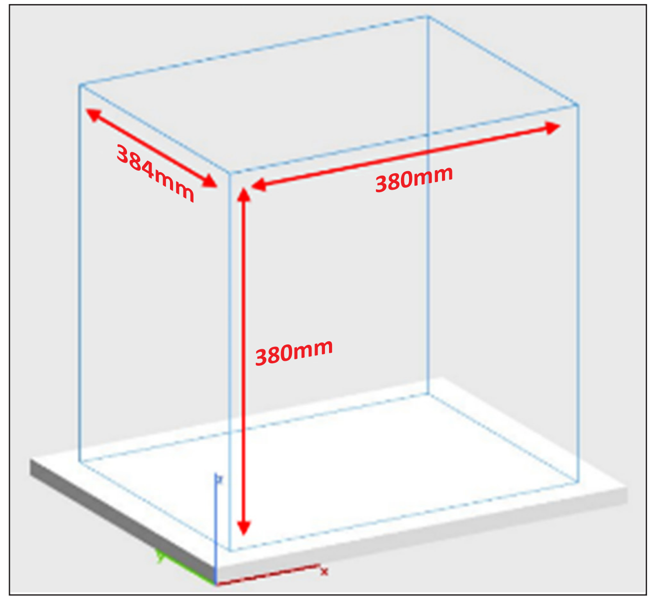


**Figure 6.** Graphical representation.




was calculated, and the percentage of waste generated was subsequently determined. This allowed for a precise quantification of the waste-to-material ratio. Table 3 presents the detailed results of these collections, along with the calculated waste percentages. This data offers valuable insights into the relationship between part geometry and waste generation, highlighting areas where process efficiency and waste reduction improvements may be achieved. By thoroughly analyzing these results, strategies for optimizing raw materials and minimizing waste can be developed, contributing to more sustainable manufacturing practices.

As previously highlighted, the amount of waste generated was notably significant, with an average mass measured in collections of 18.8 ± 8.9 kg.

This substantial waste presents an opportunity for reprocessing through the extrusion process, which has been identified as a viable method for reusing such material [7]. The recycled material can then be extruded into filaments, which can be used in other additive manufacturing processes, such as Fused Deposition Modeling (FDM) [8]. These filaments could be used to produce parts intended for industries such as oil and gas, particularly in applications requiring rapid part replacement.

This approach contributes to more effective waste management and highlights the potential for innovation in the industry. Reusing waste material aligns with the growing demand for sustainable, environmentally responsible manufacturing solutions [9].

Furthermore, this study contributes to the Sustainable Development Goals (SDGs), particularly about responsible consumption and production practices. The alignment of waste reuse with the SDGs is detailed in Table 4, which outlines how this work contributes to developing sustainable practices and environmental stewardship [10].

The results of this study lay the groundwork for future research and practical applications in waste management and additive manufacturing.

Several promising avenues for further investigation and development can be explored to optimize waste management and enhance environmental sustainability within the industry. Future research may focus on developing advanced recycling technologies to process waste materials more efficiently, potentially integrating automated systems to reduce labor and increase throughput. Additionally, exploring biodegradable materials as

**Table 3.** Quantification of waste generation.

| Collection Waste | Percentage Waste | Mass (kg) | Materials |
|---|---|---|---|
| 1 | 12.15% | 26.7 | PP, PA12, Glass Microsphere |
| 2 | 5.71% | 12.8 | PA12, Glass Microsphere |
| 3 | 4.25% | 13.7 | PP, PA12, Glass Microsphere |
| 4 | 3.26% | 10.6 | PP, Glass Microsphere |
| 5 | 6.27% | 30.1 | PP, PA12, Glass Microsphere |

**Table 4.** Main aspects and correlation with the SDGs.

| SDG | Key Aspects |
|---|---|
| Social Responsibility (SDG 8) | Efficiency in additive manufacturing, with reduced waste, contributes to sustainable economic growth. |
| | It can generate employment opportunities and improve working conditions, promoting SDG 8. |
| Innovation and Technological Development (SDG 9) | Reducing waste in additive manufacturing stimulates innovation and the development of efficient technologies. |
| | Aligned with SDG 9, which aims to promote resilient infrastructures and drive innovation. |
| Environmental Sustainability (SDG 12) | Waste reduction aligns with SDG 12, aiming for sustainable production and consumption patterns. |
| | Reducing the amount of discarded material preserves natural resources and reduces the environmental impact associated with extraction and processing. |
| Minimization of Greenhouse Gas Emissions (SDG 13) | The production of materials, such as PA12, often involves significant greenhouse gas emissions. |
| | Reducing waste in additive manufacturing contributes to a smaller carbon footprint, helping to mitigate climate change. |

alternatives to traditional polymers in 3D printing could offer significant environmental benefits.

Another critical research direction is implementing circular practices for the continuous reuse of resources. This could involve creating closed-loop systems where waste is consistently recycled back into the production process, reducing reliance on new raw materials and minimizing overall waste generation.

Moreover, conducting comprehensive environmental impact assessments will be essential to ensure the long-term sustainability of these practices. These assessments allow for identifying potential risks and developing strategies to mitigate any adverse environmental effects associated with waste recycling and new material innovations. These research directions are essential not only for improving the efficiency of the additive manufacturing industry but also for advancing its environmental responsibility, aligning with global sustainability goals.

## Conclusion

Reusing polymer waste in industrial processes is an effective strategy for reducing the demand for virgin raw materials, conserving natural resources, and minimizing the emissions associated with production. Recycling polymers transforms these materials into new products, extending their life cycle but also helping reduce the overall volume of waste generated.

Reusing materials to generate filaments through extrusion presents a sustainable and effective solution for industries such as oil and gas. By utilizing these filaments in additive manufacturing, rapid replacement parts can be produced, contributing to a reduction in waste and costs while addressing the dynamic and specific needs of this high-demand sector [10].

This approach enhances production efficiency and underscores the significance of innovation and environmental responsibility. It presents a viable pathway for sustainable practices in the industry, encouraging the adoption of environmentally conscious solutions that support long-term industry growth while mitigating the environmental impact.

Therefore, analyzing the production flow and proposing the reuse of waste generated by the blasting machine are crucial steps to improving the efficiency of the production process and fundamental strategies to promote environmental sustainability and achieve significant savings in operational costs. Ultimately, these initiatives bring economic benefits to the company and contribute to a more sustainable and responsible future for generations to come.

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# Application of Microencapsulation in Lipids: Technological and Scientific Prospection

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**The food industry has been actively developing solutions to address healthy eating challenges in today's fast-paced world. One such solution is using microencapsulation techniques for bioactive compounds, particularly lipids. This study aims to investigate the potential of microencapsulation technology in enhancing the stability of lipids against oxidation in the body, which can compromise their nutritional efficacy. A bibliometric mapping was conducted using *The Lens* database, applying a combination of keywords and filters to identify relevant patents and publications. The goal was to analyze the scientific and technological activity surrounding the topic. The results reveal a significant increase in research and patent activity over the past decade, primarily focusing on microencapsulation methods and their applications in food supplements. Furthermore, a growing trend toward using this technology to develop new functional foods with potential socioeconomic benefits was observed.**
**Keywords: Microparticles. Spray Drying. Stability. Oxidation.**

The increasing health concern is the primary driver of research in human nutrition. In parallel, the hectic pace of modern life influences both the quantity and quality of meals, impacting the population's overall health. To address these issues, the food industry has focused on developing functional foods [1] designed not only to provide essential nutritional functions but also to offer metabolic and/or physiological benefits to human health, as defined by ANVISA (National Health Surveillance Agency). For functional foods to be effective, they must be safe for consumption without medical supervision and backed by scientific evidence [2].

However, many bioactive substances—particularly fatty acids (lipids)—present challenges in functional foods due to their susceptibility to oxidation. Oxidation, a natural catalytic process in the body, can degrade these compounds, preventing the release of their nutritional content and even leading to rancidity [3]. Another challenge is the sensory properties of some functional foods, mainly taste and aroma, which can affect consumer acceptance [4].

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Microencapsulation technology offers a promising solution to these challenges. The process involves encapsulating a bioactive compound (the core) in a protective coating made from a wall material, forming microcapsules. This encapsulation shields the bioactive substance from oxidation, thus preserving its stability. Once encapsulated, the core can be released within the body at controlled times and locations, optimizing nutritional benefits. Additionally, microencapsulation can mask undesirable flavors, aromas, and colors, making functional foods more palatable and accessible. Among the various microencapsulation methods, spray drying is the most commonly used in the food sector due to its ease of operation, cost-effectiveness, and high production rates [5].

This study aims to investigate the potential of lipid microencapsulation, particularly via spray drying, to enhance resistance to oxidation. Through bibliometric mapping, it seeks to assess the technology's impact on lipid stability and controlled release and explore future directions for its application in functional food development.

## Materials and Methods

A bibliometric study analyzed the scientific and technological production related to lipid microencapsulation. This was achieved through a quantitative survey of available literature using *The Lens*, a free online database. Patents and publications on the topic were identified and analyzed to understand global research trends. Table 1 presents the filters applied on the research.

The search results were then analyzed to evaluate the global dissemination of research and patents, focusing on studies most closely related to the project's objectives.

## Results and Discussion

The bibliometric search results revealed that lipid microencapsulation, regardless of the method used, is a widely explored technology, particularly within the pharmaceutical and food industries. The database contained 6,711 patents, of which 3,140 were active and 2,292 were pending. When grouped into a "simple family" (i.e., counting only the initial document without its derivations), the total dropped to 2,349 patents. When restricting the search to the title field, only 35 records were identified, reflecting the specific focus on lipid microencapsulation in food and medical applications.

These findings indicate that the technology is widely employed to improve the stability and functionality of bioactive compounds, such as omega-3 fatty acids, by protecting them from oxidative degradation. For example, patents such as *2017/197453* [6] and *2018/0280333* [7] describe methods for microencapsulating omega-3 fatty acids to enhance their stability in food products and their potential use in treating neurological conditions and chronic diseases. Patent *10898442* [8] presents a method for microencapsulating lipids to address taste, odor, and oxidative instability issues.

In publications, 120 articles were found, with most focusing on optimizing microencapsulation techniques and assessing their effects on the gastro-resistance and stability of bioactive compounds. For example, the article "Effect of incorporating fish oil encapsulates on the physical-chemical and sensory properties of biscuits" [9] used microencapsulated fish oil (rich in omega-3) in biscuit formulations.

This study demonstrated a significant reduction in lipid oxidation and good sensory acceptance of the product. Another study, "*In vitro* bioaccessibility of spray-dried refined kenaf seed oil applied to coffee drinks," found that microencapsulated kenaf seed oil exhibited better oxidative stability than unprocessed oil, successfully incorporated into coffee drinks [10].

A more recent study, "Influence of wall materials and homogenization pressure on microencapsulation of rice bran oil," [11] explored the effectiveness of spray drying in microencapsulating γ-oryzanol (a bioactive compound from rice bran oil) for nutraceutical, pharmaceutical, and cosmeceutical applications.

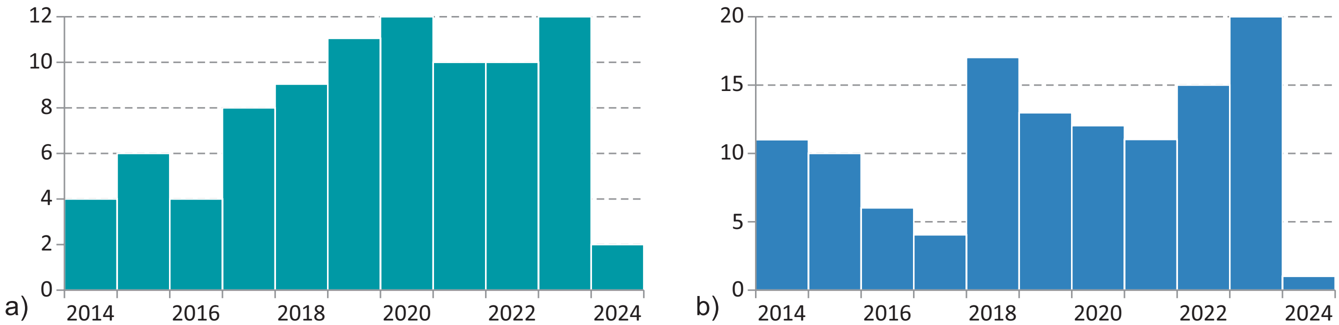
The results also show a resurgence of interest in lipid microencapsulation technology starting around 2018, with a slight dip during the COVID-19 pandemic (2020–2022) and a notable rebound in 2023–2024 (Figure 1) [12]. This trend suggests that microencapsulation technology continues to evolve and gain importance in the food and health sectors.

The geographical distribution of patents and publications reveals that countries with advanced research and development infrastructure, such as the United States, Europe, and China, lead in technological innovations in lipid

**Table 1.** Search filters applied in bibliometric study.

| Type | Keywords | Field | Grouping | Period |
|---|---|---|---|---|
| Patent | “foods AND supplemented AND by AND microencapsulated AND lipids” | All fields | Simple family | 2014-2024 |
| | "lipids" | Titles | Simple family | 2014-2024 |
| Publications | “foods AND supplemented AND by AND microencapsulated AND lipids”, “microencap*” | All fields | - | 2014-2024 |

**Figure 1.** Number of patents (a) and publications (b) filed during the period under analysis.




Source: The Lens (2024) [12].

microencapsulation. This underscores the importance of fostering research and development efforts to enhance national production and promote innovation in the food industry, ultimately improving public health and quality of life.

## Conclusion

The bibliometric study has proven invaluable for analyzing the scientific and technological activity surrounding lipid microencapsulation. The results highlight this technique's growing interest and potential in improving lipids' stability, particularly in the context of functional foods. Microencapsulation enhances the nutritional value of foods and increases consumer acceptance by masking undesirable sensory characteristics. Given the potential benefits, it is clear that microencapsulation is an emerging trend that should continue to be explored. Its application can lead to the development of innovative functional foods that offer enhanced nutritional benefits, thus contributing to better public health and offering significant socioeconomic advantages.

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# Development of Technological Routes for Extraction of Bioactives from Coffee Film and Assessment of the Potential of the Phytochemical Profile

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**The project proposes exploring the potential of coffee skins as a source of valuable compounds due to the excess coffee on the market and the devaluation of prices. Traditionally, the extraction of compounds from coffee skins occurs using methods such as pressing or the use of solvents. However, these methods may have limitations, such as low yield or toxicity. Coffee skin is rich in substances that interest various sectors, such as antioxidants, chlorogenic acids, and dietary fiber. The project seeks to develop coffee skin extraction routes, aiming to increase the yield and quality of the extracted compounds while avoiding their degradation. Furthermore, we intend to evaluate the potential of the photochemical profile of the materials obtained.**
**Keywords: Technological Routes. Sustainability. Coffee Film. Phytochemical Profile.**

In Brazil, research institutions focus on improving coffee agribusiness's productivity, competitiveness, and sustainability, addressing agronomic, genetic, biotechnological, and chemical composition aspects [1,2]. There is a clear need for studies on coffee waste and the sustainability of its production process.

The silver film on coffee, a by-product of its processing, is recognized for its favorable chemical composition and health-promoting properties [3]. Composed of various nutrients, including proteins, lipids, minerals, and bioactive compounds such as polyphenols, this film stands out for its high dietary fiber content, both soluble and insoluble. Furthermore, its extract has demonstrated significant antioxidant activity, offering potential benefits against inflammation, allergies, diabetes, and obesity [3]. The silver film emerges as a promising and sustainable option for several industries. With applications ranging from ingredients in functional foods to substrates for cultivating microorganisms and cosmetics [2].

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In this panorama, the present study aims to identify the industrial potential of coffee film, through effective extraction methods, with greater emphasis on supercritical fluid extraction and ultrasound extraction, thus enabling the use of this residue in the desired industrial areas.

## Materials and Methods

A literature review was conducted to identify and understand the extraction processes and essential process optimization factors. Furthermore, a practical comparison between traditional methods and their disadvantages regarding the compounds to be extracted must be carried out.

Nevertheless, laboratory analyses must be conducted to determine the phytochemical composition, including the content of fatty acids, phenolic compounds, and antioxidants.

## Results and Discussion

Coffee growing is one of the most important agricultural activities for the Brazilian economy, placing the country as one of the world's leading producers and exporters of coffee.

However, large-scale production generates significant waste that must be managed effectively to mitigate its environmental impact. A promising strategy is reusing this waste, especially coffee film, through advanced extraction methods [4,5].

Supercritical fluid extraction (EFS) is a technique that stands out for its efficiency in extracting valuable compounds from coffee skins. Using $CO_2$ in supercritical conditions, EFS allows the selective extraction of antioxidants, chlorogenic acids, and phenolic compounds, which have functional properties beneficial to health. This approach not only maximizes the yield of desired compounds but also minimizes the use of organic solvents and reduces the environmental impact of the extraction process [5]. Conversely, ultrasound emerges as an effective and versatile alternative for extracting compounds from coffee film. This technique uses ultrasonic waves to promote the rupture of film cells, facilitating the release of antioxidants, dietary fiber, and other nutrients. In addition to increasing

**Table 1.** Techniques for extracting compounds of industrial interest from coffee skins.

| Extraction Technique | Compounds of Industrial Interest | Possible Applications | Working Principle |
|---|---|---|---|
| Sohxlet extraction [4] | Caffeine | Use of coffee residues as immunostimulants. | Extraction of the lipid fraction using solvent. |
| Sohxlet extraction[5] | Cellulose, lignin, hemicellulose | Membrane production for separation process | Extraction of the lipid fraction using solvent. |
| Aqueous extraction in alkaline medium, microwave radiation [6]. | Polysaccharides, Flavonoids, Cellulose | Immune stimulators for the immune system, cellulose for bioethanol production. | Microwave radiation extraction is an extraction method that uses microwaves to heat the solvent and sample, accelerating the extraction process. |
| Sohxlet extraction [7] | Oily fractions, caffeine | Antimicrobial activity | Soxhlet extraction is a method used to extract compounds from a solid sample using a solvent. |
| Ultrasound-assisted extraction [8] | Phenolics | Antibacterial activity | Ultrasound-assisted extraction is an extraction method that uses ultrasonic waves to facilitate the transfer of solutes from a solid or liquid matrix to a solvent. |
| Extraction by methanol, acetone, ethanol [3] | Dietary fiber | Food enrichment, additives in the production of low-calorie cakes. | Solvent extraction is a method traditionally used to extract compounds from a solid or liquid matrix using a suitable solvent. |
| Aqueous Extraction, Decoction, Infusion [9] | Phenolics, flavonoids | Antioxidant compounds, clusters from wood production. | Decoction extraction is a method of preparing plant extracts that involves prolonged cooking of plant materials in water or another suitable solvent. |
| Simple extraction [10] | Caramel Color IV | Replacement of artificial colors in the food industry. | Basic separation method used to isolate or purify a substance from a mixture using a suitable solvent. |

extraction efficiency, ultrasound reduces the time required for the process. It preserves the quality of the extracts, making it an attractive option for using coffee farming waste [4]. Table 1 lists the most used techniques.

## Conclusion

After bibliographical reviews and research into extraction methods that complied with innovation and preservation of the raw material, it was decided to use supercritical fluid and ultrasound extraction. At the same time, it was comparing the efficiency of traditional methods, factors that influence the process, and the quality of the substances. Furthermore, the laboratory analyses to be carried out, focusing on the coffee film, reveal a comprehensive and promising approach to exploiting natural resources sustainably and efficiently. In summary, the search for sustainable methods of extraction and diversified application of coffee and its derivatives highlights their significant role in the economy, industrial innovation, and sustainability.

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# Bibliometric Study of the Production of Scaffold by Polycaprolactone and Graphene Electrospinning

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**This bibliometric study investigated the production of scaffolds using electrospinning with the incorporation of graphene into polycaprolactone (PCL) for biomedical applications. Bibliometric methods were employed to analyze relevant scientific literature and identify trends, publication patterns, key authors and institutions, and primary application areas. Using specific keywords in the Web of Science database, 54 articles published over the past five years were identified. Results indicate a decline in annual publications, potentially due to the impact of the COVID-19 pandemic. Iran emerged as the leading country in research on this topic, while the most cited journals included Materials Science Multidisciplinary, Polymer Science, and Materials Science Biomaterials. These findings provide a comprehensive overview of the current research landscape, highlighting areas of interest and potential future directions.**

**Keywords: Scaffold. Electrospinning. Graphene. Polycaprolactone (PCL).**

Electrospinning is a nanofiber fabrication technique that has gained increasing attention due to its versatility and potential applications in fields such as biomedicine, filtration systems, and advanced composite materials [1]. This technique applies an electric field to a polymer solution, forcing the solution through a needle or nozzle, resulting in ultrafine fibers with nanometer-scale diameters. Recent research has focused on improving the properties of electrospun fibers, with one promising approach being the incorporation of nanomaterials like graphene into polycaprolactone (PCL) solutions [2]. PCL is widely used in tissue engineering due to its flexibility, biocompatibility, biodegradability, and ease of processing into various forms, such as thin films or three-dimensional scaffolds [3].

Graphene, a two-dimensional carbon material, possesses unique properties such as high electrical conductivity, mechanical strength, and surface area, making it a valuable additive for enhancing the characteristics of electrospun fibers [2].

This study explores the current research landscape on electrospun scaffolds with graphene-reinforced PCL by employing bibliometric methods to analyze trends, publication patterns, leading authors and institutions, and critical application areas [4]. The findings aim to provide a comprehensive overview of this emerging field and identify opportunities for further research in regenerative medicine, tissue engineering, and other biomedical applications.

## Materials and Methods

Bibliometric analysis measures and describes the evolution of research across various disciplines, enabling the identification of trends, collaboration patterns, and research gaps. This method is widely applied in science, technology, medicine, and social sciences to assess research impact and guide future investigations [5].

This study used the Web of Science database to identify relevant publications. The keywords "scaffold," "electrospinning," "graphene," and "polycaprolactone" were used in the search. Data collected included article records and cited references, exported as tab-delimited files for further

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analysis. The research was conducted on March 10–11, 2024, identifying 54 articles published between 2019 and 2024. The evaluation focused on publication trends, productive countries, and key journals. Table 1 outlines the analyzed elements and their objectives.

**Table 1.** Data evaluated in the study.

| Item | Objective |
|---|---|
| Articles per year | Assess productivity trends over time |
| Countries | Identify the most productive and cited nations |
| Journals | Determine the most influential journals |

## Results and Discussion

The data revealed the number of articles published annually from 2019 to 2024 (Figure 1). A decline in publication was observed, likely due to the pandemic's impact on research activities. Even with the gradual resumption of laboratory operations, the 2023 publication count had not yet returned to pre-pandemic levels seen in 2019.

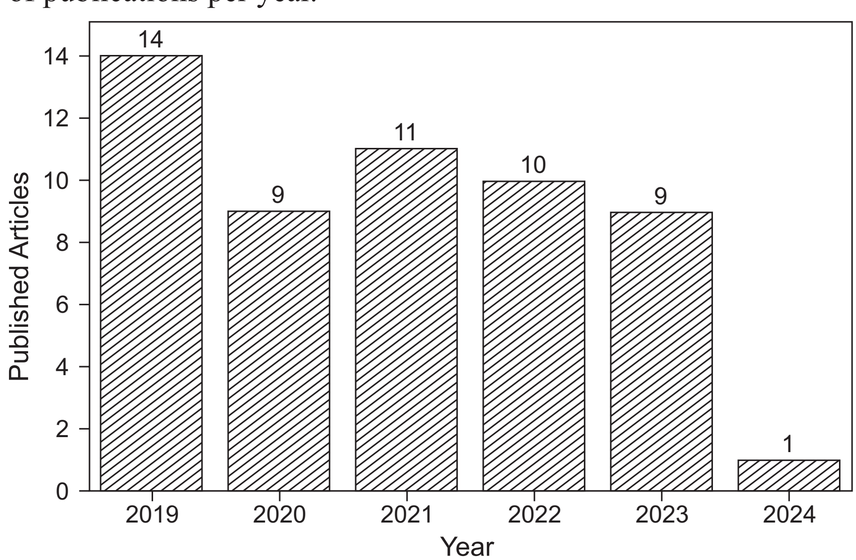
The bibliometric analysis also identified countries with significant research contributions. Iran led with 19 publications (35.18%), followed by China with 9, Canada and India with 4 each, and Brazil with 2 (0.37%). These results highlight Iran's dominant role in this field and suggest that Brazil should increase its scientific contributions to research on PCL-graphene electrospinning for tissue engineering (Table 2).

**Table 2.** Top 10 countries publishing on the topic.

| Country | Number of Publications |
|---|---|
| Iran | 19 |
| China | 9 |
| Canada | 4 |
| India | 4 |
| Italy | 3 |
| United States | 3 |
| Türkiye | 3 |
| South Korea | 3 |
| Brazil | 2 |
| Colombia | 2 |

Source: Web of Science (2024).

**Figure 1.** Number of publications per year.




Source: Web of Science (2024).

The analysis of critical journals revealed that Materials Science Multidisciplinary and Polymer Science each accounted for 16 articles (29.63%), followed by Materials Science Biomaterials with 12 articles (22.22%) (Table 3).

**Table 3.** Journals publishing the most articles.

| Journal | Number of Publications |
|---|---|
| Materials Science Multidisciplinary | 16 |
| Polymer Science | 16 |
| Materials Science Biomaterials | 12 |
| Nanoscience Nanotechnology | 8 |
| Applied Physics | 8 |

Source: Web of Science (2024).

These journals' focus on multidisciplinary research aligns with the broad applicability of electrospinning and scaffold technologies in tissue engineering and regenerative medicine.

## Conclusion

This bibliometric study highlights a decline in publications, potentially influenced by the pandemic, and identifies Iran as the leading contributor to research on PCL-graphene scaffolds. Brazil's limited output underscores the need for increased scientific efforts. The analysis of critical journals provides valuable insights into the current research landscape, offering guidance for future investigations. These findings are crucial for advancing applications in tissue engineering and regenerative medicine.

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# Study of the Potential of the Green Hydrogen Economy in Bahia: A Multiscale Approach

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**Given the urgent need to decarbonize global energy sources, this study aims to provide an in-depth understanding of the green hydrogen economy, addressing the challenges, opportunities, and benefits of its development in the Brazilian state of Bahia, which is the fifth largest state in the country. The research focuses on demonstrating the potential of this emerging economy in the state, employing a framework based on a multiscale methodology. This framework is designed to enhance understanding of Bahia's energy and fuel markets. Furthermore, the study explores the technologies and opportunities associated with green hydrogen in Bahia, detailing a framework that maps its potential in various regions, highlighting the primary production hubs and applications. The multiscale methodology plays a pivotal role in achieving these goals.**
**Keywords: Multiscale Approach. Sustainable Energy. Brazilian Study Case. Bahian Economy. Green Hydrogen.**

The adverse effects of the relentless reliance on fossil fuel-based energy sources are evident, including the consequences of climate change. Transitioning from polluting, carbon-intensive energy to clean, sustainable alternatives, such as green hydrogen, is increasingly essential for achieving sustainable development [1].

Bahia, in particular, possesses numerous opportunities to make Brazil's national energy matrix more sustainable and reduce environmental impacts. One prominent example is solar energy, an area where Bahia excels due to its high potential for photovoltaic generation, which can help meet current and future electricity demands in Brazil [1].

Additionally, the state boasts abundant natural resources and existing infrastructure, making it well-positioned to lead in the production and utilization of green hydrogen ($H_2V$) and its derivatives [2]. However, one of the major challenges of green hydrogen is achieving accessibility and economic viability compared to traditional production routes. Beyond tax incentives and policy measures, the advancement of basic and applied research into water electrolysis technologies is critical, as renewable, clean, and efficient energy sources are key to sustainable development.

This study adopts a multiscale approach to advance the green hydrogen economy in Bahia. By examining this system at different scales—from microscopic to macroscopic—the research aims to construct a comprehensive framework for developing this economy in Bahia and optimizing its implementation.

## Materials and Methods

The method includes a narrative literature review, focusing on articles published between 2020 and 2024, alongside a theoretical multiscale approach to examine green hydrogen production, storage, transport, and applications in different regions of Bahia. The multiscale approach allows for a detailed analysis of the hydrogen production cycle, from the microscopic processes of water electrolysis to large-scale storage, transport, and applications [3].

<u>Main Scales Studied</u> (Figure 1)

*Microscopic Scale*

Literature review focusing on results from simulations of key water electrolysis technologies,

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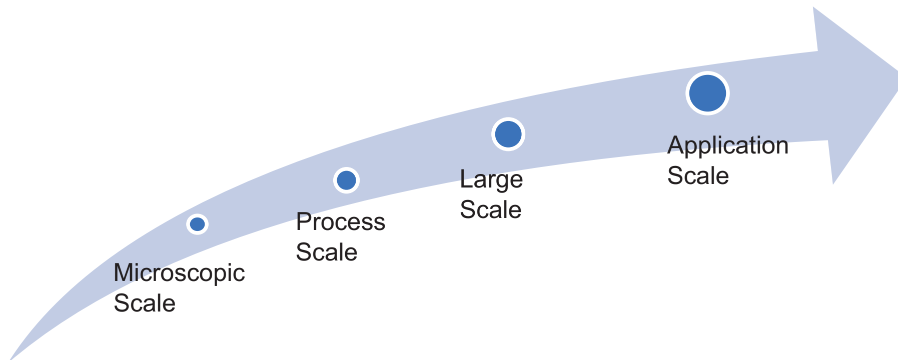
**Figure 1.** Scales of development of the green hydrogen economy in Bahia.




such as Alkaline and PEM. An example is the study of the PEM structure, which involves a set of cells composed of current collectors, bipolar plates, electrocatalysts, and a polymeric membrane (electrolyte), usually Nafion®, which acts as an ion conductor [4].

*Process Scale*

Investigation of water and energy sources for electrolysis in Bahia, the primary electrolysis technologies and process otimization. The most suitable water sources are seawater, Rainwater, and treated urban wastewater, regarding the different characteristics of each location [5]. And for the main energy sources, Bahia has a predominantly renewable and diversified electrical matrix composed of wind, solar, water and biomass [2].

*Large Scale*

Examination of hydrogen storage and transport methods, analyzing the most suitable options for Bahia. The hydrogen supply chain can include diverse echelons, depending on the specifications and needs of each application [6]. Figure 2 presents a hydrogen supply chain.

*Application Scale*

Exploration of green hydrogen applications as an energy matrix in different regions of the state. Hydrogen utilization technologies involve using hydrogen as a fuel or energy carrier in various applications across different sectors, including transportation, electricity generation, heating, and industry, some common hydrogen utilization technologies include fuel cells, hydrogen combustion, industrial processes, and energy storage and grid balancing [7]. For example, green hydrogen can be used in a plant for ammonia and urea production [8].

By integrating these scales, the study performs a preliminary techno-economic analysis, develops a detailed framework, and enhances understanding of the key steps necessary for developing Bahia's green hydrogen economy.

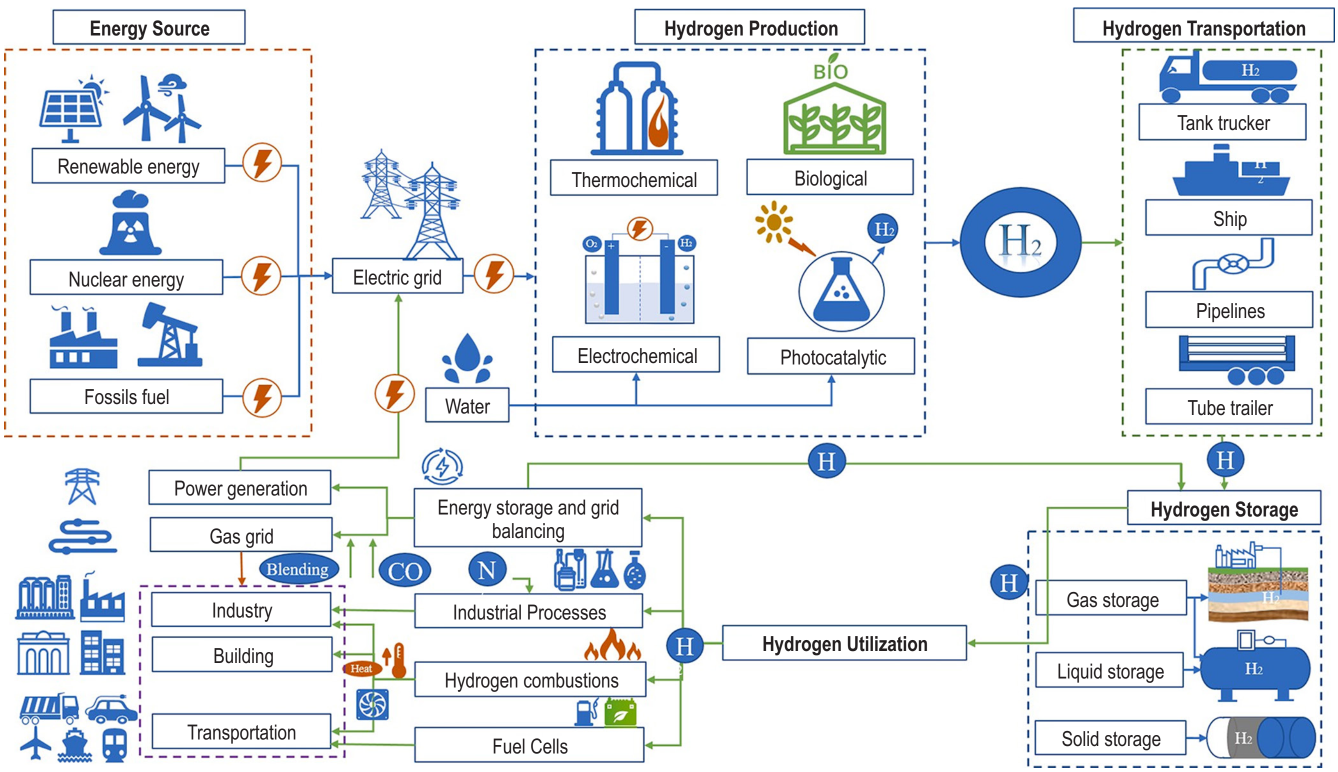
## Results and Discussion

<u>Green Hydrogen Production</u>

Hydrogen can be produced by numerous different processes (Figure 3), but green hydrogen is produced via water electrolysis powered by renewable electricity sources [9].

While the green hydrogen process is currently costly and less economically feasible than traditional energy sources, it represents one of the most promising alternatives to decarbonize the economy [9], combat climate change and achieve sustainable development.

**Figure 2.** An overview of hydrogen production, transportation, storage, and utilization (HPTSU) technologies [7].




## Energy Potential in Bahia

Brazil, particularly the Northeast, holds significant competitive advantages in green hydrogen production due to its abundant wind and solar resources, as well as the cost-effectiveness of energy generated by these sources compared to other countries [9]. Bahia's predominantly renewable energy matrix [2] and wealth of natural resources make it an ideal candidate for implementing the green hydrogen economy.

## Multiscale Approach

The success of this project hinges on the multiscale approach, which is well-suited for studying complex systems characterized by hierarchical, multi-scale phenomena in space and time. Complex systems involve nonlinear interactions, dissipative structures, and continuous exchanges of energy, matter, and information [10].

Key considerations for the multiscale method include:

- Correlations between phenomena at different scales;
- Trade-offs between dominant mechanisms;
- Combined spatial and temporal structural changes;
- Critical phenomena within complex systems [10].

This approach ensures a comprehensive analysis of green hydrogen's potential, from microscopic processes to macroscopic applications.

## Conclusion

This study provides a thorough overview of the green hydrogen economy in Bahia, emphasizing its challenges, opportunities, and potential benefits. The findings underscore the importance of transitioning to clean energy sources to mitigate climate change and foster sustainable and resilient economic development.

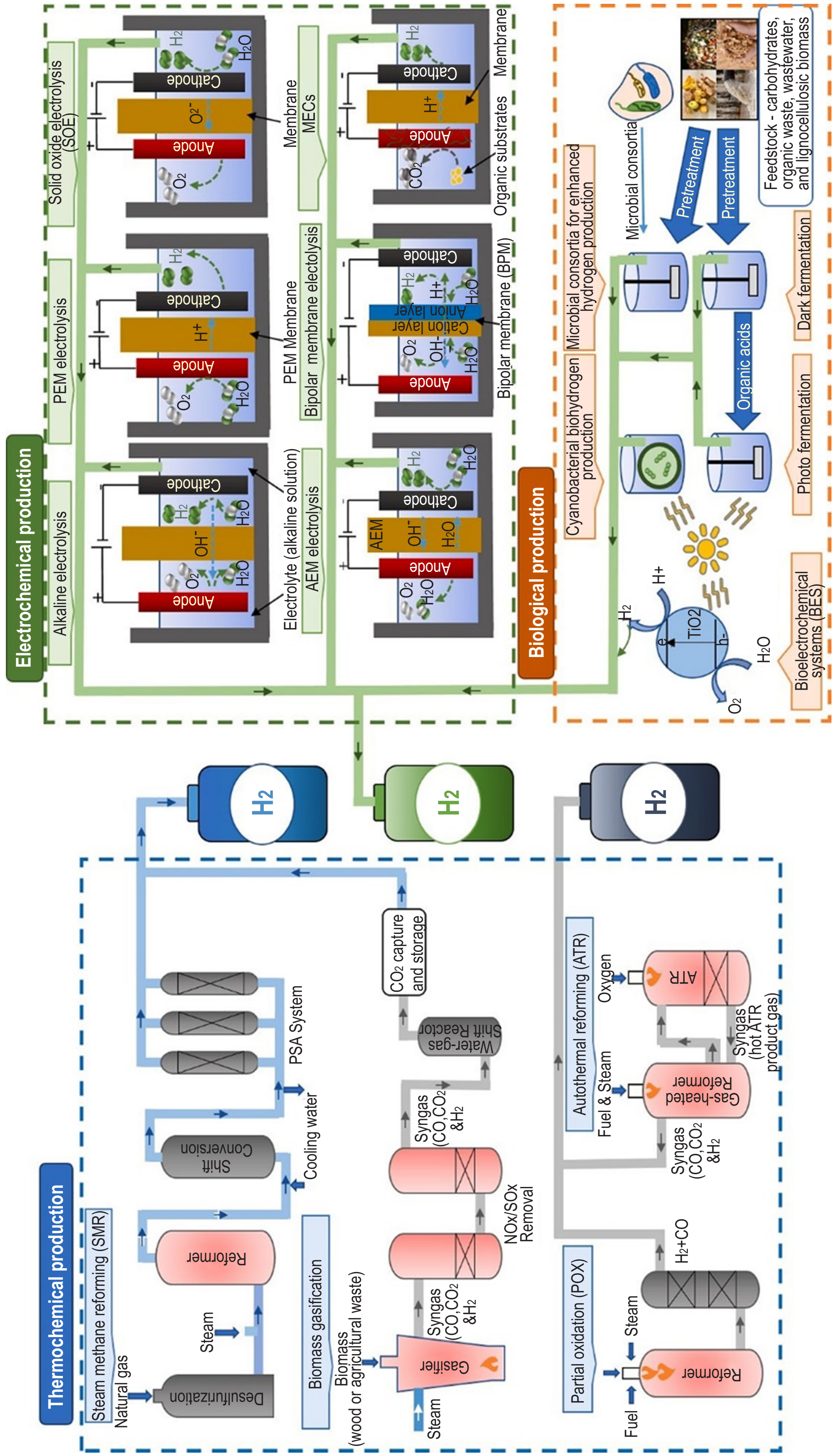



Figure 3. Overview of different hydrogen production technologies [7].

The multiscale method is essential for understanding this complex system, enabling detailed analyses across different levels—from production technologies to the infrastructure required for implementation.

Bahia's favorable conditions, including its renewable energy matrix and abundant solar and wind resources, offer a promising environment for developing the green hydrogen economy. However, investments in research and technology, coupled with public policies and incentives, are necessary to make green hydrogen a viable and competitive alternative to traditional energy sources.

In conclusion, the green hydrogen economy holds significant potential to drive Bahia's transition to a sustainable energy model, reduce greenhouse gas emissions, and build a more inclusive and resilient economy.

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# A Systematic Review of the Regulation of Green Hydrogen-Based Electricity Generation in Brazil

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**This article presents a systematic review of the current state of the art regulating electricity generation from green hydrogen in Brazil. The study was conducted through searches using selected descriptors in the SciELO and Google Scholar databases, supplemented by consultations in the ANEEL Virtual Library, Google, and ChatGPT. The goal was to identify documents related to laws, norms, and regulations addressing the use of green hydrogen for electricity generation in Brazil without any temporal restriction. The analysis of multiple documents revealed that, to date, no regulatory framework has been officially approved for green hydrogen in Brazil. This regulatory gap highlights the need for comparative studies with legislation from other countries to inform the development of an appropriate framework for the Brazilian context.**
**Keywords: Green Hydrogen; H2V; Brazil Legal Regulation; Brazilian Legislative Framework; Energy Legislation in Brazil.**

The global discourse on sustainable development gained momentum at the World Summit on Sustainable Development (Rio 92) [1], a United Nations (UN) forum that deliberated on strategies to mitigate greenhouse gas emissions and decarbonize the global energy matrix. Out of these discussions emerged the Sustainable Development Goals (SDGs) [2], a universal call to action aimed at ending poverty, protecting the environment, combating climate change, and fostering peace and prosperity for all.

In pursuit of these objectives, numerous technological advancements have been made globally to maintain international competitiveness while progressing toward energy transition goals. One such innovation is green hydrogen, which major global players have heralded as a critical tool for achieving planetary decarbonization.

While the concept of a "Hydrogen Economy" was first coined in the 1970s as a response to oil crises and embargoes, the vision for hydrogen as a renewable energy carrier dates back to the late 19th and early 20th centuries. For instance, Poul la Cour utilized wind energy and electrolysis to produce hydrogen and oxygen between 1891 and 1908. Similarly, in 1923, J.B.S. Haldane hypothesized a future where wind-powered electrolysis could supply high-voltage electricity grids, with surplus energy used to decompose water into hydrogen and oxygen [3]. These early examples underscore the long-standing recognition of hydrogen's potential, although technical and economic challenges historically limited its application to niche markets.

Today, classifying hydrogen based on the carbon intensity of its production process is a critical step in understanding its role in decarbonization. According to the Energy Research Agency [4], hydrogen is categorized into different "colors" depending on the production pathway, associated costs, and the extent of carbon dioxide management through Carbon Capture, Utilization, and Storage (CCUS). Figure 1 illustrates this classification system, reflecting the diverse routes available for hydrogen production. This evolving understanding of hydrogen's potential and production routes underscores its significance as a cornerstone of the global energy transition.

Brazil is uniquely positioned to leverage green hydrogen for its energy transition. Eighty-five percent of its energy matrix is derived from clean sources of electricity generation free from carbon dioxide emissions. The remaining 15 percent

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**Figure 1.** Summary of the hydrogen production process.

| Color | Summary of the hydrogen production process |
|---|---|
| Black | Coal gasification (anthracite[1]) without CCUS[2] |
| Brown | Coal gasification (hulha[3]) without CCUS |
| Gray | Steam reforming of natural gas without CCUS |
| Blue | Steam reforming of natural gas with CCUS |
| Turquoise | Pyrolysis of methane[4] whithout generating $CO_2$ |
| Green | Water electrolysis with energy from renewable sources (wind/solar) |
| Moss | Catalytic reforming, gasification of waste plastics or anaerobic biodigestion of biomass or biofuels with or without com energia de fontes renováveis (eólica/solar) |
| Pink | Nuclear power source |
| Yellow | Power from the electrical grid, composed of several sources |
| White | Extraction of natural or geological hydrogen |

Notes: 1 - From the least to the rechest types in carbon: carbon, peat, lignite, hard coal and anthracite, the latter having more than 86% carbon. 2 - CCUS - *Carbon Capture, Utilization and Storage*. 3 - Hard coal has between 69% and 86% carbon. 4 - Pyrolysis of methane is understood as pyrolysis of natural gas, cince it is the main component of natural gas.

Source: EPE, Technical Note: May 2021 p. 4 [4].

comes from thermal power plants powered by diesel or biodiesel, as reported in the ANEEL Retrospective 2022.

This remarkable distribution reflects Brazil's reliance on renewable resources such as hydroelectric, wind, solar, and biomass energy. Figures 2 and 3 illustrate the breakdown of energy production sources, providing insights into the diversity of production methods and the origin of the fuels used.

Such a predominantly renewable energy matrix positions Brazil as a global leader in clean energy, making it an ideal candidate for large-scale green hydrogen production. By harnessing its abundant renewable resources, Brazil has the potential to produce green hydrogen sustainably and cost-effectively, supporting both domestic energy needs and international markets aiming to decarbonize their energy systems.

This context underscores the strategic importance of developing a robust regulatory framework for green hydrogen that aligns with Brazil's energy strengths while addressing the gaps identified in comparative global studies.

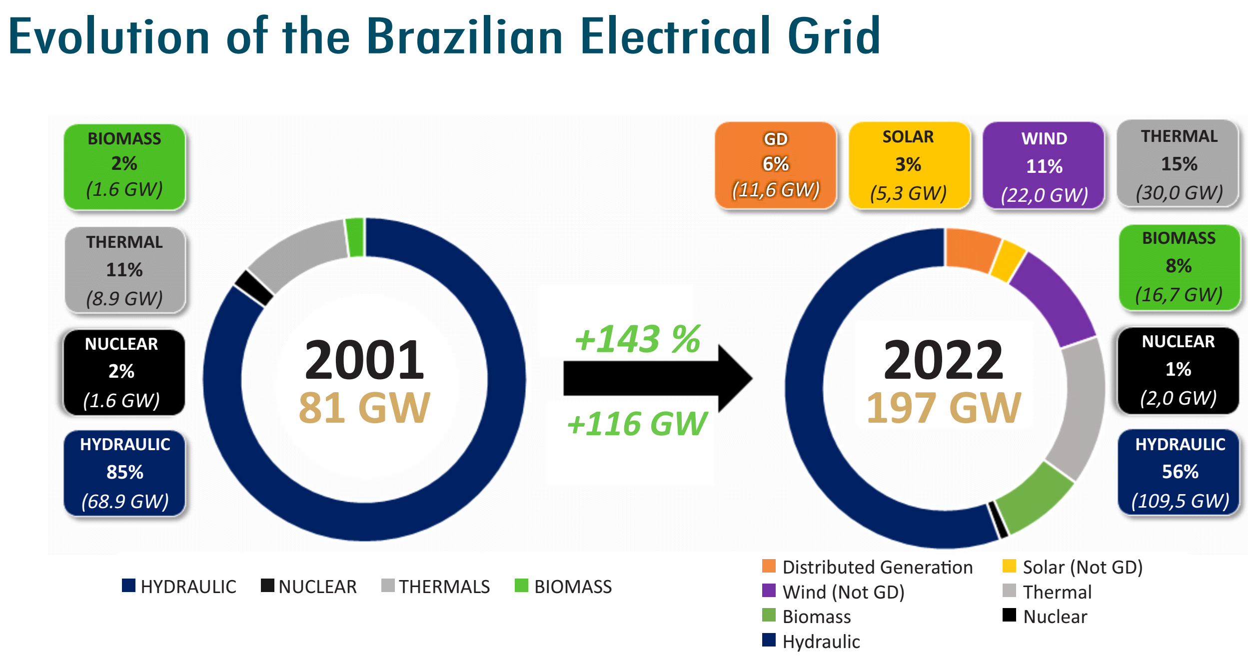
There is strong evidence of Brazil's commitment to prioritizing electricity generation from clean and decarbonized sources and significant growth in wind and solar power generation. These renewable sources are increasingly leveraged for green hydrogen production due to their declining costs, which have dropped consistently year after year. This unique combination of factors positions Brazil as one of the top global contenders for developing a robust Green Hydrogen Industry, as recognized by multiple energy agencies and working groups focused on green hydrogen.

However, establishing a green hydrogen supply chain requires more than abundant renewable resources. It necessitates creating a comprehensive regulatory framework encompassing legislation, regulations, and standards to provide the legal certainty needed to attract the investments essential for this industry's emergence and growth.

## Goals

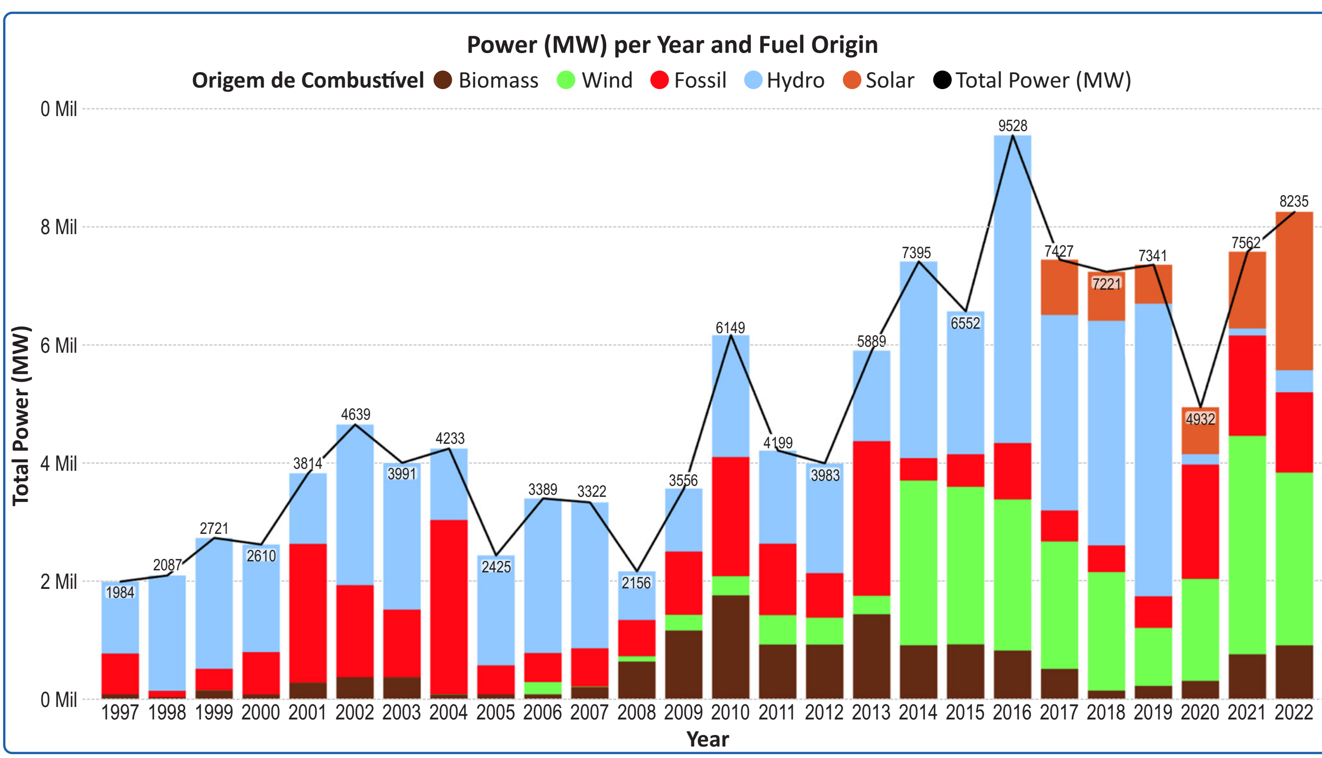
The primary objective of this study is to examine the state of the art in regulating the

**Figure 2.** Evolution of the electrical matrix in Brazil.




Source: ANEEL 2022 Retrospective, p. 26.

**Figure 3.** Power per year and fuel origin.




Source: ANEEL 2022 Retrospective, p. 27.

production of electricity from green hydrogen in Brazil. While most published works in Brazil focus on methods for producing green hydrogen (H2V) or highlight case studies of Research and Development (R&D) projects, they rarely address the existing legislation necessary to regulate this nascent and promising industry.

Insights from studies by Polish and German researchers emphasize the global regulatory gap in this emerging sector, sparking interest in exploring Brazil's regulatory landscape for electricity production from green hydrogen. This investigation holds particular relevance given the potential of green hydrogen to replace or eliminate the 15% of fossil fuels still present in Brazil's energy matrix.

Moreover, Brazil's strong and judicious regulatory framework for electricity production heightened the importance of this subject. Understanding how this framework might accommodate or adapt to the development of a green hydrogen industry is critical to shaping its future role in Brazil's clean energy transition.

## Materials and Methods

Using the following descriptors: ("Green Hydrogen " OR H2V) AND ("Legal Regulation" OR " Current Legislative Framework" OR " energy legislative ") papers were searched in the Scielo and Google Scholar databases, with 122 and 39 papers identified, respectively. To search for papers more focused on the theme, only those in which the descriptors appear in the title were considered. a search in the Legislation issued by the National Electric Energy Agency of Brazil – ANEEL, using the ANEEL Virtual Library, which is a research tool available on the internet, on the ANEEL website, whose address will be part of the references of this work [5]. A search for this topic was also carried out, using Google and ChatGPT to identify documents dealing with Laws, Rules and Regulations on the use of Green Hydrogen in Brazil for the generation of Electric Energy that had been issued by other authorities. different from the National Electric Energy Agency.

## Results and Discussion

### Findings from the ANEEL Virtual Library

When the term green hydrogen was searched in ANEEL's Virtual Library, only four documents were identified:

**Two Ordinances (PRTs) [6]:** These addressed administrative matters related to ANEEL staff participation in international events (e.g., seminars and workshops) focused on energy transition, market regulation, and green hydrogen. While these documents did not contribute directly to the study's objectives, they indicated ANEEL's interest in the topic.

**Two Regulatory Impact Analyses (AIRs):**

- Five-Year Strategic Innovation Plan (PEQuI 2023–2028) ((Report on Regulatory Impact Analysis No. 0001/2023-SPE/ANEEL) [7]): Addressed general innovation and strategic goals for the energy sector but did not include specific green hydrogen regulations.
- Locational Signal for TUST/TUSDg ((Report on Regulatory Impact Analysis No. 03/2022-SGT/ANEEL) [8]): Examined regulatory impact analysis related to tariff methodologies but did not mention green hydrogen.

When analyzing the 04 documents located, it is identified that the ordinances deal with administrative matters of ANEEL and served to release the removal of the agency's employees from the country to participate in Seminars, Workshops, and technical visits on energy transition, market regulation, green hydrogen, and decarbonization, in an event held in Portugal. Despite not adding content to develop the results intended by the work in question, they demonstrated the topicality of the topic discussed and the interest of the National Electric Energy Agency.

Analysis of Relevant Normative Resolutions

**ANEEL Normative Resolution No. 1,029 (07/25/2022) [9]:** Consolidates norms related to the production and commercialization of electricity. While it defines procedures for maintaining operational conditions and power specifications for electricity generation enterprises, it does not explicitly address green hydrogen.

**ANEEL Normative Resolution No. 1,033 (07/26/2022) [10]:** Consolidates regulations under the Alternative Sources Incentive Program (PROINFA), including criteria for quality and reliability of electricity generation services. However, it does not mention green hydrogen.

The results demonstrate a notable lack of specific regulations or guidelines for producing electricity from green hydrogen within ANEEL's framework. While the identified documents suggest a growing interest in the topic, particularly through international engagement and strategic planning, no concrete regulatory framework is currently in place.

This gap aligns with global observations about the nascent state of regulatory frameworks for green hydrogen, as noted in comparative studies from countries such as Poland and Germany.

The absence of clear legislation in Brazil highlights the urgency of establishing policies to foster the development of this promising industry, especially given Brazil's renewable energy potential and the opportunity to eliminate the remaining 15% reliance on fossil fuels in its energy matrix.

Future research should explore comparative international legislation and propose actionable recommendations for Brazil's regulatory framework to accelerate the development of a green hydrogen-based energy system.

The findings underscore the evident lack of regulation by the National Electric Energy Agency (ANEEL) concerning the production and use of green hydrogen for electricity generation. To address this gap, the search was expanded using Google and ChatGPT, which led to identifying key legislative and policy documents related to green hydrogen in Brazil.

Key Documents Identified

**Draft Bill No. 1878/2022 [11]:** This bill, proposed by the Environment Commission of the Federal Senate of Brazil [8], aims to establish a policy framework to regulate the production and use of green hydrogen for energy purposes. The draft was forwarded to the Special Commission for the Debate of Public Policies on Green Hydrogen for further analysis on April 20, 2023.

**Roadmap for Structuring the Hydrogen Economy in Brazil (2005) [12]:** Published by the Ministry of Mines and Energy (MME), this document outlines strategic directions for integrating hydrogen into Brazil's energy sector. It includes recommendations to promote norms and standards for certification of products, processes, and services related to hydrogen and fuel cell technologies.

**Science, Technology, and Innovation Program for the Hydrogen Economy (ProH2, 2002):** Developed by the Ministry of Science and Technology (MCTI), this program emphasizes fostering innovation in hydrogen technologies and calls for establishing technical standards and regulatory frameworks [13].

Current Status and Observations

Despite the presence of these initiatives, Brazil does not have an approved regulatory framework specifically addressing green hydrogen as of 2023. While the identified documents demonstrate intent and preliminary planning, the lack of concrete regulations hinders establishing a structured green hydrogen industry. This regulatory vacuum presents a significant barrier to attracting investments and enabling the large-scale deployment of green hydrogen technologies. The absence of clear guidelines also delays Brazil's ability to capitalize on its abundant renewable resources and strategic position as a potential leader in the global green hydrogen market.

Next Steps

The draft of Bill No. 1878/2022 represents a critical opportunity to establish foundational regulations for green hydrogen. Advocating for its swift approval and implementation should be a priority.

Efforts to update and operationalize the Roadmap and ProH2 [14] program recommendations are necessary to translate policy objectives into actionable outcomes.

Comparative analysis with regulatory frameworks from other countries could provide valuable insights to accelerate Brazil's progress in this emerging sector.

## Conclusion

The systematic review of the existing regulatory framework for using green hydrogen in electricity production in Brazil highlights a critical gap: the lack of norms and regulations issued by the Brazilian Legislature (Federal Chamber of Deputies and Federal Senate) and the National Electric Energy Agency (ANEEL). This absence signifies a complete lack of legal protections for the commercial-scale use of green hydrogen, whether for domestic consumption or export.

This regulatory void not only underscores the absence of a structured framework but also highlights the challenges of accessing consolidated and comprehensive information on existing and proposed regulations related to green hydrogen in Brazil.

Furthermore, the lack of clear rules and legal certainty appears to deter investment in this promising industry, potentially limiting Brazil's ability to develop and capitalize on its immense potential as a global leader in green hydrogen production.

## Recommendations

The study identifies a significant gap that suggests the necessity of conducting a comparative analysis of existing regulations and standards in the world's five largest hydrogen-producing countries—namely, the United States, the United Kingdom, Germany, Ukraine, and Russia. This analysis should also include Chile and Argentina, given their geographical proximity to Brazil and their potential role as competitors in exporting green hydrogen to Europe. Such a study could provide insights and best practices to guide the development of Brazil's regulatory framework and enhance its competitive positioning in the global market.

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# Methods for Prospecting and Monitoring Hydrocarbon Gases on Oil and Gas Platforms and Basins: A Brief Review

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**This work provides an overview of oil and gas prospecting methods and techniques, focusing on their advantages and limitations. It also highlights their application in monitoring hydrocarbon leaks on platforms and basins. A mapping of techniques, classified into geological, geophysical, and geochemical categories, illustrates their relevance, offshore or onshore suitability, and practical applicability. The discussion underscores the need for integrated approaches to improve exploration efficiency and safety while aligning with sustainable development goals (SDGs).**
**Keywords: Prospecting. Oil and Gas. Geochemistry. Geophysics.**

Global oil consumption continues to outpace exploration, intensifying the need for effective prospecting techniques to maintain market balance.

According to the ANP statistical yearbook [1], oil production grew by 1.6% from 2022 to 2023, reaching 93.8 million barrels per day, while consumption rose by 6%, totaling 97.3 million barrels per day. Efficient oil and gas prospecting is crucial for identifying hydrocarbon-rich regions, reducing costs in unpromising areas, and improving exploration success rates. Over time, geological, geophysical, and geochemical techniques have evolved to enhance reliability and minimize environmental impact [2]. However, when applied individually, these methods often need to provide precise predictions. A combination of techniques is necessary for comprehensive assessments [3].

Monitoring hydrocarbon leaks on platforms and storage sites is equally critical, as light hydrocarbons identified during prospecting can also indicate potential leak sources [4]. Moreover, this study aligns with UN Sustainable Development Goals (SDGs), particularly SDG 9 (Industry, Innovation, and Infrastructure) and SDG 12 (Responsible Consumption and Production) [5].

Thus, this work aims to map the most relevant and commonly used oil and gas prospecting techniques, evaluate their advantages and limitations, and highlight opportunities for technological advancements in the sector.

## Materials and Methods

The study's methodology involves a systematic mapping of existing techniques for oil and gas prospecting, using the Web of Science database to identify key methods published between 2013 and 2024. A flowchart (Figure 1) outlines the research steps:

- Review and identify relevant techniques.
- Evaluate techniques based on criteria such as efficiency, theoretical framework, validated data, and application.
- Map methods by relevance, identifying offshore or onshore suitability and references.

The findings highlight the most relevant methods, their advantages, limitations, and specific applications.

## Results and Discussion

Oil and gas prospecting methods fall into geological, geophysical, and geochemical

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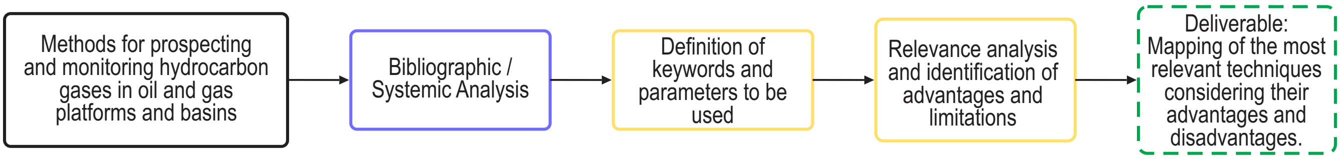
**Figure 1.** Work flowchart.




categories. While geological and geophysical methods provide a qualitative overview, geochemical methods offer quantitative analyses, enhancing precision [6,7]. Table 1 presents an overview of essential techniques within each category.

Geological Methods

Typically the first step in prospecting, these methods use geological maps and sound data to identify potential hydrocarbon formations. While effective for initial assessments, they lack the precision needed for detailed exploration [4,8].

Geophysical Methods

Techniques like seismic surveys provide high-quality subsurface images, making them invaluable for complementing geological analyses. Advanced methods, such as 3D seismic imaging, offer enhanced accuracy but come with high costs and operational challenges [6].

Geochemical Methods

These techniques detect hydrocarbons released to the surface, providing direct evidence of oil and gas presence. They are particularly useful for

**Table 1.** Mapping of oil and gas prospecting techniques.

| Methods | Techniques | Usage | Advantages | Limitations | Reference |
|---|---|---|---|---|---|
| Geological | Aerial Photogrammetry | On-shore/Off-shore | Detailed information about sedimentary basins | Indicates only the possibility of oil and gas activity, without guaranteeing acceptable levels of confidence. | 4.6 |
| | Photogeology | On-shore/Off-shore | Identification of structures favorable to oil accumulation | | |
| Geophysical | Seismic | On-shore/Off-shore | Low cost compared to others and high-quality results on subsurface soil | Uses many sensors and devices to generate elastic waves (requires high manpower). Requires extensive data processing. | 6.12 |
| | Seismic 3D | On-shore/Off-shore | | | |
| | Seismic 4D | On-shore/Off-shore | | | |
| | Magnetometry | On-shore/Off-shore | Provides another perspective of analysis regarding magnetic anomalies | External influences in data reading and analysis (e.g., dissociated salt in the sea, fields generated by other sources) | 9 |
| | Electromagnetism | On-shore/Off-shore | | | |
| Geochemical | Pre Gas Analysis | On-shore | Practical and does not require sample treatment | Collection must be done between 1-10m from the surface for better results | 3.9 |
| | Adosrbed Gas Analysis | On-shore | Better results and more studies available | Requires sample treatment | 10.9 |
| | Dissolved Gas Analysis | On-shore/Off-shore | Used for prior leakage detection | Requires the presence of a water table and is less practical | 3 |
| | Microbiological Analysis | On-shore | Can be used in any type of region where other methods are ineffective | May be influenced by other volatile hydrocarbon generations | 11.8 |

validating findings from geological and geophysical methods. However, their effectiveness depends on complementary data and environmental conditions [9].

Prospecting methods also monitor hydrocarbon leaks, as similar detection principles apply. This dual utility emphasizes the importance of continued innovation and integration of techniques to improve reliability and reduce risks.

## Conclusion

The analysis reveals various prospecting techniques, each with distinct advantages and limitations. While newer methodologies are gaining prominence due to their precision and innovation, gaps still need to be found in their effectiveness across varying environments.

Combining multiple techniques is essential to achieving reliable exploration outcomes. This integrated approach ensures efficient resource allocation and aligns with the SDGs by promoting sustainable and responsible resource management.

Future research should focus on developing cost-effective, adaptable technologies that address current limitations and enhance the industry's capability to prospect and monitor hydrocarbons efficiently.

## Acknowledgments

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# Analysis of the $CO_2$ Separation Process from Natural Gas Streams by Absorption with MEA using Aspen HYSYS

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**The increasing concern for environmental preservation and efforts to mitigate global warming has intensified studies on process decarbonization. Simultaneously, natural gas (NG) consumption has been rising due to its lower environmental impact than other fossil fuels. To meet commercial standards, natural gas undergoes a $CO_2$ separation stage, with amine absorption technology being the most widely used due to its industrial applicability. This study aims to organize a test spreadsheet to initiate a sensitivity analysis of the $CO_2$ absorption process in natural gas streams based on simulations conducted using Aspen HYSYS. The analysis identifies combinations of process parameters that optimize separation results.**
**Keywords: $CO_2$ Separation. Absorption. Amines, Aspen HYSYS.**

Natural gas consists of various chemical compounds, predominantly hydrocarbons, with methane ($CH_4$) as its main component. Natural gas is classified into three types:

**Dry Gas**: Primarily sold as compressed natural gas (CNG) or liquefied natural gas (LNG).

**Wet Gas**: Contains higher quantities of ethane, propane, and butane, commonly referred to as liquefied petroleum gas (LPG).

**Gas Condensate**: Comprises heavier fractions of natural gas, such as naphtha [1].

The growing demand for sustainable energy and reduced greenhouse gas (GHG) emissions have increased the appeal of natural gas as a cleaner energy source [1]. However, to meet market requirements, natural gas must have a $CO_2$ concentration of no more than 3% v/v, as carbon dioxide is a contaminant affecting the gas's characteristics [2].

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$CO_2$ is typically removed from natural gas streams through amine absorption [3], a widely used technology known for its high absorption efficiency at low concentrations and ease of solvent recovery. However, the energy-intensive nature of the absorption process has prompted research into optimization through simulation tools. This study focuses on organizing a test spreadsheet for sensitivity analysis using Aspen HYSYS, enabling the identification of optimal process configurations.

## Materials and Methods

This project began with a literature review to examine the importance of $CO_2$ removal from natural gas streams. It focused on current methods and the role of amines in this process.

The review included a qualitative bibliographic survey using keywords such as "$CO^2$ separation," "alkanol amines," and "natural gas." The study highlighted monoethanolamine (MEA) as the primary solvent due to its high $CO^2$ absorption capacity at low concentrations and efficient recovery.

Using Aspen HYSYS V12.1, a simulation model of the $CO_2$ capture process with MEA was developed. A test spreadsheet was then organized to initiate sensitivity analysis, targeting key process parameters.

**Theoretical Foundation**

Absorption is an industrial process used to recover high-value compounds. It is categorized into three types:

Physical Absorption

Chemical absorption with irreversible reaction Chemical absorption with reversible reaction The absorption process relies on mass transfer between a gaseous solute and a liquid solvent in a countercurrent distillation column. The column contains trays or packing material to enhance contact between phases, enabling the solvent to absorb the gaseous solute [4].

This project used Aspen HYSYS to simulate a chemical absorption process with a reversible reaction. $CO_2$ (the gaseous solute) was separated from the natural gas stream using MEA as the liquid solvent. The primary equipment involved includes an absorber column, a distillation column, a heat exchanger, and auxiliary equipment like pumps and valves [5].

Process Flow (Figure 1)

Natural gas enters the absorber at the column's bottom, while the MEA solution enters at the top. The amine absorbs CO2, exiting as a rich solvent at the column's bottom. The purified gas exits at the top.

The $CO_2$-rich solvent is heated in a heat exchanger using a hot stream from the bottom of the distillation column.

The heated solvent enters the distillation column's top. The distillation column separates $CO_2$ from the MEA using steam generated by a reboiler

The $CO_2$ exits the column's top for collection, while the lean solvent is recycled back to the absorption column after cooling and replenishing with MEA and water. Input and output parameters such as temperature, pressure, flow rate, and $CO_2$ concentration were collected for sensitivity

**Figure 1.** Flowchart of the $CO_2$ absorption process from natural gas stream simulated in the Aspen HYSYS [6].

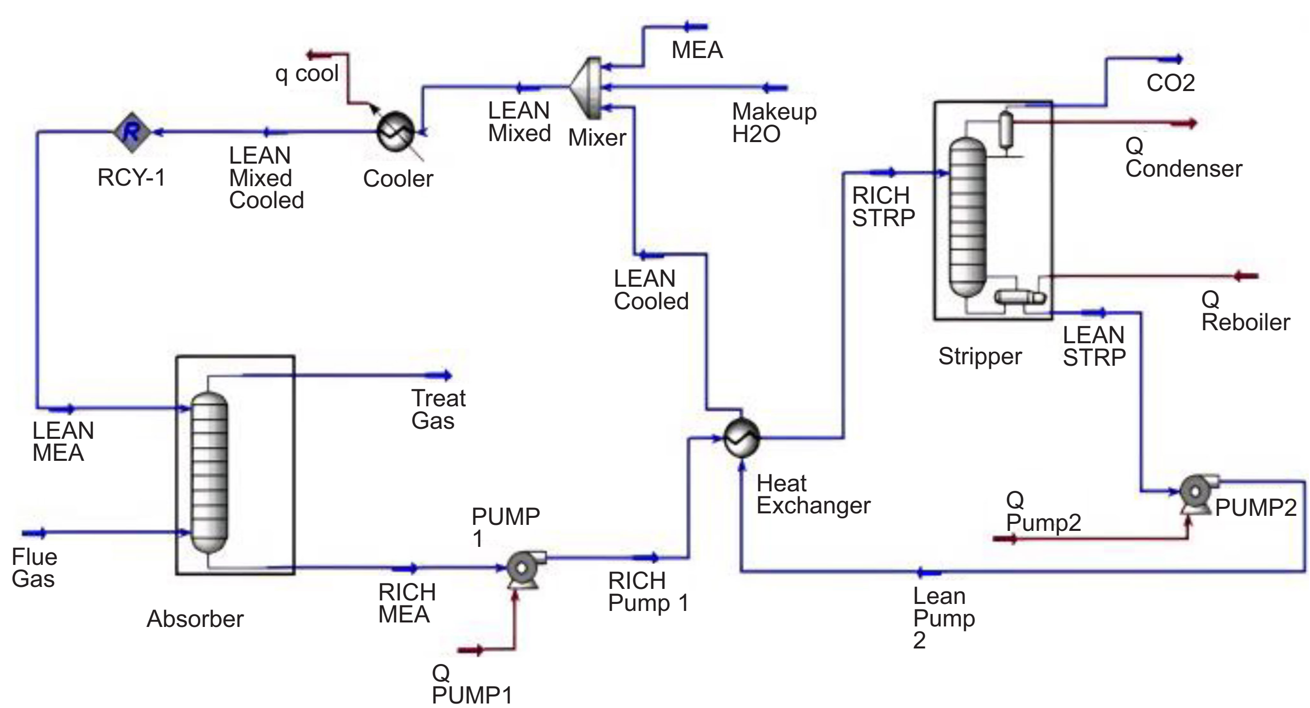

**Table 1.** Test table for sensitivity analysis.

| Test | Current | Stream Modified Parameter |
|---|---|---|
| 1 | Pump | Temperature |
| 2 | MEA Makeup | Flow Rate |
| 3 | MEA Makeup | Composition |
| 4 | Heat Exchanger | Temperature |
| 5 | Gas Supply | Temperature |
| 6 | Gas Supply | Flow Rate |
| 7 | Gas Supply | Composition |

analysis.Seven scenarios were constructed for a test table (Table 1) to evaluate the influence of variable modifications on process efficiency.

The sensitivity analysis aims to identify the best process configurations for efficient $CO_2$ separation.

## Conclusion

The $CO_2$ absorption process from natural gas streams is of significant environmental relevance. Given its energy demands, continuous research and development are essential. Simulation tools like Aspen HYSYS facilitate the exploration of alternative process routes and improve efficiency.

Future studies should focus on enhancing solvent recovery, reducing energy consumption, and exploring alternative technologies to further optimize the $CO_2$ separation process.

## Acknowledgments

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# Seawater Refinary: A Pathway for Sustainable Metal Recovery and Green Hydrogen Production

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**With the growing environmental challenges of saltwater desalination, seawater mining is emerging as a sustainable alternative to traditional onshore mining. This paper explores the potential of recovering metals from seawater and producing green hydrogen, proposing a "seawater refinery" concept inspired by oil and biorefineries. The refinery leverages advanced separation technologies and "Zero Liquid Discharge" methods to convert brine into valuable products, including green hydrogen ($H_2$) while minimizing environmental impacts.**
**Keywords: Desalination. Metal Recovery. Membrane Processes. Green Hydrogen.**

The global shift toward a hydrogen-based economy, coupled with carbon dioxide ($CO_2$) capture technologies, offers a promising pathway for decarbonizing industrial sectors. However, the increasing demand for hydrogen ($H_2$) could exacerbate water consumption, raising concerns about competition with potable water supplies essential for human and environmental needs [1,2].

Seawater has been identified as a viable water source for $H_2$ production, provided it undergoes desalination before electrolysis. However, desalination processes generate brine discharge with detrimental environmental impacts. This waste contains elevated salinity levels, heavy metals, and residues of chemical additives used during desalination, such as anti-scaling, anti-foaming, and anti-corrosion agents. Discharge affects local ecosystems by altering the receiving environment's physicochemical properties, including temperature, turbidity, and dissolved oxygen levels. These changes adversely affect biodiversity, metabolic rates, and the physiological health of marine life [3,4].

In parallel, the global demand for rare and valuable metals has heightened interest in sustainable extraction methods. Seawater mining presents a compelling alternative, mainly through brine concentrate mining, which offers energy-efficient and environmentally friendly means to extract valuable metals like magnesium (Mg), lithium (Li), uranium (U), potassium (K), and sodium (Na). These elements are crucial in energy storage, transportation, agriculture, and electronics [5,6].

Inspired by the operational principles of oil and biorefineries, this paper introduces the concept of a "seawater refinery." This approach focuses on maximizing resource efficiency and minimizing waste by separating various valuable products—including metals, green $H_2$, and chemicals—directly from seawater.

## Materials and Methods

The method for this study involved a detailed and systematic approach to explore the feasibility of a seawater refinery for metal recovery and green hydrogen ($H_2$) production. Key steps are outlined below:

<u>Comprehensive Literature Review</u>

A thorough review of existing literature was conducted, focusing on:

- Mining and recovery of metals from brine.
- Desalination technologies specific to seawater.

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- Water consumption during the electrolysis process for $H_2$ production.

The Web of Science database was used as the primary search platform to gather relevant literature. Additionally, the snowballing method was applied, employing two complementary approaches:

- Backward snowballing: Analyzing the reference lists of selected papers.
- Forward snowballing: Review articles that cited the primary papers.

Suggestions from journal recommendation algorithms were also incorporated to ensure a well-rounded collection of resources.

Synthesis of Information

Data and insights from the literature were synthesized to comprehensively understand the potential for adding value to brine.

Brine, a byproduct of desalination, presents environmental challenges and contains valuable resources that can be recovered.

Process Flowsheet Development

Based on the synthesized information, a conceptual process flowsheet for the seawater refinery was developed. The flowsheet outlines the main stages of resource recovery and green $H_2$ production.

Assessment of Technological Feasibility

The complexity and readiness of the proposed refinery were evaluated using Technology Readiness Levels (TRLs) and Manufacturing Readiness Levels (MRLs):

- TRLs: Represent the maturity levels of tangible technologies involved in the refinery processes.
- MRLs: Denote the maturity levels of production processes (intangible assets) required to implement the refinery.

Table 1 presents the TRL and MRL classifications, providing insights into technological development and production readiness. This dual assessment approach ensures that the seawater refinery's technological and operational aspects are critically evaluated for feasibility and scalability [7].

This structured method ensures that the study addresses both the theoretical and practical dimensions of the seawater refinery concept, paving the way for its potential implementation.

## Results and Discussion

Challenges in Conventional Mining

Traditional mining practices face numerous difficulties, including:

- Depletion of high-grade ores: Resources of superior quality are becoming scarce, making extraction increasingly uneconomical
- Rising environmental costs: Managing the ecological impact of mining has become costly.
- Reduced ore quality: Available reserves often consist of lower-quality ores, further complicating extraction processes.
- Stricter regulations: Environmental policies are becoming progressively stringent, adding compliance challenges.

Given these constraints, metal recovery from seawater presents an innovative and sustainable alternative, reducing dependence on terrestrial mining while tapping into an underutilized resource.

Historical Context of Seawater Mining

The idea of extracting valuable components from desalination concentrate dates back to Dr. John F. Mero in 1964. He predicted that desalination brine could play a pivotal role in

**Table 1.** TRLs and MRLs levels for complexity assessment [7].

| Level Definition | TRL | MRL |
|---|---|---|
| Ideation | This is the lowest level, where the technology is still in the theoretical or conceptual stage, and there is no experimental evidence or proof of concept. | The manufacturing process is still in the early conceptual stage, and basic principles are being explored. |
| Conception | At this level, the technology concept is defined, and there might be some initial experimental evidence to support its feasibility. | The manufacturing concept is defined, and initial analyses are conducted. |
| Proof of concept | The technology is now proven to work in a laboratory environment or through analytical studies, demonstrating its feasibility | The process is proven to be feasible through studies and experiments. |
| Otimization | A prototype of the technology is built and tested in a controlled laboratory setting, showing its potential functionality. | The process is demonstrated in a laboratory setting. |
| Prototyping | The technology's prototype is tested in a relevant environment that simulates realworld conditions, confirming its performance capabilities. | Process is validated in a relevant environment. |
| Escalonation | A more advanced prototype is tested and demonstrated in an actual operational environment. | A prototype manufacturing system is tested in a productionlike environment. |
| Demonstration in operational environment | At this stage, a system prototype is tested and proven to work in an operational setting. | The prototype manufacturing system is demonstrated in a relevant operational environment. |
| Production | The technology is now fully developed, and it has undergone rigorous testing to ensure it meets the required specifications. | A pilot manufacturing system is fully operational and represents a near-final design. |
| Continued production | The technology has been successfully deployed and used in real missions or operational scenarios. | The manufacturing process is fully matured and ready for fullscale production. |

future mineral production from seawater. This concept gained renewed attention in 1994 through the work of Petersen, inspiring several subsequent research efforts to develop viable extraction methods [6,8,9].

Brine Mining Technologies

The development of brine mining technologies, particularly advancements in membrane-based separation processes, has dramatically enhanced the feasibility of extracting metals from desalination concentrate.

*Desalination Technologies*

Desalination methods are categorized into conventional and emerging technologies based on their maturity and market presence. Conventional methods like:

- Reverse Osmosis (RO)
- Nanofiltration (NF)
- Electrodialysis (ED)

have significantly reduced operational costs. For example, the cost of seawater desalination has decreased from US$10.00/m³ in the 1970s to US$0.15/m³ by 2021 [10], making it a more economically viable option. Emerging technologies are described as innovative approaches with the potential to enhance recovery efficiency and sustainability.

Economic Viability of Metal Recovery

The recovery of metals such as Na, Ca, Mg, K, Li, Sr, Br, B, and U from seawater is deemed feasible under certain economic conditions. Loganathan and colleagues (2017) correlated the estimated quantities of these minerals in seawater with their terrestrial reserves (Figure 1).

For economic viability, the Market Price (Pm) of the metal must satisfy the following conditions:

$$P_m \geq \frac{POWCL}{C_m} \quad (1)$$

Where: Pm = Market Price (Pm); LCOWP = Levelized Cost of Water Processing, and Cm = Metal Concentration [6,11-13].

Figures 1 and 2 illustrate: the recovery potential of various metals., and the economic thresholds for profitability in brine mining operations.

These results underscore the transformative potential of seawater refineries in addressing resource scarcity and promoting sustainability.

Kumar and colleagues (2019) discuss the direct electrosynthesis of NaOH and HCl from seawater desalination brine, and water electrolysis is gaining momentum globally as a route to decarbonize our energy systems. Table 2 shows the most common minerals and chemicals potentially produced from seawater and its primary uses. The most common desalination system is based on RO and ED.

Membrane distillation (MD) is a standard process to recover Na, Ca, Mg, K, and the Adsorption/desorption process (ADSM) to recover Li, Sr, Br, B, and U Table 3 describes these treatment technologies and some other technologies required for metal recovery [3,6,12,13].

**Figure 1.** Estimated ratio of the amounts of minerals in oceans [6].

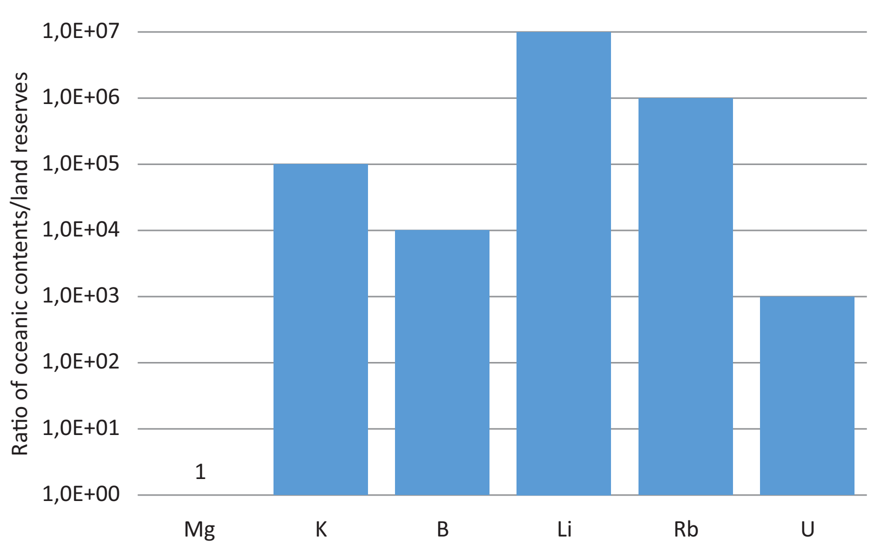
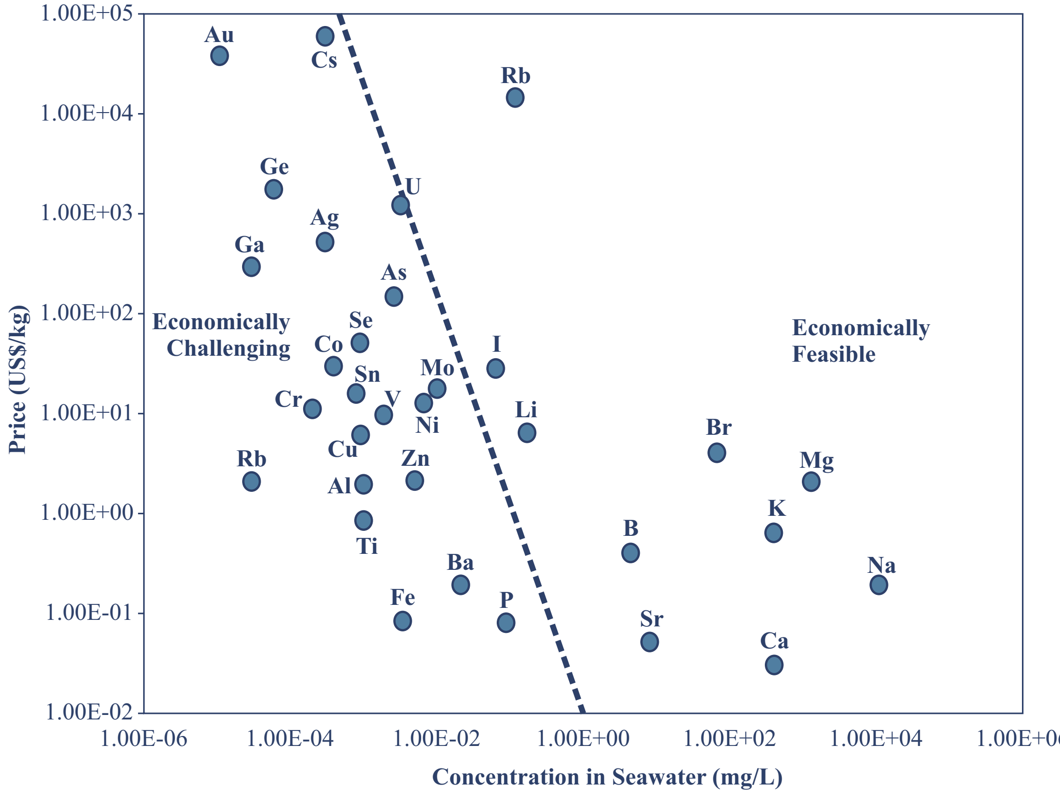


**Figure 2.** Minerals that can be economically extracted from seawater [6].




The technological advances of each method described in Table 3 demonstrate a promising potential for its application in mining seawater brine minerals. From bibliographical studies, using Table 3 and with the intention of recovering or producing the products listed in Table 1, Figure 3 presents the proposed flowchart for the seawater refinery. This refinery makes metal recovery economically viable from Loganathan (2017) (Figure 3) and produces green hydrogen through PEM electrolysis and chemicals through the chloralkaline process, using a membrane electrolyzer for this purpose.

## Conclusion

The concept of a "Seawater Refinery" demonstrates promising technological and economic potential, as evidenced by the high Technology Readiness Levels (TRLs), which exceed 7 for its core processes. These levels indicate that many underlying technologies are mature and capable of operational deployment. However, the Manufacturing Readiness Levels (MRLs) for the seawater refinery are relatively low, currently around 3 or 4. This reflects the early stage of development, where the concept has been defined, and initial proof-of-concept work has been conducted. Further efforts are required to advance to higher MRLs, including piloting or full-scale demonstrations of the proposed refinery.

Future research directions should focus on mathematical modeling and process simulation, enabling an economical and environmental analysis by evaluating it though UN SDG and green engineering principles, or its environmental and social impacts using LCA approaces.

## Acknowledgments

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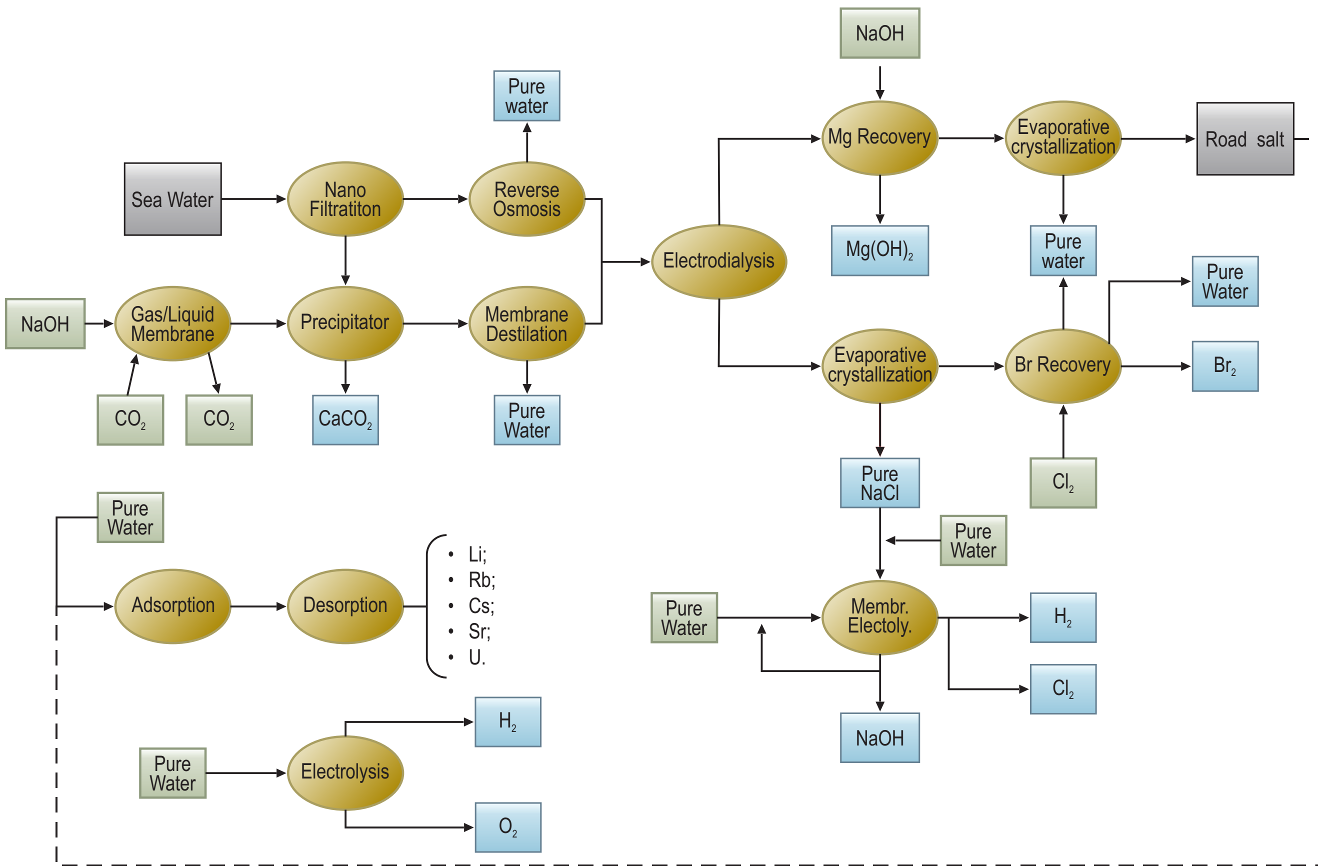
**Table 2.** Significant uses of valuable minerals and chemicals that can be economically mined from seawater.

| Mineral | Major Uses |
|---|---|
| Na (NaCl, $Na_2CO_3$, $Na_2SO_4$) | Food, glass, soap, detergent, textiles, pulp and paper industries, road deicing. |
| Mg (Mg, $MgSO_4$, $MgCO_3$) | Steel, chemical and construction industries, fertilizer. |
| Ca ($CaCO_3$, $CaSO_4$) | Soil amendment, construction industries, fertilizer. |
| K (KCl, $K2SO_4$) | Fertilizer. |
| Br | Fire retardant, agriculture, well-drilling fluids, petroleum additives. |
| B | Glass products, soap and detergents, fire retardants, fertilizer. |
| Sr | Ceramics; glass, oil, gas and pyrotechnics industries; ceramic ferrite magnets; phosphorescent pigments; fluorescent lights. |
| Li | Batteries; glass manufacturing; lubricants and greases; pharmaceutical products. |
| Rb | Fibre optics; lamps; night vision devices; laser technology. |
| U | Nuclear fuel in nuclear power reactor. |
| NaOH | Used in the production of various chemicals like detergents; soaps; and paper; water/wastewater treatment; aluminum production. |
| HCl | Production of various chemicals; including hydrochlorides; metal pickling; pH adjustment; water treatment. |
| $Cl_2$ | Widely used for water disinfection to kill bacteria and pathogens; PVC production; pulp and paper industry for bleaching wood pulp; synthesis of various chemicals, like hydrochloric acid. |
| $H_2$ | Clean and renewable energy source for fuel cells and combustion engines; ammonia production; food industry for hydrogenation reactions (e.g., margarine production); hydrocracking process to produce high-quality fuels. |
| $O_2$ | Used in respiratory support and medical gas therapies; combustion; metal cutting; welding and oxy-fuel combustions. |

**Table 3.** Technology descriptions.

| Treatment Technology | Synonyms | Description | TRL |
|---|---|---|---|
| Adsorptive Media | N/A | New materials used to remove pollutants via surface adhesion. Do not use this code for packed-bed or any granular-filtration process. Expect these to have copyrighted names. This code excludes GAC. | 7 |
| Electrodialysis | Electrodialysis Reversal (EDR) | Involves moving ions in a potential field across alternating polymeric anion- and cation-exchange membranes. A potential difference applied across the membranes traps ions and separates a brine waste stream from purified water. Electrodialysis works best for removing low molecular weight charged species. | 8 |
| Reverse Osmosis | Desalination | A membrane filtration method used to remove small ions (e.g., Na+) from water. Requires a high-pressure hydraulic pressure gradient to counteract the osmotic pressure gradient that would otherwise favor movement of water into (instead of out of) the concentrated wastewater or saltwater. | 9 |
| Nanofiltration | N/A | A membrane filtration method used to remove particles as small as 1 nm from wastewater. This includes divalent and large monovalent ions (e.g., heavy metals). Used for desalination and softening. | 7 |
| Membrane Distillation | N/A | A Hydrophobic membrane separates two aqueous solutions in a temperature-driven process. Water vapor passes through the membrane due to vapor pressure and condenses. | 7 |
| Evaporation | N/A | Water is vaporized, can be condensed for reuse, and leaves concentrated brine with dissolved solids. It occurs in solar evaporation ponds or with commercial equipment. Brine can be further concentrated during crystallization (CYS). | 9 |
| Crystallization | Fluidized Bed Crystallization | A Crystallization forms solid crystals from a solution, that can be applied post-evaporation for solid waste or product recovery. For recovery, it combines coagulation, flocculation, sludge/water separation, and dewatering, producing high-purity water. | 7 |
| Chemical Precipitation | Coagulation and Flocculation | A Chemical addition removes suspended solids from water. It neutralizes charged particles (coagulation) and promotes clump formation (flocculation), aiding settling. Additionally, it removes soluble metals through precipitants forming insoluble compounds. | 8 |
| Water Electrolyser | PEM electrolyser | Uses PEM to produce clean $H_2$ from water. Splitting the water into O2 and protons. | 8 |
| NaCl Electrolyser | Chlor Alkali electroyser | Utilizes electrolysis of NaCl solution to produce Cl2, NaOH, H2, essential for chemical manufacturing and water treatment. | 9 |

**Figure 3.** Flowsheet for the seawater refinery.

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