WREN Symposium 2025

COLLABORATING TOWARDS
THE SUSTAINABLE DEVELOPMENT GOALS

Book of Abstracts

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PREFACE

Welcome to the Conference Proceedings of the Women's Research Engineering Network (WREN) Symposium 2025

The WREN Symposium 2025, held on May 20-21, brought together a diverse group of researchers, practitioners, and students from across the globe. This free, international, and multidisciplinary event provided a platform for sharing knowledge, fostering collaboration, and contributing to global efforts toward achieving the United Nations Sustainable Development Goals (SDGs).

This year, we had over 100 registrants from 18 countries, demonstrating the symposium's growing global reach and impact. In these proceedings, we present 26 extended abstracts showcasing innovative research and solutions aimed at addressing the world's most pressing challenges. From improving social equity to advancing digital transformation and sustainable infrastructure, the contributions reflect the dedication of researchers working toward a more sustainable and inclusive future.

The research presented at this symposium exemplifies the power of collaboration and innovation in driving positive change. We are proud to highlight the best-voted presentations from our 4 sessions:

- Decentralized Sanitation for Social Equity and Environmental Justice in Informal Settlements – Ms. Thalita Lacerda dos Santos
- Driving Technology Adoption: Digital Tools to Drive Non-Profit Organisations' Efficiency – Ms. Xintong Li
- Methodologies for Monitoring the Groundwater Aquifer in Solid Waste Disposal Areas: A Systematic Review – Ms. Ana Laura Pascucci de Oliveira
- Advancing Smart Traffic Infrastructure with AI-Based Vehicle Detection Across Computing Configurations – Ms. Zi Xuan Lim

We are grateful to all the authors, reviewers, and contributors for their invaluable efforts. Their expertise and passion have made these proceedings possible and have enriched our collective understanding of the critical issues we face today.

Thank you for joining us in this collective journey.

WREN Organizing Committee 2025

ABOUT THE WOMEN'S RESEARCH ENGINEERING NETWORK (WREN)

At WREN, we are committed to achieving gender equity in engineering fields, striving to increase participation and retention among all genders, with a special focus on women. Our vision is a world where engineering is equally accessible and rewarding for everyone, and our purpose is rooted in creating a sustainable and equitable environment that values diversity and inclusivity. This commitment is reflected in our mission to serve as a dynamic platform for international collaboration among women research engineers, enhancing their visibility and encouraging supportive policies. We connect women across various stages of their careers — early, mid, and senior — through international collaborations, including grant proposals, joint publications, and co-teaching partnerships. Additionally, we maintain and deepen relationships with international partners, equip our members with career-advancing tools, amplify research led by women and underrepresented groups, and tackle systemic barriers through grassroots advocacy. Through these efforts, WREN not only supports individual career growth but also contributes to reshaping the engineering landscape into a more inclusive and equitable field. To learn more about our work or to join our network, please visit our website (https://thewren.global/) and get in touch.

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CONTENTS

GOAL 3: ENSURE HEALTHY LIVES AND PROMOTEWELLBEING FOR ALL AT ALL AGES

Source: UN's The Sustainable Development Goals Report 2023 – Special Edition

GEOSPATIAL CLEAN COOKING ACCESS MODELLING-USING ONSTOVE - A CASE STUDY OF GHANA

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ABSTRACT

The transition to clean cooking technologies offers opportunities to maximize societal benefits. Using OnStove geospatial tool, this study evaluated net benefits of nine cookstove technologies compared to a defined baseline. Net benefits were calculated as total benefits minus total costs. Social and private scenarios were investigated. Social scenario, electricity achieved 86% of the population split, LPG 13%, and biogas 1%. Private scenario, LPG accounted for 98% of the population split and biogas 2%. Investment costs and net benefits varied by technology and scenario. In the social scenario, electricity had the highest net benefits (3231.7M USD), followed by LPG (474.4M USD) and biogas (67M USD). In the private scenario, LPG (1551.9M USD) and biogas (52.7M USD) showed significant net benefits. The social scenario achieved greater health and environmental gains, including 10,749 deaths avoided and 3.44B USD in health cost savings, compared to 8,411 deaths and 2.30B USD in the private scenario.

Keywords: Clean Cooking, Geospatial Modelling, OnStove, Net benefit, Ghana.

INTRODUCTION

Access to clean cooking remains a significant global challenge, with approximately 2.1 billion people still relying on traditional biomass fuels such as wood, charcoal, and crop residues [1]. This reliance has severe consequences for health, the environment, and gender equality, making it a critical issue for achieving several Sustainable Development Goals (SDGs), particularly SDG 7, SDG 3, SDG 15, and SDG 5. The World Health Organization estimates that 3.2 million people die prematurely yearly due to illnesses caused by household air pollution from inefficient stoves and open fires [2].

In Ghana, traditional cooking methods contribute to a significant public health crisis, with approximately 18,000 deaths annually linked to indoor air pollution from biomass combustion [3]. About 80% of Ghanaian households rely on biomass fuels for cooking, leading to high levels of smoke exposure that cause respiratory diseases, cardiovascular complications, and other health problems. The use of biomass fuels is a major contributor to deforestation and greenhouse gas emissions, accounting for over 25% of global black carbon emissions [3]. Women and children, who are primarily responsible for cooking and fuel collection, are disproportionately affected. Women in Ghana spend an average of 1.3 hours daily collecting firewood, limiting their opportunities for education and economic activities [4]. In cases where biomass fuels are not collected, households incur high costs in purchasing them, placing additional financial burdens on already vulnerable communities.

The transition to clean cooking technologies is widely recognized as a crucial step toward reducing health risks, environmental degradation, and socio-economic inequalities [2]. Various clean cooking solutions, such as improved biomass stoves, liquefied petroleum gas (LPG), biogas, and electric cooking, have been promoted to address these challenges. However, adoption rates remain low due to affordability, fuel availability, infrastructure limitations, and socio-cultural preferences [3].

OnStove, a geospatial modelling tool, has emerged as a promising approach for evaluating different cooking technologies' costs, benefits, and policy impacts. Despite its potential, limited studies have assessed the

application of OnStove in optimizing clean cooking transitions in Ghana, particularly in rural and low-income communities where biomass reliance is highest.

This study aimed to model clean cooking access in Ghana using OnStove and propose the most suitable clean cooking technologies based on net benefits. The objectives were to create a spatial repository for modifying data, calculate the net benefits of various cooking solutions, and visualize the results. The findings of this study contribute to the growing body of knowledge on clean cooking transitions, providing evidence-based recommendations for policymakers, development organizations, and private-sector stakeholders.

MATERIALS AND METHODS

The study was conducted in Ghana, where many households still use traditional biomass fuels for cooking. Using geospatial modeling, the research assessed access to clean cooking options across different regions of the country. Ghana's varied geography and socio-economic conditions made it a suitable location for studying clean cooking transitions. The OnStove model was used to compare the benefits and costs of clean cooking technologies; electricity, LPG, and biogas against traditional methods. It included data on population density, energy infrastructure, and environmental variables. The analysis covered both social and private scenarios, with net benefits calculated by subtracting total costs (capital, fuel, operation, and maintenance costs) from total benefits (reduced mortality, morbidity, emissions, and time saved). The OnStove model integrates various data types to evaluate the costs and benefits of different cooking technologies. The cooking technologies modelled were Electricity, LPG, and Biogas stoves.

DATA SOURCES

1. Geospatial Data: used to capture various characteristics across the study area. It included administrative boundaries and medium voltage lines.
2. Socio-Economic Data: related to the study area that was modelled. It included the population, global data on disease, electrification rate, and household size.
3. Techno-Economic Data: related to each stove included in the analysis. It included fuel prices, electricity generation, and operational and maintenance costs.

MODELLING APPROACH

1. GIS Processing: The spatial data were geo-processed into the correct format for the OnStove analysis. This includes masking, clipping, reprojection, aligning, and resampling.
2. Model Calibration: The key data were calibrated to align with the national statistics.
3. Net-benefit calculation: All costs and benefits of switching from current cooking methods to every defined alternative were calculated.
4. Results visualization: The graphical (plots and maps) results and tabular formats of the technology split that maximizes the net benefits in every study area region were presented.

SCENARIOS

1. Social scenarios: all inputs such as environment, health, spillover, and time are considered.
2. Private scenarios: considered inputs such as health and time.

RESULTS

SOCIAL AND PRIVATE SCENARIO
MAXIMUM BENEFIT COOKING TECHNOLOGY

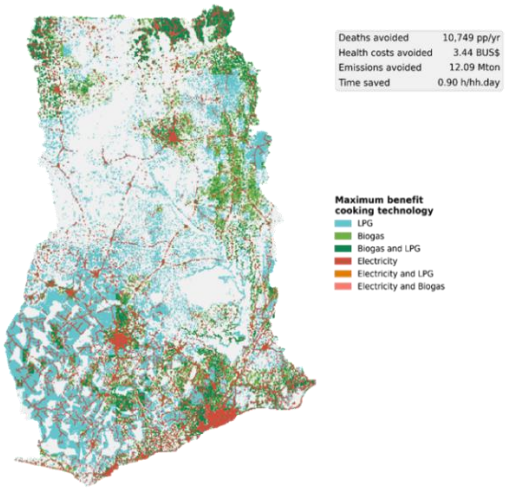

Figure 1 Maximum benefit for social scenario

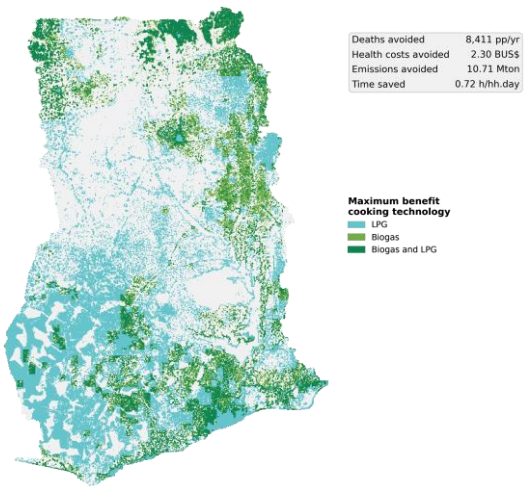

Figure 2 Maximum benefit for private scenario

Figures 1 and 2 show the map of Ghana illustrating the maximum benefits for the two scenarios under consideration. The maps show where each stove has the highest net benefit, indicating where and what technology to invest in. This is important as many factors connected to barriers and enablers of clean cooking are spatial and change across areas. The areas with more than one (1) stove do not mean fuel stacking, but the stove with the highest net benefit is unavailable for all, so the second-highest stove must be included.

POPULATION SPLIT

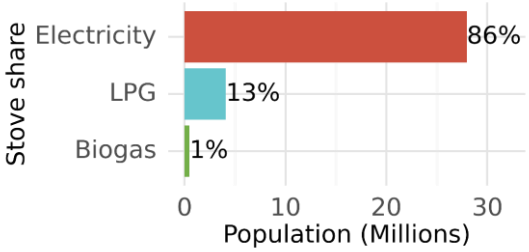

Figure 3 Population split of social scenario

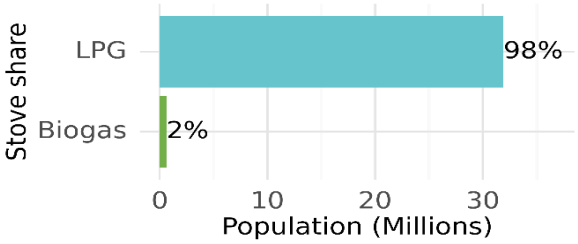

Figure 4 Population split of private scenario

Figure 3 and 4 present graphs showing how many live in the areas where each stove has the highest net benefits. Therefore, in Figure 3, the social scenario, Electricity had 86%, LPG 13%, and Biogas 1%, and for Figure 4, the private scenario, LPG had 98% and Biogas 2% in the population split. Stoves not included in this scenario never had the highest net benefit. The graphs are, therefore, important for giving the map context. The maps look like the opposite case because the population density is higher in areas with electricity (urban areas).

WEALTH DISTRIBUTION

Figure 5 and 6 show the number of households that should get each technology from a net-benefit perspective. It shows the level of wealth of the households. The wealth is lower moving further to the left, indicating the more struggles households will have with affordability. The usefulness of this graph is to understand the share of people who could be struggling with affordability issues for each technology. This

can be used to understand subsidy programs; in the social scenario, subsidize LPG and Biogas, and in the private scenario, subsidize biogas.

Figure 5 Wealth distribution of social scenario

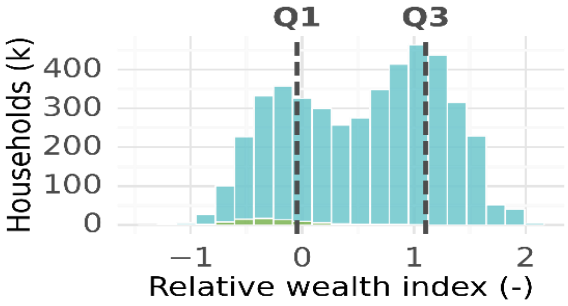

Figure 6 Wealth distribution of private scenario

CONCLUSIONS

This study used the OnStove geospatial tool to evaluate access to clean cooking in Ghana, comparing nine stove types: two traditional, four improved, and three clean cookstoves. Some technologies were excluded based on low performance. Under the social scenario, 86% of the population preferred electric cooking, 13% chose LPG, and 1% selected biogas—showing the high societal value of electricity. In the private scenario, LPG was the top choice (98%) due to its affordability for households. The study recommends subsidizing LPG, lowering electricity tariffs, and supporting hybrid clean cooking systems. It also emphasizes the need for community education to increase acceptance of new technologies.

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RESISTANCE TRAINING AND ITS RELATIONSHIP WITH PROSTATE-SPECIFIC ANTIGEN: INTEGRATIVE REVIEW

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ABSTRACT

Objective of this study was to locate, identify, and analyze high-quality scientific production relating resistance training (RT) and PSA concentrations. **Methods:** Integrative literature review, guided by evidence-based practice (EBP), identification of the research question and descriptors, based on PICO, articles searched in the databases: SCIELO, BVS, CAPES, ACADEMIA.EDU, and PUBMED, descriptors extracted from the DeCS and MeSH platforms. Inclusion criteria: full published articles with free access, in the period from 2017-2020 and 2021-2024, in Portuguese and English, relating RT and PSA concentrations, QUALIS CAPS A1 extract. Exclusion criteria: articles indexed in more than one platform/journal, articles that did not specify the correlation of RT with PSA, without primary/secondary outcome. **Results:** Five studies were included. **Discussion:** This study reflects the current condition of WEB QUALIS A1 extract scientific publications, complete and freely available. **Conclusion:** RT should be coupled with conventional prostate cancer treatment, but there is divergence regarding reducing PSA concentration.

Keywords: Prostate-Specific Antigen; Resistance Training; Prostatic Neoplasms.

INTRODUCTION

The constantly growing aging population presents challenges in all areas of society, including healthcare. A prospective study by the United Nations (UN) projects that the number of people aged 60 or over may double between 2017 and 2050, and may triple by 2100 [1]. With this increase in life expectancy, health-related problems also increase [2], such as prostate cancer, a disease associated with aging [3,4], being the second leading cause of cancer in men, and also the main disease in this population, being the fifth leading cause of cancer deaths [5,6].

In 2012, the disease was already the second most prevalent and the fifth leading cause of death in men worldwide [7]. In 2014, the lifetime risk of a positive diagnosis for prostate cancer was 14.3%, and the risk of dying from the disease was 3.6%. The number of prostate cancer diagnoses after death was more than 40% in the male population aged 40 to 49, and more than 70% for older men, aged 70 to 79 [8]. In Brazil, it is estimated that between 2023 and 2025, prostate cancer will be the most common disease among men, rising from second to first place, with 71,730 new cases [9].

The literature has shown that physical exercise has beneficial effects on the treatment of prostate-associated diseases [10], and that sedentary behavior has negative effects on the onset of various diseases, including prostate cancer [11,12,13], Physical activity may also influence the reduction of PSA levels [10,14], although the relationship between the reduction of prostate-specific antigen and the most suitable type of activity and/or exercise is not clear [10]. Thus, with this study, we hope to contribute to improving current training prescription guidelines and prevention and screening issues for prostate-related diseases, as well as to reflections on investigations on the subject. We also aim to provide an important compilation of information for the development and direction of more precise public policies on this subject. Additionally, we offer

information on scientific publications of the highest quality and academic weight. This study is also offered as a model for future studies.

The present study aims to analyze the scientific production regarding resistance training and its relationship with prostate-specific antigen (PSA).

MATERIALS AND METHODS

STUDY TYPE

This is an integrative literature review study.

STUDY DESIGN

This research is guided by the evidence-based practice (EBP) guidelines [15,16], for identifying the research question and choosing the descriptors/Boolean operators, the PICO strategy was used [17]. For the article search, the following online databases were used: SCIELO, BVS, CAPES, ACADEMIA.EDU, and PUBMED. The controlled descriptors were extracted from the DeCS and MeSH platforms [17]. The keywords were chosen according to the descriptor terms: “Treinamento Resistido AND Antígeno Prostático Específico” (Resistance Training AND Prostate-Specific Antigen) and their combinations in the Portuguese language. For the search in the English language, the translated descriptor terms were used: “resistance training AND prostate-specific antigen” and their combinations [18]. The inclusion criteria were: full published articles with free access, from the last two four-year periods (2017-2020 and 2021-2024) in Portuguese and English; articles with a correlation between resistance training and prostate-specific antigen levels; articles with QUALIS CAPES extract A1; articles indexed in the online search platforms SCIELO, BVS, CAPES, ACADEMIA.EDU, and PUBMED, in Portuguese and English. The exclusion criteria were: articles indexed in more than one platform or journal, in which case only one article was considered; articles that did not specify the correlation of resistance training with the effects on prostate-specific antigen levels; articles that did not have the primary/secondary outcome complete, due to future collections.

RESULTS

Table 2 – Studies included in this review. Source: Authored by the authors.

Authors	Studied Intervention	Results	Recommendations and conclusions	Journal/extract
Wall et al. (2017)	Examine the effect of an aerobic and resistance exercise program in men with PCa receiving ADT.	↑ in fat oxidation for EG, no significant difference in PSA.	Despite ADT, RT was effective and safe. It promoted ↑ lean mass and prevented ↑ fat.	Medicine & Science in Sports & Exercise - A1
Taaffe et al. (2018)	Report the effects of an RCT in men with PCa on ADT and resistance exercise at the start of treatment, compared with late start.	There was a ↓ in PSA and testosterone after the start of ADT.	Exercise should be included in treatment alongside ADT for men with PCa, aiming to attenuate musculoskeletal toxicity.	BJU International - A1
Lam et al. (2020)	Provide a rationale for the in-depth investigation of RT, and its biological effects in men with PCa on ADT.	RT improves body mass index in patients with PCa, among other positive results.	Several oncology societies endorse adopting physical activity as synergistic medicine to PCa treatment. RT acts in maintaining body composition.	Sports Medicine - A1

Authors	Studied Intervention	Results	Recommendations and conclusions	Journal/extract
Lopez et al. (2022)	Review and analyze the effects of RT on body composition, functional capacity tests, cardiorespiratory fitness, muscle strength, BMI, and PSA levels.	No significant difference in BMI or PSA in patients with PCa, ↑ overall lean mass and ↓ fat mass.	There is no difference in intensity prescription regarding RT for men with PCa.	Sports Medicine - A1
Lin et al. (2022)	Investigate the chronological change in body composition in people with high-risk prostate cancer in the usual and exercise groups, and investigate the association of body composition, PSA level, and nutrition.	At 6 months, EE improved lean mass, muscle function, and PSA.	The combination of RT and cardiorespiratory, ↑ body composition and PSA of patients with high-risk PCa, even with ADT.	Nutrients - A1

CONCLUSIONS

Despite the scarcity of high-quality studies on the topic, the literature provides us with strong evidence regarding the importance of the resistance training program being coupled with the conventional treatment of patients with prostate cancer, but still diverges regarding resistance training having a direct relationship in reducing prostate-specific antigen levels. What is necessary is further investigation on the topic.

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PRIVACY CHALLENGES IN MHEALTH APPLICATIONS

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ABSTRACT

The increasing adoption of mobile health (mHealth) applications has enhanced healthcare access but raised critical privacy concerns due to the sensitive nature of health data. This study systematically reviews recent literature to identify key privacy challenges in mHealth app development. Seven major challenges are identified: heightened user privacy concerns, lack of comprehensive privacy guidelines, insufficient developer expertise in privacy, limited user control over personal data, trade-offs between privacy and usability, individual differences in privacy expectations, and AI-driven privacy risks. We situate these challenges within Sustainable Development Goal 3 (universal health coverage) and Goal 9 (responsible digital infrastructure). These challenges expose shortcomings in current design practices, such as inadequate privacy frameworks, insecure data handling, and poor transparency. The findings highlight the need for privacy-by-design principles, user empowerment, and enhanced developer education. Addressing these challenges is essential for fostering trust, ensuring ethical data use, encouraging widespread adoption of mHealth technologies. This study offers actionable insights for developers, researchers, and healthcare providers to improve privacy protections in mHealth ecosystems. Future work will focus on designing and empirically validating a user-driven framework that balances privacy with usability.

Keywords: mHealth applications; health data; privacy; artificial intelligence; Sustainable Development Goals.

INTRODUCTION

Today, global mobile network subscriptions have rapidly increased, reaching 6.4 billion in 2022 and projected to exceed 7.7 billion by 2028 (Taylor, 2023). This growth highlights advancements in mobile technology, where applications significantly enhance communication, productivity, and daily convenience (Maaß et al., 2022). Particularly, mobile health (mHealth) applications, offering users access to health services via smartphones, have grown substantially (Kay et al., 2011). This ubiquity supports SDG 9 objectives for resilient digital infrastructure. Within healthcare, AI-enabled mHealth apps align with SDG 3 targets for universal, quality care, yet their data intensity magnifies privacy risks and can erode trust (Schroeder et al., 2022).

Privacy encompasses controlling access to personal information. Initially defined by Westin (1968) as the right to select what personal information is shared, privacy now extends to digital data, highlighting autonomy as a core principle (Levin & Abril, 2009; Mokrosinska, 2018). Altman (1976) emphasizes "selective control over access to the self," while Himma and Tavani (2008) highlight control over personal information and access to personal affairs. Privacy thus supports individual empowerment, personal identity, and autonomy (Michelfelder, 2001; Zhang et al., 2021).

Research by Brandimarte et al. (2012) found that users empowered with greater data control willingly share more information. Conversely, users often remain unaware of extensive data collection practices, undermining their control and heightening privacy concerns (Hajli & Lin, 2016). Studies consistently show perceived control reduces privacy fears and enhances trust (Hoadley et al., 2010; Krasnova et al., 2010).

Recent literature emphasizes growing privacy issues in mHealth applications due to sensitive data handling, underscoring the necessity of robust privacy measures (Schroeder et al., 2022). Effective privacy management requires providing users greater control over their health data, thus promoting trust and

adoption (Jusob et al., 2022). Ensuring data security, confidentiality, and integrity through secure frameworks and protocols is crucial for delivering quality healthcare (Qayyum et al., 2020).

CONTRIBUTION AND MOTIVATION

mHealth applications are increasingly used by consumers and healthcare providers for remote care, self-monitoring, and improved decision-making. While they offer benefits such as enhanced patient engagement and efficient data collection, they also raise significant privacy concerns due to the handling of sensitive health data. Risks include data breaches, unauthorized access, and misuse, which can undermine user trust and well-being.

Although prior research has addressed security in mHealth, privacy-specific challenges have received less attention. This study addresses that gap by surveying recent literature on privacy in mHealth. These applications span various functions—telemedicine, diagnostics, data collection, health promotion, education, and medication adherence—making privacy protection essential across contexts (Plachkinova et al., 2015). Our analysis identifies six major privacy challenges, summarized in Table 1, and emphasizes the need for strategies that safeguard data while respecting user preferences.

Table 1 – Privacy challenges in developing secure mHealth applications.

Privacy Challenges	Key points from reviewed studies	Number of papers, n
Privacy concerns	▪ Raising privacy concerns (Schroeder, Haug et al. 2022), (Tangari, Ikram et al. 2021), (Kolasa, Mazzi et al. 2021). ▪ Potential privacy threats (Iwaya, Fischer-Hübner et al. 2019) Indirect influence of privacy concerns on users' trust and mHealth adoption (Liu, Lu et al. 2022), (Zhang, Guo et al. 2014), (Guo, Zhang et al. 2016), (Wottrich, van Reijmersdal et al. 2018).	8
Comprehensive privacy guidelines	▪ Lack of comprehensive privacy guidelines (Hussain, Zaidan et al. 2018), (Papageorgiou, Strigkos et al. 2018), (Sim, Kim et al. 2023). Poor privacy practices (Hutton, Price et al. 2018), (Philip, Abdelrazek et al. 2023).	5
Developers' privacy understanding	▪ Lack of developers' privacy understanding and expertise (Hussain, Zaidan et al. 2018), (Müthing, Jäschke et al. 2017), (Papageorgiou, Strigkos et al. 2018), (Aliasgari, Black et al. 2018). ▪ Lack of participants' understanding regarding potential threats to their privacy (Velykoivanenko, Niksirat et al. 2021).	5
User's control over information	▪ Lack of control users have over their personal information (Hajli and Lin 2016), (Hoadley, Xu et al. 2010, Krasnova, Spiekermann et al. 2010).	3
Balance between privacy and usability	▪ Lack of balance between privacy and usability (Giebel, Speckemeier et al. 2023), (Arora, Yttri et al. 2014).	2
Individual differences	▪ Different privacy concerns and requirements among users (Allen and Turkington 2002), (Solove 2008, Fogel and Nehmad 2009), (Madden, Lenhart et al. 2013, Wisniewski, Knijnenburg et al. 2017), (Schroeder, Haug et al. 2022).	5
AI-driven privacy risks	▪ AI-driven privacy risks (WHO, 2024), (Esteva et al. 2019).	2

mHealth applications support efficient, high-quality care but raise persistent privacy concerns. Studies consistently report user apprehension, especially regarding sensitive or stigmatized health topics (Schroeder et al. 2022; Tangari et al. 2021; Kolasa et al. 2021). Iwaya et al. (2019) identified 97 privacy threats, spanning consent to data security. These concerns significantly affect user trust and willingness to adopt mHealth technologies (Liu et al. 2022; Zhang et al. 2014; Guo et al. 2016; Wottrich et al. 2018).

Despite the risks, there is a lack of comprehensive privacy frameworks. Many apps exhibit poor privacy practices (Hussain et al. 2018; Hutton et al. 2018), and recent research calls for user-centric, operational guidelines (Philip et al. 2023; Sim et al. 2023). Developer expertise is also limited—insufficient privacy knowledge often leads to insecure apps (Müthing et al. 2017; Aliasgari et al. 2018; Velykoivanenko et al. 2021), highlighting the need for targeted education.

User concerns include limited control over personal data and extensive data collection (Hajli & Lin 2016). Studies show that perceived control mitigates privacy concerns and fosters trust (Hoadley et al. 2010; Krasnova et al. 2010). However, enhancing privacy often comes at the cost of usability (Giebel et al. 2023; Arora et al. 2014), a trade-off underexplored in current research.

Privacy attitudes vary across individuals, shaped by diverse preferences and contexts (Solove 2008; Fogel & Nehmad 2009). Assuming uniform expectations risks poor user experiences. As Madden et al. (2013), Wisniewski et al. (2017), and Schroeder et al. (2022) emphasize, accounting for individual differences is essential in privacy-aware mHealth design.

AI components embedded in symptom checkers, wearables and decision-support tools introduce threats such as inference attacks, model inversion and federated-learning drift. Mitigations include differential privacy, secure aggregation and post-deployment bias auditing (WHO, 2021; Esteva et al. 2019).

DISCUSSION

While mobile health (mHealth) applications facilitate healthcare delivery, ensuring users' data privacy remains a significant challenge. Although prior reviews have examined privacy and security issues, few have directly explored the real-world challenges faced by developers and users. This survey aims to address that gap by identifying seven major privacy challenges in the current literature: (1) growing privacy concerns, (2) lack of comprehensive privacy guidelines, (3) limited developer knowledge of privacy, (4) insufficient user control over personal data, (5) the trade-off between privacy and usability, (6) individual differences, and (7) AI-driven privacy risks.

Findings indicate that privacy concerns discourage users from sharing sensitive health information, highlighting the need for trust-building measures in mHealth applications. Identifying and addressing these challenges during the development process is crucial to ensure responsible data handling and foster adoption.

Privacy frameworks play a key role in protecting user data. Studies by Alibasa et al. (2017), Xie et al. (2022), and Shuwandy et al. (2020) propose advanced architectures for securing shared health information. Similarly, Jusob et al. (2022), Katarahweire et al. (2021), and Barth et al. (2021) introduce frameworks that address specific privacy threats comprehensively. Guillén-Gámez et al. (2017) further warn that some biometric systems lack adequate privacy safeguards, leaving them vulnerable to exploitation.

Developer knowledge is another critical factor. Inadequate understanding of privacy principles can lead to insecure apps that expose sensitive data (Velykoivanenko et al. 2021). Educating developers on privacy best practices is essential.

Privacy concerns deter disclosure of sensitive conditions, limiting SDG 3 progress toward inclusive care. The scarcity of actionable guidelines and AI expertise threatens SDG 9 ambitions for trustworthy innovation. A

coherent, user-driven privacy–usability framework—grounded in the challenges identified here—remains an open research priority.

Finally, prior research consistently shows that user control over personal information alleviates privacy concerns (Hoadley et al. 2010; Krasnova et al. 2010). Enhancing such control can foster trust and encourage information sharing, though this has been underexplored in many studies.

CONCLUSIONS

This review draws together evidence from recent scholarship to show that mobile-health applications face a cluster of seven, tightly linked privacy challenges: heightened user concern, the absence of comprehensive guidelines, limited developer expertise, inadequate user control, an unresolved privacy–usability tension, diverse privacy expectations and emerging AI-specific risks. Left unchecked, these weaknesses erode trust, suppress data sharing and slow progress towards Sustainable Development Goals 3 (good health and well-being) and 9 (resilient digital infrastructure).

The findings point to three immediate priorities. First, privacy safeguards must be embedded at the design stage through context-aware frameworks that are transparent, auditable and aligned with prevailing regulations. Second, sustained developer education is essential so that good intentions translate into sound engineering practice. Third, users need granular, easily revocable controls that make data sharing a matter of informed choice rather than blind faith.

Many tensions surface only when privacy features are bolted on late; therefore, the next phase of our work will concentrate on devising—and rigorously validating—a user-driven framework that reconciles privacy with usability across the mHealth life-cycle. By pinpointing where current practice falls short, this survey provides a clear research and development agenda for building trustworthy, widely adopted mHealth ecosystems.

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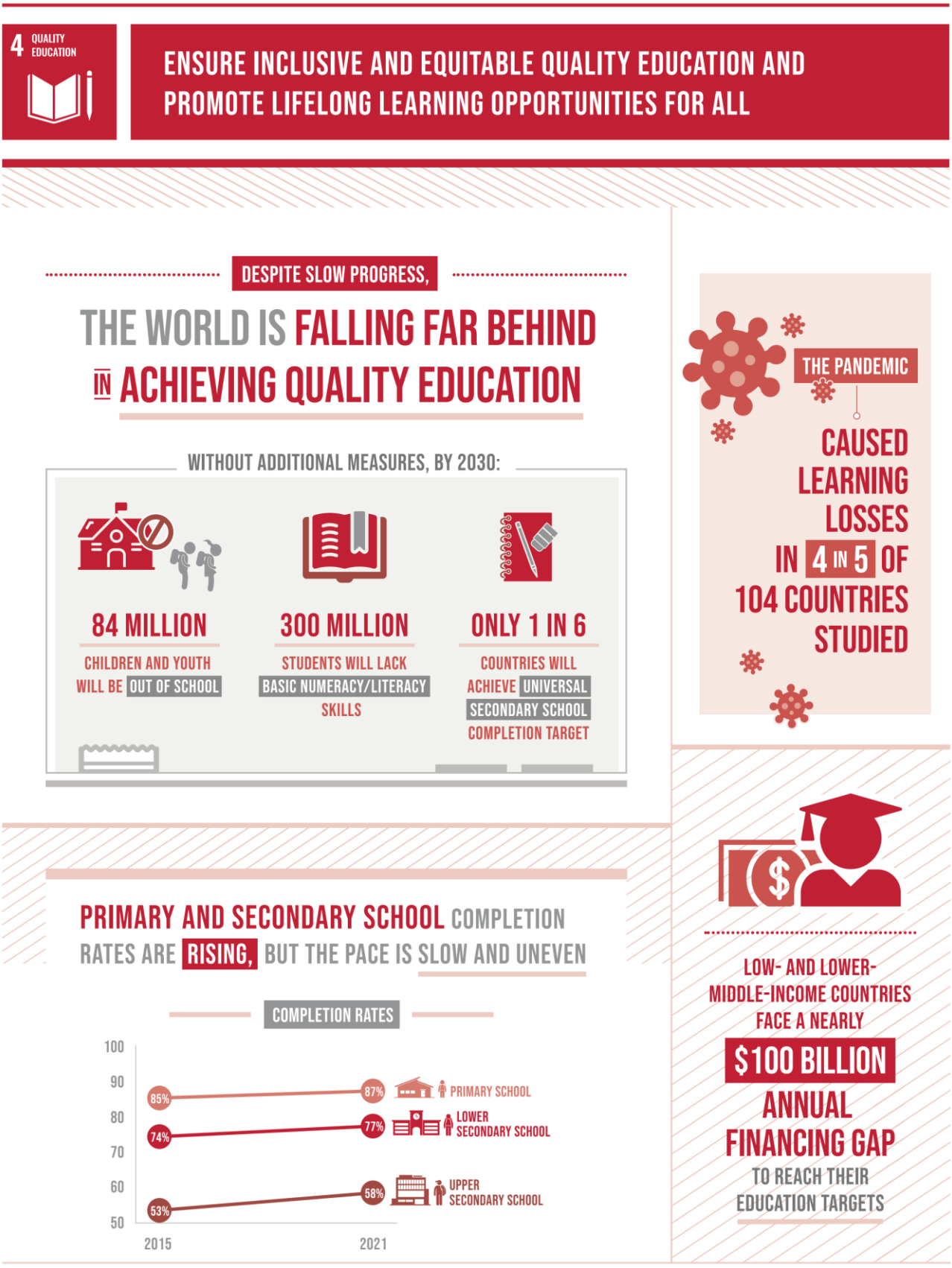
GOAL 4: ENSURE INCLUSIVE AND EQUITABLE EDUCATION AND PROMOTE LIFELONG LEARNING OPPORTUNITIES FOR ALL



Source: UN's The Sustainable Development Goals Report 2023 – Special Edition

ENHANCED CHEMICAL ENGINEERING TEACHING USING AUGMENTED REALITY: A MOBILE APP FOR 3D VISUALIZATION

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ABSTRACT

The teaching of chemical engineering often requires abstracting complex concepts, such as molecular structures, traditionally represented in two dimensions. This can hinder spatial understanding and the correlation between 2D and 3D representations. Augmented reality (AR) enhances content assimilation by enabling interactive 3D visualization. This study aims to develop AR-based teaching tools for chemical engineering using Unity and ARCore. ChemSketch and Blender were employed for structure modeling. Two applications were created: *ZeoliteApp*, for visualizing zeolite structures, and *IsomeriaApp*, for understanding stereochemistry concepts. A survey with high school, undergraduate, and graduate students evaluated AR's impact on learning and motivation. The results showed AR is effective and well-received, making learning more dynamic and improving comprehension of complex concepts. Although AR is still an emerging technology, it has already proven valuable for education, offering immersive and engaging experiences that enhance student understanding and motivation.

Keywords: Chemical Engineering; Augmented Reality; Modelling and Simulation; Teaching Methodologies; Software Development.

INTRODUCTION

The visualization of three-dimensional (3D) structures in two-dimensional (2D) spaces, such as classroom boards or textbooks, presents significant challenges, particularly when dealing with abstract scientific concepts like molecular structures and catalytic surfaces [1]. These limitations hinder students' ability to develop spatial reasoning and transition between 2D and 3D representations—skills that are essential in chemical engineering, where understanding of reactors, molecular frameworks, and equipment relies heavily on 3D visualization. Traditional teaching methods often fall short in delivering this type of content in an engaging and effective way. Augmented Reality (AR) emerges as a promising solution, positioned within the Reality-Virtuality Continuum [2–6]. Unlike Virtual Reality (VR), which fully immerses users in a synthetic environment, AR overlays digital elements onto the physical world, enabling simultaneous interaction with both realms [2, 3, 7]. This makes AR especially suitable for educational applications, as it enhances engagement, comprehension, and knowledge retention by allowing students to explore and manipulate 3D models in real-time [8, 9]. Furthermore, AR is part of the broader Extended Reality (XR) spectrum [1], and its accessibility through mobile devices—without the need for specialized hardware—makes it an effective and practical choice for classroom use [1, 8, 7, 10-13]. This study leverages these advantages by developing AR-based mobile applications focused on zeolite structures and stereochemistry, aiming to improve the teaching of complex 3D content in chemical engineering education.

METHODOLOGY

This study developed two AR applications, ZeoliteApp and IsomeriaApp, using Unity for real-time 3D visualization. Unity's C# based programming facilitated interactive features, while Python scripts converted molecular structure files (.pdb, .x3d, .mol) to Unity-compatible .fbx using py3Dmol, RDKit, ASE, and Blender. ZeoliteApp, designed for graduate students, focused on zeolite structures, enabling 3D visualization, rotation, zooming, and oxygen atom representation. IsomeriaApp, aimed at undergraduates, covered stereochemistry

and isomerism, with models created in ChemSketch and Blender. While most isomer types were successfully integrated, diastereo isomerism and conformational isomerism posed visualization challenges. This study evaluated the effectiveness of AR applications in teaching chemical concepts across different education levels. ZeoliteApp (for zeolites) and IsomeriaApp (for stereochemistry) were tested with graduate, undergraduate, and technical high school students, enhancing spatial understanding and conceptual learning. Students completed pre-use surveys, interacted with 3D molecular models on mobile devices, and then took post-use evaluations measuring engagement, usability, and comprehension. Results showed AR improved learning, making abstract concepts more tangible and interactive, with a notable increase in motivation and understanding, reinforcing AR's value in chemistry and engineering education.

RESULTS

ZEOLITEAPP AND ISOMERIAAPP

The ZeoliteApp was developed to enhance the visualization and understanding of common zeolite structures within catalysis-related courses. Its main features include the projection of 3D frameworks in augmented reality (AR), interactive manipulation through rotation and zoom, highlighting of oxygen atoms, and the display of additional information about each zeolite structure. These functionalities aim to support the comprehension of the spatial arrangement and complexity inherent to zeolite materials. In turn, the IsomeriaApp focuses on facilitating the understanding of stereochemistry and molecular symmetry, particularly in organic chemistry courses. The application allows the visualization of 3D molecular structures in AR, provides interactive features such as rotation and zoom, and enables the simultaneous display of different isomers to support comparative learning. Figure 1 illustrates the main interface and functionalities of the ZeoliteApp, while Figure 2 presents examples of the molecular visualizations and interaction tools available in the IsomeriaApp.

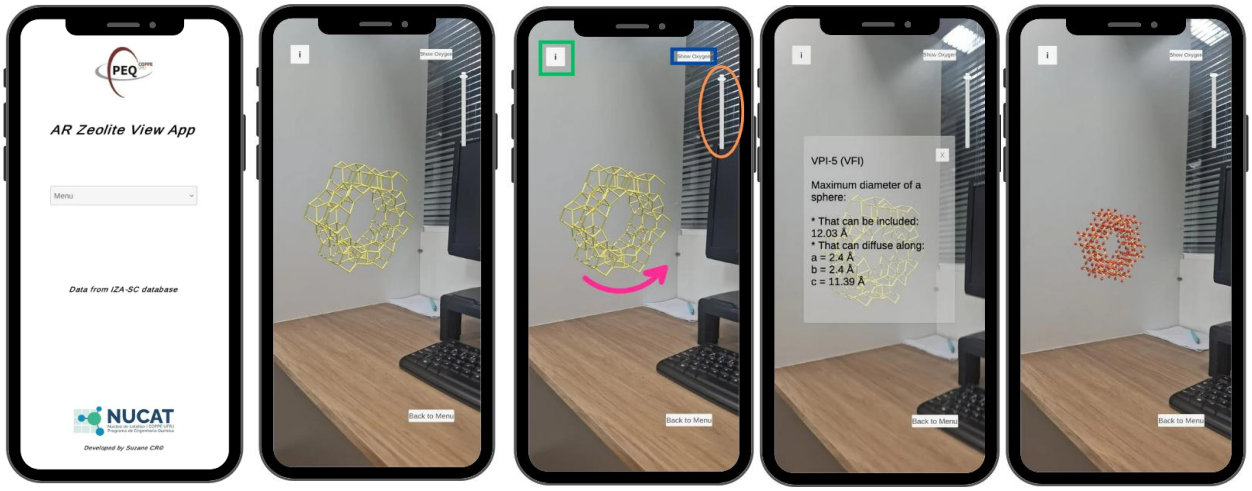

Figure 1 - Photo compilation of the ZeoliteApp application. From left to right: homepage, initial screen of the selected zeolite projected in AR, representation of interaction modes (pink – rotation; orange – zoom; green – information popup; blue – oxygen atoms), information popup menu, and zeolite structure projected with oxygen atoms visible. Source: authors [14].

Figure 2 – Photo compilation of the IsomeriaApp application. From left to right: homepage, example of the submenu chosen, example of a submenu for selecting the structure to be projected, projection of the selected structure in AR (in orange, button for isomer visualization) and simultaneous display of the isomers. Source: authors [14].

STUDENT EVALUATIONS

In total, 40 students participated in the evaluation of the applications developed in this study, including 4 evaluations for ZeoliteApp and 36 for IsomeriaApp, encompassing three educational levels: technical high school, undergraduate, and graduate students. Table 1 below presents the percentage of responses obtained from the pre-use and post-use surveys, focusing on the most relevant questions and indicators analyzed in this study.

Table 1 – Comparative percentage of responses at the Pre-use and the Post-use Forms. Source: authors [14].

	Pre-use Forms			Post-use Forms		
	Disagreed	Neutral	Agreed	Disagreed	Neutral	Agreed
Familiarity with AR	90%	-	10%	2,5%	22,5%	75%
Engagement in Class	2,5%	15%	82,5%	2,5%	27,5%	70%
Understanding of Concepts	2,5%	10%	87,5%	-	7,5%	92,5%
Intuitive Interface	-	-	-	-	15%	85%
Interest in AR Applications	-	17,5%	82,5%	-	17,5%	82,5%

Overall, the findings demonstrate AR's transformative potential in education, offering an innovative and efficient way to teach abstract concepts.

CONCLUSIONS

This study explores the potential of augmented reality as a complementary tool for teaching complex chemistry and engineering concepts, focusing on zeolites and stereochemistry. Two AR applications were developed to provide an interactive and engaging learning experience, confirmed through tests with undergraduate and technical students. The use of 3D representations enhanced concept visualization, improving engagement, comprehension, and knowledge retention. Despite its effectiveness, limitations such as device dependency and a small sample size impacted accessibility and result generalization. The short-term study also limited the assessment of AR's long-term impact on learning. The positive reception suggests an increasing role for AR in the classroom. Further technological refinements and integration strategies could enhance student engagement and understanding, making learning more interactive and immersive.

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TRANSFORMING CLASSROOMS: DIGITAL AND COLLABORATIVE INNOVATIONS IN GLOBAL EDUCATION

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ABSTRACT

The rapid advancement of digital technology, coupled with the rise of collaborative learning, is transforming the landscape of education. Traditional classroom models are evolving into interactive, technology-driven environments that emphasize connectivity, flexibility, and active student participation. This systematic literature review examines how educational innovations—such as blended learning, smart classrooms, mobile learning platforms, and Collaborative Online International Learning (COIL)—are reshaping teaching practices across various global contexts through analysis of 45 peer-reviewed studies published between 2018-2024. The study develops a comprehensive conceptual framework integrating technological adoption with collaborative pedagogies, identifying three key implementation pathways: infrastructure development, educator training, and student engagement strategies. Findings indicate that these emerging tools offer substantial benefits, including 35% broader access to education, more personalized learning pathways, and increased student engagement rates of up to 60%. However, significant challenges persist related to infrastructure gaps affecting 40% of institutions surveyed, equitable access disparities, and varying digital literacy levels among both students and educators. The research concludes that successful integration requires coordinated investment in technology infrastructure, comprehensive professional development programs, and inclusive policy frameworks to ensure equitable access across diverse educational contexts.

Keywords: Blended Learning; Educational Technology; Collaborative Learning; Personalized Learning; Virtual Collaboration

INTRODUCTION

The international education landscape is undergoing a fundamental transformation, driven by the convergence of technological innovation and collaborative learning approaches. With the emergence of Education 4.0, classrooms are evolving into dynamic, technology-enhanced environments that transcend geographical and physical boundaries. Learning is no longer confined to traditional settings; instead, digital solutions now support greater flexibility, accessibility, and personalization in education. The COVID-19 pandemic further accelerated this shift, highlighting the critical role of technology in maintaining educational continuity and fostering engagement across diverse learning contexts. This paper examines the impact of digital transformation and collaborative pedagogy on global education systems. By analyzing empirical research and international case studies, it assesses how advancements in smart learning environments, mobile and cloud-based platforms, and student-centered teaching methods are reshaping pedagogical practices. The discussion highlights key benefits—such as expanded access to learning and improved student interaction—while also addressing challenges related to infrastructure development, equity in access, and digital literacy among both learners and educators.

COIL (Collaborative Online International Learning) is implemented through a structured four-phase approach. The Icebreaker phase allows students from different countries to get acquainted, followed by the Organization phase where teams are formed and project details are clarified. During the Collaboration phase, students actively work together on joint assignments using digital platforms like Microsoft Teams and shared workspaces. The final Reflection phase involves evaluating the collaborative experience to deepen learning

outcomes. Faculty members from partner institutions co-design curricula and facilitate intercultural exchanges, while students develop global competencies through project-based learning that transcends geographical boundaries.

LITERATURE REVIEW

Current studies emphasize the transformative impact of digital technologies and collaborative pedagogy on international education systems. Education 4.0, as described by Aristin et al. [1], leverages emerging technologies such as artificial intelligence (AI), the Internet of Things (IoT), and big data to create smarter and more interconnected learning environments. The COVID-19 pandemic accelerated this shift, compelling institutions to adopt digital platforms and rethink traditional teaching models [2].

Blended learning has become a mainstream instructional approach, combining online and face-to-face components to enhance flexibility and student engagement [3], [5]. Mobile platforms and smart classroom technologies have further enabled personalized, on-demand learning, while tools such as Google Classroom and cloud-based systems facilitate seamless instructional delivery [6], [7]. Pedro et al. [4] emphasize mobile learning's role in enabling real-time, peer-to-peer collaboration and interaction. Furthermore, initiatives like COIL promote global competencies and cross-cultural engagement among learners [9].

Despite these advancements, challenges persist—particularly regarding infrastructure, equitable access, and varying levels of digital literacy [2], [5]. Scholars advocate for inclusive educational strategies and increased investment in digital infrastructure to bridge these gaps. Overall, the literature reflects a growing trend toward adaptive, collaborative, and increasing number of studies emphasize the impact of Education 4.0 on contemporary learning environments. [1] conceptualize Education 4.0 as an environment shaped by the intersection of artificial intelligence (AI), big data, cloud computing, and the Internet of Things (IoT), which collectively foster intelligent and responsive educational settings. These technologies support adaptive learning pathways, automated grading systems, and instant feedback mechanisms revolutionizing how students interact with content and educators.

Several researchers have also explored how the COVID-19 pandemic accelerated the adoption of digital educational technologies. [2] highlighted how this global disruption forced institutions to rapidly embrace remote teaching tools and reassess their digital readiness. During this period, platforms such as Google Classroom and other learning management systems (LMS) gained prominence, aiding in maintaining instructional continuity and enhancing student engagement [7].

In addition to technological integration, collaborative pedagogies have emerged as significant contributors to modern education. Studies by [9] and [11] underscored the benefits of global virtual collaboration initiatives—particularly COIL in fostering cross-cultural competencies and teamwork skills. These approaches align closely with 21st-century educational goals, including communication, problem-solving, and intercultural understanding. However, existing literature also identifies key challenges. [4] and [5] caution that disparities in digital literacy, inconsistent infrastructure availability, and a lack of adequate teacher training can hinder the effectiveness of these innovations. This underscores the need for more inclusive strategies that ensure equitable access to digital education across different socioeconomic groups. Overall, the literature reveals a strong global movement toward flexible, student-centered, and collaborative learning models enabled by technology. This research builds on those insights to synthesize global best practices and propose future directions for advancing transformative education.

To strengthen the abstract's value, incorporating minimal primary data would provide empirical grounding to support the theoretical claims. Interview data from educators implementing blended learning models could reveal specific challenges and success factors in real classroom settings. Survey insights from students experiencing mobile learning platforms would quantify engagement levels and learning outcomes, moving

beyond general assertions. Case study results from institutions successfully integrating COIL programs could demonstrate measurable improvements in cross-cultural competencies and collaboration skills. These primary data elements would transform the abstract from a purely literature-based synthesis into evidence-supported research, providing concrete examples of how digital transformation actually impacts educational practices and student outcomes in diverse global contexts.

PROPOSED METHODOLOGY

Conventional learning strategies are increasingly insufficient to meet the diverse and evolving needs of global learners. In response, the growing shift toward digitalization and collaborative learning paradigms has become essential for addressing these challenges. Technological innovations such as mobile learning [4], blended learning models [3,5], smart classroom technologies [6], and collaborative digital platforms [9,11] significantly contribute to enhancing student motivation and academic performance.

For this study, we employed a Systematic Literature Review (SLR) approach, analyzing peer-reviewed research published between 2018 and 2024. Key academic databases consulted included Scopus, Web of Science, IEEE Xplore, and Google Scholar. Our review focused on literature exploring digital transformation [1,2], collaborative learning [12], blended learning [3], mobile learning [4], and smart classroom technologies [6]. These studies were analyzed using both thematic and comparative analysis to identify core educational strategies effectively applied across global contexts.

Our methodology supports the following key practices:

- **Integration of blended learning models** to foster flexible and interactive learning opportunities [3,5].
- **Adoption of mobile learning technologies** to enhance accessibility and ensure continuous learner engagement [4].
- **Implementation of smart classroom systems** that utilize digital tools to promote collaboration and real-time interaction among learners [6].
- **Incorporation of extended reality technologies** to provide immersive and engaging educational experiences [8].
- **Continuous validation through expert feedback** from educational technology professionals to ensure the relevance, effectiveness, and adaptability of innovative teaching methods [10,11].
- **Development of a comprehensive conceptual framework** to guide global educational institutions in the effective integration of digital and collaborative learning strategies, aiming to optimize learning outcomes and promote equitable access to educational resources [1,12].

CONCLUSIONS

The global educational landscape is undergoing a profound transformation, driven by digitalization and collaborative learning paradigms. With the advent of Education 4.0, emerging technologies—such as blended learning models, mobile applications, intelligent classroom systems, and extended reality—have revolutionized traditional pedagogy. These innovations foster personalized, adaptive, and engaging learning environments, enhancing student participation, enabling international collaboration, and nurturing essential 21st-century competencies. While the benefits of these technologies are increasingly evident, persistent challenges remain. These include disparities in access to digital infrastructure, varying levels of digital literacy, and the need for comprehensive teacher training. Addressing these barriers requires the implementation of inclusive educational policies, strategic investments in educational technologies, and continuous professional development for educators.This research emphasizes that the effective integration of digital and collaborative learning approaches is essential for building education systems that are resilient, equitable, and future-ready.

As more educational institutions adopt these innovations, it is imperative to prioritize both accessibility and quality to ensure that learning experiences are not only more meaningful but also transformative for learners around the world.

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A CONCEPTUAL FRAMEWORK FOR EMBEDDING AI IN STUDENT LEARNING: A STRUCTURED APPROACH

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ABSTRACT

Artificial Intelligence (AI) is increasingly influencing learning and teaching, but effective integration into student learning remains a challenge. This paper proposes a conceptual framework that guides students through intentional, critical, and ethical engagement with AI tools. Rather than jumping directly into AI use, the framework is structured in four phases: Pre-AI engagement, AI Integration, Post-AI synthesis, and output & application. Each phase is designed to enable independent thinking, collaborative learning, and the development of AI literacy. Cross-cutting themes; AI literacy, ethical awareness, and human-centered learning; support students in using AI not as a shortcut, but as a partner in the learning journey. The framework aligns with Sustainable Development Goal 4 (SDG 4), particularly Target 4.7, emphasizing skills for informed and responsible citizenship.

Keywords: AI Literacy; Ethical Engagement; Framework; SDG 4.

INTRODUCTION

The rise of AI-powered tools in education has opened up new opportunities for personalised and scalable learning [1]. However, students often use these tools without enough guidance or critical frameworks, which can lead to surface-level learning or ethical concerns [2]. This paper introduces a flexible, student-centred framework designed to support the thoughtful integration of AI into learning experiences. The aim is not just to take advantage of what AI can offer, but to keep student involvement, reflection, and collaboration at the core.

The framework is aligned with the principles of Sustainable Development Goal 4 (SDG 4), especially Target 4.7, which focuses on equipping all learners with the knowledge and skills needed to promote sustainable development. In other words, the connection to SDG 4.7 is intentional: it highlights that educating students to use AI thoughtfully and ethically aligns with global goals for sustainable, responsible citizenship. While discipline-neutral, the framework encourages the development of higher-order thinking, digital responsibility, and ethical reasoning; key elements in preparing informed and active citizens for a sustainable future.

AI in education has been explored through adaptive learning systems [3], chatbots [4], and assessment tools [5]. Existing research highlights the importance of digital literacy and ethical awareness when engaging with these technologies [1 , 2]. At the same time, pedagogical approaches rooted in constructivist and experiential learning stress the value of reflection, collaboration, and knowledge construction. This paper brings these perspectives together by proposing a framework in which AI supports learning; rather than replacing it.

However, a review of related work suggests that no prior framework combines phases in the manner proposed here for student AI engagement; existing AI-in-education frameworks tend to focus on teacher guidelines or isolated aspects of AI literacy. This indicates that our student-centered multi-phase model addresses a gap in the literature, offering a novel approach. Several recent frameworks echo elements of our four-phase model. For instance, Acar [6] proposes the PAIR model (Problem, AI, Interaction, Reflection) that structures AI learning into pre-use, interaction, and reflection stages. Similarly, Willey et al. [7] introduce a Prompt Development Life Cycle (PDLC) covering planning, prompting, testing, and evaluation; steps closely aligned

with our phases 1 to 3. Classic educational models like Kolb's experiential learning cycle [8] and the 5E inquiry model [9] also emphasize reflective, staged learning processes. Additionally, recent classroom-based studies report educators designing AI-based assignments with preparation, interaction, evaluation, and output stages. What distinguishes our framework is its integrated, student-centered structure that explicitly positions AI interaction as the core of the learning cycle, bracketed by intentional preparation and reflective application. This combination of structured AI engagement and holistic pedagogy is a distinctive contribution.

The methodology used in this paper draws on a synthesis of existing research in AI, personal teaching experience, and principles of digital literacy. While the framework has not yet been tested in practice, it is shaped by reflective practice and pedagogical insight, offering a foundation for future classroom implementation and refinement. Thus, our approach is methodological in a design sense: it systematically combines insights from literature and teaching practice to inform the framework's development, bridging theory and practice in a way that justifies the framework as a product of this research-based method. Each part of the framework is shaped by well-known ideas in education and current examples of AI use in learning.

THE AI-ENHANCED STUDENT LEARNING FRAMEWORK

The proposed framework (shown in Figure 1) is structured around four interconnected phases that guide students through a meaningful engagement with AI in learning environments. *Phase 1, Pre-AI Engagement,* emphasizes the importance of preparing learners before they interact with AI tools. This includes encouraging self-reflection, where students examine their existing knowledge and assumptions; promoting collaborative discussions to explore diverse perspectives; and engaging in brainstorming and question design to craft purposeful inquiries that will later guide AI use. *Phase 2, AI Interaction,* centers on the active use of AI tools in the learning process. Students learn to formulate clear and meaningful prompts, engage in conversational exploration through iterative questioning and clarification, and conduct AI-supported analysis by using the technology to identify patterns, solve problems, or deconstruct complex concepts. This interaction is followed by *Phase 3, Post-AI Synthesis*, which involves critically evaluating the relevance and accuracy of AI-generated outputs. Students share insights through group work, refining their understanding collaboratively, and construct new knowledge based on their combined learning experiences.

Finally, *Phase 4, Output and Application,* focuses on producing individual or group deliverables; such as reports, presentations, or design prototypes and includes a reflective commentary where students articulate their learning journey and the role AI played. Throughout all four phases, the framework is underpinned by cross-cutting themes of AI literacy, ethical awareness, and human-centered learning. These ensure that students develop responsible AI practices, consider bias and transparency, and remain active participants in shaping their own learning outcomes.

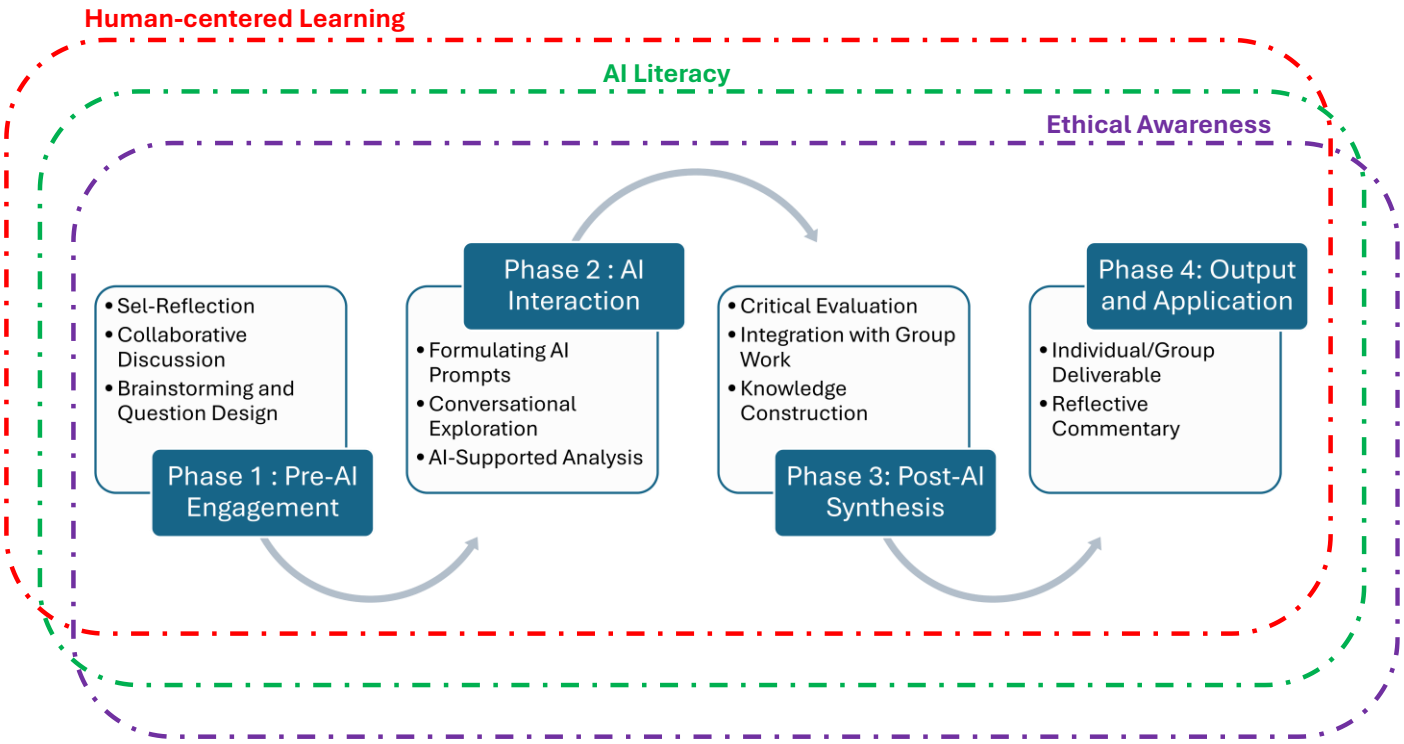

Figure 1 – The AI-Enhanced Student Learning Framework.

EVALUATION OF THE FRAMEWORK

To illustrate how the framework could be applied in practice, accessible tools like ChatGPT (free version) are used hypothetically. Table 1 presents a proposed mapping of student actions to framework components, suggesting how AI tools might support learning and evaluation.

Table 2 – Evaluation of the offered framework via a free AI tool (ChatGPT, free version).

Framework Phase	Student Action	Example AI Prompt	Expected Learning Output	AI's Role in Learning
Phase 1: Pre-AI Engagement	• Self-Reflection • Collaborative Discussion • Brainstorming and Question Design	No AI prompt yet; students discuss: "What aspects of smart buildings and IoT are unclear to us?"	List of student-generated questions about IoT and sustainability (e.g., energy efficiency, carbon footprint).	AI not used directly; students identify what they don't know, fostering ownership of inquiry.
Phase 2: AI Interaction	• Formulating AI Prompts • Conversational Exploration • AI-Supported Analysis	"How can IoT-based energy monitoring systems reduce environmental impact in residential buildings?"	Detailed response listing use cases that students learn from, such as smart meters, HVAC automation, and real-time analytics; Offering structured knowledge that supports understanding of sustainability applications.	AI acts as an exploration partner and learning support tool, helping structure information and guide student inquiry.
Phase 3: Post-AI Synthesis	• Critical Evaluation • Integration with Group Work • Knowledge Construction	No AI prompt – Students evaluate the AI-generated response or assistance. "Does the AI's explanation of IoT energy monitoring address all relevant factors, or are there any gaps, oversimplifications, or assumptions?"	Annotated notes identifying overlooked data privacy issues, or even overly general responses showing lack of AI knowledge in the topic.	AI becomes a critical thinking partner; Students validate, critique, and co-construct meaning.

Framework Phase	Student Action	Example AI Prompt	Expected Learning Output	AI's Role in Learning
Phase 4: Output and Application	• Individual/Group Deliverable • Reflective Commentary	"Help me draft a project outline showing the benefits and challenges of IoT in sustainable architecture."	Project report draft with student-authored sections, and reflective notes on the AI's usefulness.	AI supports initial structure, but students shape the final deliverable and reflect on learning impact.

CONCLUSIONS

This paper introduces a general framework for integrating AI into student learning in a structured and thoughtful way. By emphasizing preparation, critical interaction, and synthesis, the model supports students as active, reflective, and ethical learners, while promoting AI literacy and human-centered engagement. Although the framework offers a solid foundation, it is not exhaustive. It has not yet been tested across multiple disciplines or education levels and requires further refinement through classroom implementation and learner feedback. Adaptation for specific subject areas will also be necessary.

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The author used ChatGPT to check grammar issues and to improve readability. After using this tool, the authors reviewed and edited the content as needed and take full responsibility for the content of the publication.

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GENERATIVE AI IN HIGHER EDUCATION: ASSESSING STUDENTS' AND EDUCATORS' PERCEPTION AND ETHICAL CONCERNS

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ABSTRACT

The growing adoption of Generative AI in Higher Education creates both potential and ethical challenges for students and teachers. This study investigates how university students and educators see the ethical implications of AI-generated content in academic settings with a particular emphasis on academic integrity, responsible AI use, and institutional policies. To strengthen its analytic impact, the study is grounded in the Fairness, Accountability, and Transparency (FAT) framework, commonly used in AI ethics as well as virtue ethics, which considers the cultivation of intellectual honesty and responsibility in educational contexts. Utilising a convergent parallel mixed-methods strategy, this study collects qualitative and quantitative data through surveys. Applying a pretest-posttest approach, this research explores how students' perceptions and ethical awareness of Generative AI change after an intervention. Preliminary survey findings show that students have moderate ethical awareness, are familiar with academic AI policies and have overall positive perceptions of Generative AI use in academic and professional growth. By analysing AI literacy and ethical AI use in higher education, this study contributes to SDG 4: Quality Education, ensuring that students and educators are prepared to navigate the advancing technological landscape responsibly.

Keywords: Generative AI; AI Ethics; Higher Education.

INTRODUCTION

Generative AI (GenAI) has become a valuable tool in the classroom that has allowed for enhanced student collaboration and more personalised learning experience. From customised learning plans to structured feedback, GenAI tools are transforming how students and educators engage with content [1] [2]. However, as these tools become increasingly embedded in educational settings, they also introduce complex ethical concerns around privacy, fairness, accuracy, and accountability [3].

This study addresses these challenges by grounding its analysis in two ethical frameworks: the FAT (Fairness, Accountability, and Transparency) framework and virtue ethics. The FAT framework is commonly used in AI ethics to assess how systems align with principles of justice, explainability, and institutional responsibility. In parallel, virtue ethics considers the moral character and personal responsibility of users in this case, students and educators in making ethical choices when using AI tools. These frameworks provide a dual lens: one focused on the structural and technological dimensions of AI ethics, and the other on the cultivation of moral judgment and integrity.

With these perspectives in mind, this study explores how students and educators at the University of Technology Sydney (UTS) perceive the ethical implications of Generative AI in higher education. It particularly investigates concerns around academic integrity, responsible AI use, and awareness of institutional policies. Understanding these viewpoints is crucial for developing ethical practices that encourage responsible AI engagement, support critical thinking, and contribute to Sustainable Development Goal 4: Quality Education.

MATERIALS AND METHODS

This research adopts a convergent parallel mixed-methods approach, collecting both qualitative and quantitative data through surveys to examine attitudes, concerns, and regulatory standards associated with Generative AI. The participants, both students and educators, are from UTS and have provided their consent.

SURVEY

Students from the BIS (Bachelor of Information Systems) major at UTS participated in a pre-post test design to explore students' perceptions and ethical awareness of Gen AI and how these aspects change following the intervention. This study consists of a pre-survey containing Likert questions and one open-ended question to gain initial insight into students' perceptions. This is followed by a Gen AI Intervention exercise which students complete in class. As part of the intervention in one of the weeks, students participated in a Microsoft Copilot activity titled AI-Powered Business Problem Framing & Solution Generation. Working in their existing groups, students were guided in using effective prompting techniques to engage with Microsoft Copilot. The design of the survey and in-class GenAI intervention was informed by ethical considerations grounded in the FAT (Fairness, Accountability, Transparency) framework and virtue ethics. Students were encouraged to critically reflect on AI systems not only for accuracy and usefulness, but also in terms of fairness, bias, and personal ethical responsibility. Lastly, students completed the post-survey to assess changes in students' knowledge, judgement, and ethical awareness of GenAI.

The survey data was analysed using IBM SPSS statistics, and descriptive statistics are used to gain insights into students' perception and ethical awareness of Generative AI usage in Higher Education. Key constructs for the survey items consist of Technology proficiency and experience, Confidence in using GenAI, Perceived Value and career impact of GenAI, Awareness and Understanding of Ethical Concerns of GenAI. In addition to statistical analysis, qualitative responses to open-ended survey questions were analysed using word cloud, revealing repeated themes and concerns on ethical issues in AI adoption. This mixed-methods approach encapsulates a deeper understanding of participants' perspectives.

RESULTS

The study's initial findings include descriptive statistics from the pre-test survey and a word cloud analysis. The pre-test survey data summarises participants' initial perceptions and ethical awareness about Generative AI. Table 1 displays the participant data gathered from pre-survey analysis showing the mean and standard deviation in relation to participants' perceptions and use of Generative AI.

Table 3 – Pre-survey Participant Data on Generative AI (N = 122).
Source: Author's own data, derived from pre-test survey responses (2025).

Individual Constructs	Mean	Std. Deviation
Level of experience with technology and digital tools	1.85	.639
Frequency of use of GenAI tools for study-related activities	3.13	.944
Confidence in using GenAI for learning and assessment	3.08	1.025
Confidence in critically evaluating the accuracy and quality of AI-generated content	3.10	.999
Belief that GenAI tools enhance learning experience	2.77	.758

Individual Constructs	Mean	Std. Deviation
Interest in developing skills in GenAI for academic and professional purposes	3.30	.978
Belief that GenAI skills will benefit career/future job prospects	2.56	.561
Awareness of ethical concerns related to GenAI in academic work	3.72	1.031
Awareness of institutional policies on ethical AI use	2.75	.583
Understanding of UTS policies on ethical AI use	3.91	.941
Preparedness to apply ethical judgment when using AI-generated outputs	3.37	.883

As shown in Table 1, participants demonstrate a moderate level of ethical awareness related to Generative AI and a high level of understanding of academic AI policies. Due to the inclusion of Generative AI guidelines in each subject, this may have led students to have a stronger understanding and ethical awareness of GenAI in their work. Students' perceptions of Generative AI tools lean towards positive responses, viewing Generative AI as a beneficial tool that can benefit their career. These insights suggest that students are optimistic and open to the responsible use of Generative AI in higher education.

Despite students having low to moderate experience with technology, majority of students display confident attitudes in applications and critical judgement of AI technology. This can be due to the accessibility and intuitiveness of GenAI which allows them to use these tools with greater confidence. Students may also have been introduced to GenAI in coursework which has given them guidance on effectively using them and evaluating its outputs.

Figure 4 – Word Cloud of Students' concerns of GenAI in coursework.
Source: Author's own data, derived from pre-test survey responses (2025).

The word cloud analysis shown in Figure 1, identifies the most frequently used terms and concepts linked to Generative AI, representing the participants' main concerns of its use in coursework. From the open-ended survey question, one participant expressed "Causing a lack of understanding of the content and skipping through with the assistance of AI.", as a key concern. Another participant noted "Plagiarism and AI providing me the wrong information.", as a significant challenge. With GenAI becoming a widespread tool in education, many students are concerned of the reliance that students have on these tools. The accuracy and convenience of GenAI, have led to reduced engagement with learning content among students, impacting their understanding and critical thinking skills.

These concerns are reflected in the word cloud where terms like ‘accuracy’, ‘unethical’, and ‘plagiarism’ occur frequently, highlighting their importance as recurring themes in participants’ responses. In contrast, other students used the terms ‘assistance’, ‘tutor’, and ‘teach’, suggesting that students use GenAI as a personal tutor to help them to understand coursework effectively. This qualitative analysis allows us to see the varying perspectives students have regarding GenAI in academic work, with students feeling concerned of GenAI’s impact and other students approaching GenAI with a positive mindset.

These findings highlight the value of applying multiple ethical lenses when evaluating students’ engagement with GenAI. The FAT framework illuminates systemic concerns such as institutional responsibility and AI transparency, while virtue ethics helps examine how students internalize ethical behavior in technology use. Addressing both perspectives is essential for shaping holistic AI literacy and promoting ethical growth in higher education.

CONCLUSIONS

This research provides an in-depth understanding of the attitudes, challenges, and ethical judgement related with Generative AI utilising a convergent parallel mixed-methods design. By incorporating both the FAT framework and virtue ethics, the study provides a comprehensive lens through which ethical concerns are evaluated, addressing both the system-level implications of AI (e.g., fairness, bias, institutional accountability) and individual moral responsibilities (e.g., integrity, critical thinking). These findings offer insights that can inform ethical AI education, support better policy design, and foster a culture of responsible innovation within academic institutions. Ultimately, this research contributes to ongoing efforts to equip students and educators with the knowledge and ethical grounding necessary to engage thoughtfully and responsibly with emerging technologies.

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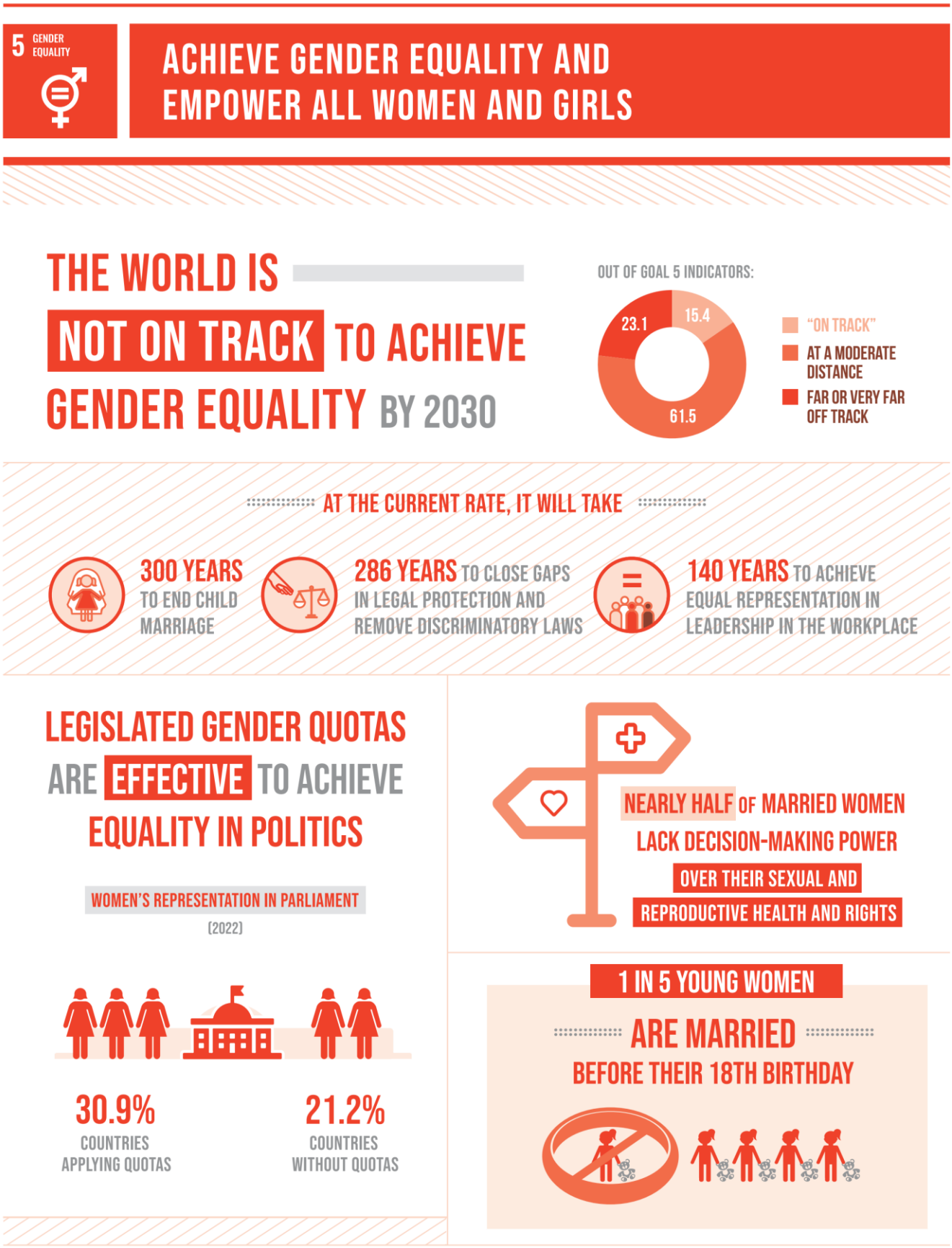
GOAL 5: ACHIEVE GENDER EQUALITY AND EMPOWER ALL WOMEN AND GIRLS



Source: UN's The Sustainable Development Goals Report 2023 – Special Edition

DESIGNING GENDER-INCLUSIVE PRIVACY FRAMEWORKS FOR DIGITAL PLATFORMS IN AUSTRALIA: BRIDGING ETHICS, POLICY, AND PRACTICE

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ABSTRACT

As digital platforms become integral to everyday life in Australia—from e-health to e-government—privacy concerns have intensified. Yet current frameworks seldom recognise the distinct needs and vulnerabilities of women and gender-diverse users. To address this gap, we conducted an integrative literature review (n = 112 peer-reviewed studies, 2010-2024) alongside documentary case analysis of three flagship Australian platforms (My Health Record, MyGov, and an enterprise learning-management system) and 27 relevant policy texts. Guided by feminist HCI and privacy-by-design principles, we performed a thematic synthesis that surfaced five recurring design patterns that systematically heighten privacy risk for marginalised users. The resulting five-pillar Gender-Inclusive Privacy Framework bridges ethics, technical design, and regulatory alignment, providing actionable guidance for researchers, technologists, and policymakers committed to inclusive digital innovation.

Keywords: Gender equity; privacy engineering; digital platforms; inclusive design; Australia.

INTRODUCTION

Digital transformation across Australia's public and private sectors has accelerated the deployment of AI-driven and data-intensive platforms across domains such as health, education, welfare, and finance. While these systems offer efficiency and accessibility, they often introduce privacy risks that disproportionately affect women and gender-diverse individuals [1]. Conventional privacy approaches tend to treat users as homogenous and privacy as a universal concept, failing to account for social and cultural differences, power imbalances, and contextual vulnerabilities.

Australia's ongoing revision of the Privacy Act 1988 seeks to modernize data protection in the digital age [2]. However, gender-sensitive perspectives remain underrepresented in these reforms. Furthermore, documented cases of algorithmic bias, consent fatigue, and data misuse have exposed how marginalised groups—particularly women from culturally and linguistically diverse (CALD) and Aboriginal communities—face heightened risks from privacy breaches [2][3].

This paper addresses these challenges by proposing a gender-inclusive privacy framework that integrates principles from feminist theory, human-computer interaction (HCI), and privacy engineering with insights from the Australian policy landscape.

MATERIALS AND METHODS

This study follows an integrative literature-and-document review design combined with a documentary case approach [7], both grounded in feminist HCI and privacy-by-design principles. Peer-reviewed publications were retrieved from Scopus, Web of Science and IEEE Xplore on 21 March 2024 using the string ("privacy" OR "data protection") AND ("gender" OR "women" OR "non-binary") AND ("digital platform" OR "online service" OR "e-service"), limited to English-language work published between 2010 and 2024; the search returned 492 records, of which 112 remained after duplicate removal and two-stage relevance screening. The policy corpus comprised 27 Australian federal documents—including the Privacy Act Review, eSafety

guidelines and public consultation reports—and was supplemented by publicly available user manuals, API specifications and design white papers for three flagship platforms: My Health Record, MyGov and a large enterprise learning-management system. Each source was charted in an evidence matrix and iteratively examined against a set of privacy-by-design heuristics (after Cavoukian [5]) and feminist-HCI values to surface recurring design patterns and points of failure relevant to gender inclusion. No new data were collected from human participants; therefore ethics approval was not required.

RESULTS

The case studies and literature review revealed widespread shortcomings in current digital privacy practices, particularly in terms of addressing gender-specific risks. In the healthcare sector, systems like My Health Record often featured complex consent processes and unclear data-sharing disclosures. These were particularly inaccessible to users with lower digital literacy or those in emotionally vulnerable conditions, such as survivors of gender-based violence. In eGovernment platforms such as MyGov, default privacy settings were often rigid and failed to consider users with unique privacy needs—such as individuals managing sensitive benefits or seeking services anonymously due to safety concerns [2].

Educational platforms employed by Australian universities also exhibited gaps in privacy protection, notably in learning analytics and surveillance features embedded within online assessment tools. The lack of transparency in how data was collected, stored, and shared created an atmosphere of mistrust, particularly among minority students and gender-diverse users. Across all platforms examined, grievance and redress mechanisms for privacy violations were inconsistent or poorly communicated, limiting recourse for affected users. These findings indicate that the design of digital services frequently prioritizes administrative or commercial efficiencies over individual privacy, especially for users from underrepresented communities [6].

FRAMEWORK PROPOSAL

In response to the observed deficiencies, this paper proposes a comprehensive gender-inclusive privacy framework with five interrelated components. The ethical dimension stresses the incorporation of feminist ethics and recognition of structural inequities in the digital experience. By embedding ethical considerations early in the design process, developers can better anticipate and mitigate unintended harms to vulnerable populations.

The technical dimension promotes the implementation of privacy-enhancing technologies tailored to diverse user needs. These include context-aware privacy defaults, data minimization, differential privacy, and encryption practices—approaches rooted in the principles of Privacy by Design [5]—that provide flexibility without sacrificing usability. The participatory dimension highlights the necessity of involving a wide range of users—particularly those from gender-diverse and marginalized backgrounds—in the co-design and testing phases of digital platform development. This ensures the system reflects real-world experiences and expectations.

The policy alignment dimension ensures consistency with national privacy and anti-discrimination frameworks. It translates legal principles into practical development standards and promotes internal accountability within organizations. Finally, the evaluation dimension introduces specific metrics to assess the inclusiveness, transparency, and accessibility of privacy features. This supports a feedback loop for continuous improvement, empowering institutions to iterate based on user outcomes and emerging challenges.

DISCUSSION

The results of this study underscore that privacy vulnerabilities are not equally distributed. Women and gender-diverse individuals face amplified risks due to digital systems that overlook contextual sensitivities. Prior work has demonstrated that marginalised users often experience "privacy fatigue" when interacting with data-intensive platforms, leading to disengagement or coerced consent [3].

The absence of redress mechanisms or clear communication pathways intensifies the effects of data harm. These conditions reflect a broader issue: that privacy governance remains too focused on abstract compliance and insufficiently concerned with real-world inclusion. Designing for privacy requires an understanding of the cultural, emotional, and social contexts in which users operate. Feminist HCI theory emphasizes these principles, yet few systems apply them in practice [4].

A shift toward participatory and ethical design must be institutionalized through updated policy standards and co-designed digital infrastructures. As Australia advances its national digital identity strategy and revises its Privacy Act, it has an opportunity to embed gender inclusion in core technical systems—not as an afterthought but as a foundation. This study contributes a practical, theoretically grounded model that supports such reform efforts.

CONCLUSIONS

Digital platforms are central to Australia's public services and innovation strategy. However, the oversight of gendered privacy considerations in their design and governance perpetuates digital inequities. This research highlights how existing digital infrastructures often neglect the privacy needs of women and gender-diverse individuals, leading to tangible harms including exclusion, mistrust, and compromised safety.

The proposed gender-inclusive privacy framework addresses this gap by integrating ethics, technical safeguards, participatory methods, policy compliance, and evaluative metrics. It provides a practical guide for digital system designers, policymakers, and developers to operationalize inclusion in data governance and user experience. Moreover, it aligns privacy design not just with legal mandates, but with principles of justice, dignity, and respect for all users.

Future research should focus on applying this framework to live government or educational platforms through pilot implementations and user-centred evaluations. There is also scope to extend the model to intersectional analysis, accounting for how gender interacts with race, disability, and socio-economic status in shaping digital vulnerability.

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COLLABORATING TOWARDS THE SUSTAINABLE DEVELOPMENT GOALS: EDUCATION'S POWER IN ACHIEVING GENDER EQUALITY (EPAGE)

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ABSTRACT

This article examines how education can help achieve gender equality, using the United Nations Sustainable Development Goals, specifically SDG 4 (Quality Education) and SDG 5 (Gender Equality) as the framework. Education plays a key role in building equal and just societies, but access to education remains unequal for all. In the majority of the world, gender determines who gets to go to school, what they learn, and how they are treated. Reports from organizations like UNESCO, OECD, and the World Bank show that gender stereotypes, socio-economic barriers, and gender-based violence continue to limit educational opportunities for girls, especially in certain subjects and career pathways. By reviewing research studies and real-world examples, this paper shows how education can be utilized to overcome stereotypes and construct more inclusive classrooms. It also emphasizes the importance of collaboration between schools, communities, and governments to provide all genders with an equal chance to learn and grow.

Keywords: Education 1; Gender Equality 2; Quality Education 3.

INTRODUCTION

Gender equality is one of the United Nations Sustainable Development Goals (SDG 5), and priority is given to the empowerment of women and girls. Education has a central function in achieving this goal because it makes societies fairer and allows individuals the ability to enhance their lives. However, education still remains unequal for everybody. In most of the world, gender defines who gets to go to school, what they learn, and how they are treated. Women in some regions of Sub-Saharan Africa and South Asia face significant obstacles to education that deny them the right to gain an education and limit their potential for life [1].

The World Bank emphasizes that gender equality in education is at the heart of social inclusion and equal opportunities for women and girls. Their Gender Strategy Update (2024-2030) elaborates that with the same access to education, girls and women become more successful in society [2]. They earn better pay, are healthier, and have a more inclusive economy, and this ultimately reduces poverty.

The OECD also brings into focus the fact that stereotypes in terms of gender continue to influence both how girls and boys are taught and the career paths they are encouraged to pursue [3]. Despite girls generally performing well in school, these stereotypes restrict their potential, particularly in fields such as mathematics and technical occupations. The OECD advocates for educational policies that address and challenge these stereotypes, ensuring equal opportunities for both boys and girls to thrive in all subject areas [3].

Gender-based violence (GBV) is also confirmed by UNICEF to be a significant challenge to girls' education, especially in conflict settings where it exacerbates higher rates of dropout as well as psycho-social distress to girls. Consequently, UNICEF calls for the establishment of secure learning contexts so that the girl child does not drop out of school but rather reaches her full potential [4].

According to UNESCO, girls in Malaysia, Cambodia, and the Philippines are the same as boys in mathematics. However, gender stereotypes still prevent many girls from pursuing tertiary education and employment,

especially in technical courses [5]. Regardless of how much worldwide gender differences in education have declined, regional disparities remain, most notably in Sub-Saharan Africa and South Asia [1].

This essay explains how education can do away with gender stereotypes and make schools treat every individual on an equal basis. It also highlights the cooperation among schools, governments, and communities to enable all students to achieve equal opportunity for learning and development, leading to gender equality in education.

MATERIALS AND METHODS

MATERIALS AND DATA SOURCES

This research utilized secondary data gathered from UNESCO, OECD, World Bank, and UNICEF reports. These sources offer credible data on SDG 4 (Quality Education) and SDG 5 (Gender Equality), addressing gender disparities in education.

The primary data sources include:

- World Bank Gender Strategy Update (2024-2030) [2]
- UNESCO's Global Education Monitoring Reports [1]
- OECD reports on gender stereotypes in education [3]
- UNICEF's gender equality reports [4]

These sources were selected for their relevance to the analysis of gender equality and education and provide insights into the barriers girls face in accessing and completing education, particularly in STEM fields.

METHOD OF ANALYSIS

A qualitative content analysis approach was used to analyze the selected reports. The following steps were taken:

1. Data Collection:
   Data were gathered from the reports mentioned above, which were chosen for their relevance and credibility in addressing the gender equality issue in education.
2. Systematic Literature Review:
   A literature review was conducted using specific keywords such as "gender equality," "gender stereotypes in education," "girls in STEM," and "gender disparities in education." These keywords guided the identification of relevant themes in the reports.
3. Analysis Process:
   A manual qualitative content analysis was conducted by closely reviewing the selected reports. Key themes were identified, including gender-based barriers to education, academic performance gaps, and gender stereotypes. Particular attention was given to regional disparities, especially in Sub-Saharan Africa and South Asia, where gender inequality in education remains most severe [1][4].
4. Limitations:
   The research draws upon multiple sources, not solely on UNESCO. To ensure a broad perspective, OECD, World Bank, and UNICEF reports were included to complement the findings. Future research could include propositional studies to explore additional solutions for addressing gender inequality in education.

RESULTS

The analysis of the selected reports revealed several key findings regarding gender inequality in education. These findings are organized into the following themes: gender-based barriers to education, academic performance disparities, gender stereotypes, and regional differences in access to education. Additionally, the study identified various strategies and interventions aimed at overcoming these challenges.

1. Gender-Based Barriers to Education
   Findings:
   - Early Marriage and Child Labor: Reports from UNICEF and the World Bank highlight that early marriage and child labor are significant barriers preventing girls from accessing or completing their education [6][7]. These practices are prevalent in South Asia, where girls are often expected to prioritize domestic responsibilities over schooling.

   Strategies to Overcome:

   - Community-Based Programs: Initiatives that promote the importance of girls' education and address socio-cultural barriers, such as early marriage and child labor, have been effective. Engaging community leaders and parents in these programs is crucial for their success [8].
2. Academic Performance Disparities
   Findings:
   - STEM Field: Despite improvements in educational attainment, gender disparities persist, particularly in STEM fields. Girls in countries like Malaysia, Cambodia, and the Philippines perform on par with boys in subjects like mathematics. However, societal expectations and gender stereotypes discourage girls from pursuing careers in science and technology [5].

   Strategies to Overcome:

   - Gender-Transformative STEM Education: UNESCO advocates for delivering gender-transformative STEM education that challenges traditional gender norms and promotes equal opportunities for all students. This approach involves integrating gender equality into STEM curricula and teaching practices to create an inclusive learning environment [9].
   - Teacher Training and Professional Development: Focusing on gender-responsive pedagogies in teacher training and professional development is essential. UNESCO emphasizes the importance of equipping educators with the skills to recognize and address gender biases, fostering an environment where all students can thrive [9].
3. Gender Stereotypes in Education
   Findings:
   - Stereotypes in Subjects and Careers: gender stereotypes continue to influence students' subject choices, with girls often steered away from STEM fields. Despite performing equally well in these subjects, girls are discouraged from pursuing related careers [3].
   - Impact of Gendered Learning Materials: Textbooks often reinforce gender stereotypes by depicting women in domestic roles and underrepresenting them in technical fields. This discourages girls from pursuing non-traditional careers [3].

   Strategies to Overcome:

   - Curriculum Reform: Reforming curricula to challenge traditional gender roles and promote equal opportunities for both genders is crucial. Countries have successfully integrated gender-neutral practices in early education [10].
   - Teacher Training: Training teachers to recognize and address their biases can help create a more inclusive classroom environment for both genders, especially in STEM subjects [10].

CONCLUSIONS

Through SDG 4 (Quality Education) and SDG 5 (Gender Equality), in particular, this study demonstrates how education is essential to attaining gender equality. The results show gains in girls' education, including more attendance and greater performance in science and reading. Girls' access to school is still restricted, particularly in STEM sectors, by issues including child labor, early marriage, and gender norms.

According to the report, in order to get beyond these obstacles, tactics including community initiatives, curriculum modifications, and teacher training that emphasize gender sensitivity are crucial. For all people to have an equitable opportunity, communities, schools, and governments must cooperate.

To truly attain gender equality in education, we must keep dispelling myths and ensuring that education is available to everyone. Future research may use scholarly propositional models to support and enhance intervention strategies outlined in this paper, advancing progress toward gender equality in education.

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ANALYSIS OF GENDER-SPECIFIC CRITERIA FOR FEMALE RESEARCHERS IN FACULTY CALLS WITHIN BRAZILIAN GRADUATE PROGRAMS

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ABSTRACT

This paper analyzes gender equity policies regarding the admission, retention, and career progression of women in postgraduate teaching in Engineering in Brazil. The research focused on the postgraduate programs (PPGs) in the Engineering field as classified by CAPES, aiming to understand the practices adopted by institutions and their impact on female participation. The selection of PPGs was based on the percentage of female faculty members, using data from the Sucupira Platform. The collection of calls for proposals and faculty accreditation resolutions was carried out through the institutions' websites or via email for the analysis of the policies implemented. The results indicate the absence of effective public policies to promote gender equity in the PPGs of the Engineering field, highlighting structural barriers to female participation.

Keywords: Gender equity; Postgraduate programs in Engineering; Brazilian public policies; Female representation in academia.

INTRODUCTION

Gender inequality poses significant challenges for academic women, particularly those aspiring to a career in graduate-level teaching in Engineering. In 2022, women represented 37% of master's and doctoral students, 31% of higher education faculty, and only 24% in graduate programs [1, 2]. The greatest percentage drop occurs between the latter two groups, highlighting barriers to women's entry into graduate education. Furthermore, between 2013 and 2022, this representation has remained almost stagnant [1].

The challenges faced by female researchers extend beyond underrepresentation. Studies indicate that they have a lower chance of publishing articles, receiving citations, and patenting their work [3, 4, 5], which directly impacts their career progression. Lerchenmueller and Sorenson [6] point out that women's professional advancement in academia is 20% slower, and research also shows their lower recognition in rankings of influential scientists, awards such as the Nobel Prize, and productivity grant allocations [7, 8, 9].

This situation is driven by biases and structural barriers in academia, including implicit biases that shape perceptions and judgments unconsciously. These biases often associate intelligence and STEM (Science, Technology, Engineering and Mathematics) performance with men, while linking emotion and caregiving to women, which affects the recognition of women's competence and achievements in research [10, 11].

In 2015, the UN established gender equality as a key goal, emphasizing equal rights and opportunities [12]. In Brazil, achieving this requires effective public policies and the transformation of sexist scientific culture [13]. This study examines gender equity policies in graduate teaching in Engineering, addressing gaps in the literature and proposing solutions to support gender equity and the achievement of the UN's fifth Sustainable Development Goal.

MATERIALS AND METHODS

The analysis focused exclusively on graduate programs (PPGs) within the Engineering Field of CAPES, categorized as follows: (I) Engineering I – Civil, Sanitary, and Transport Engineering; (II) Engineering II – Mining, Materials, Metallurgical, Chemical, and Nuclear Engineering; (III) Engineering III – Mechanical, Production, Naval, Oceanic, and Aerospace Engineering; and (IV) Engineering IV – Electrical and Biomedical Engineering. Engineering fields related to other areas, such as Agricultural and Fisheries Engineering (Agrarian Sciences I), were excluded, which represents a limitation of this study.

The first step was to select the graduate programs by classifying them according to the percentage of female faculty members. As the Sucupira Platform [14] does not provide gender data, estimation was based on first names. A standardized name database (uppercase, without accents) was created and classified as male or female using GenderAPI, which considers geographic data, and ChatGPT, which relies on linguistic and statistical patterns. A MATLAB script automated the classification, reducing unconscious bias. While widely accepted in the literature [15, 16], this method has limitations, such as not accounting for gender identity, non-binary individuals, or uncommon names (e.g., a man named "Maria").

After classifying the percentage of female faculty members in each PPG, programs were grouped by Engineering divisions (I, II, III, and IV), and the 10 with the highest and lowest female participation in each division were selected, totaling 80 programs. This sample represents approximately 16,67% of the 480 Engineering PPGs in Brazil, based on data from CAPES covering the period from 2013 to 2022. It is worth noting that the aim was not to offer a representative overview of gender disparities, but to analyze extremes in order to explore contrasts between programs and identify factors associated with higher or lower female participation.

Subsequently, public notices and faculty accreditation resolutions were collected from institutional websites between August and December 2024, prioritizing the most recent versions available. Since 71 PPGs (88.75%) did not have these documents online, they were requested via email. Two requests were sent per institution, spaced one month apart. By the end of the process, documents from 57 PPGs were obtained (15 from Engineering I and 14 from each of the other divisions).

The collected documents were then analyzed to identify the presence of specific criteria for female researchers in the faculty accreditation process.

RESULTS

Table 1 presents the criteria identified in the analyzed documents, along with data from the respective PPG. Only 7 programs (12.2%) have specific requirements, with 5 related to maternity leave and 2 focused on women in general.

The maternity leave-related criteria comprise adjustments in the evaluation of female researchers, such as extending the curriculum evaluation period, applying correction factors, and granting re-accreditation extensions. Typically, an additional year is considered for the curriculum evaluation period for women who have taken maternity leave. However, studies such as the one by Machado et al. [17] suggest that the impact of motherhood on scientific productivity may extend for at least 4 years after the birth of the first child. Another criterion found was the guarantee of special treatment for breastfeeding women during exams, allowing the breastfeeding of infants under 6 months old— a right already ensured by Law No. 13.872/2019.

The criteria specifically targeting women in general include correction factors for scoring and tie-breaking criteria to promote gender equity. No clear relationship was identified between the presence of these criteria and female representation or the location of the PPG. Of the 7 programs that adopt such measures, 2 have

higher female participation and 5 have lower. The only region without specific criteria was the North, which represents only 2.5% of the analyzed PPGs.

Table 5 - Specific criteria for female researchers, along with the corresponding data for each PPG. Note: "+F" indicates programs with higher female representation, and "-F" indicates programs with lower female representation.

Area	Female Representation		Region	Specific Criterion
	Percentage	Class.		
Eng. I	62,5%	+F	South	In the case of maternity leave, changes in the productivity evaluation criteria.
Eng. I	0,0%	-F	Southeast	In the case of maternity leave, a correction factor is applied to the score: 1.2 for one leave and 1.3 for more than one.
Eng. II	10,0%	-F	South	In the case of maternity leave, re-credentialing is extended by the same duration as the leave.
Eng. II	7,7%	-F	Northeast	Special accommodations for breastfeeding women during the exam
Eng. III	0,0%	-F	South	In the case of maternity leave, guarantee of re-credentialing.
Eng. IV	38,1%	+F	Central-West	For women, a 15% increase in the credentialing parameter. For mothers, a 25% increase in the productivity evaluation period.
Eng. IV	0,0%	-F	Southeast	In case of a tie, gender justice criteria are applied.

CONCLUSIONS

The results reveal a lack of effective public policies promoting gender equity in Engineering graduate programs (PPGs), perpetuating barriers to female participation. The few existing initiatives primarily address maternity leave, but their effectiveness remains questionable, as highlighted in the literature. This suggests that current policies are inadequate for overcoming structural barriers in graduate education. While growing discussions on the topic are a step forward, the limited scope of existing measures and persistent biases in selection processes remain significant challenges. Engineering, historically marked by low female participation, will only see meaningful change with more comprehensive policies that go beyond maternity leave, addressing disparities in opportunities, access to leadership roles, and the retention of women in research. These findings, although grounded in the Brazilian context, offer insights that may be transferable to other countries facing similar disparities in STEM fields. The structural nature of gender inequality in academia suggests that international dialogue and cooperation are essential to promote more inclusive academic environments globally.

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AN EXPERIENCE REPORT ABOUT THE SUBJECT ENTITLED "WOMEN AND GENDER EQUALITY IN ENGINEERING"

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ABSTRACT

Higher education faces challenges in promoting diversity, reflecting gender and ethnic-racial inequalities in Science, Technology, Engineeringand Mathematics (STEM) , despite access and permanence policies. This paper reports on the experience of the subject entitled “Women and Gender Equality in Engineering”, offered by the School of Civil and Environmental Engineering at the Federal University of Goiás (EECA-UFG), which aims to problematize gender barriers in academia and the job market. Having a dialogical and intersectional pedagogical approach, it encourages active participation and the collective construction of strategies for equity and inclusion. Since it was implemented in 2017, it has attracted students from a wide range of courses, with a prevalence in engineering. The data shows impacts on raising awareness among the academic community, solving problems and qualified debates on gender in higher education and the professional field. Thus, it contributes to mitigating structural inequalities, especially those affecting women pursuing careers in engineering.

Keywords: STEM; higher education; SDG 5; permanence, diversity

INTRODUCTION

The lack of gender, ethnic-racial and class diversity in the areas of Science, Technology, Engineering and Mathematics (STEM) is a challenge that persists, even after advances in inclusion policies and access to public universities in Brazil. According to INEP (2022), female enrolments accounted for around 36% of graduates from engineering, production and construction courses. At the Federal University of Goiás (UFG), in 2025, enrollment in the thirteen engineering courses offered by the institution comprised 31% female students (UFG/ANALISA, 2025). These figures are similar to the world average, since, according to UNESCO (2024), women make up only 28% of engineering graduates. Making an ethnic-racial cut, the participation of women in the Civil, Environmental and Sanitary, Electrical, Mechanical and Computer Engineering courses at UFG was 23%, but only 9% of these women were black (Mascarenha et al., 2021). In the aforementioned courses, there is a significant number of brown students (41.9%), but there is no information on whether they are black or white (UFG/ANALISA, 2024). This lack of information prevents the development of permanence policies for this social group.

Democratization of access to higher education marks a milestone in the struggle for equity waged historically by social movements. However, ensuring a training environment is diverse requires not only inclusion policies, also but a critical-pedagogical stance and effective actions that support student retention and success . In 2017, the Women and Gender Equality in Engineering course was created at the School of Civil and Environmental Engineering (EECA/UFG), involving female staff from EECA/UFG and the School of Electrical, Mechanical and Computer Engineering at UFG (Hora et al., 2019 and Souza et al. 2022). The proposal of this theoretical-pedagogical course, based on seminars, debates, lectures and practical actions at UFG, has contributed to addressing racial and gender-based violence in the engineering training environment. Thus, this text presents an experience report on the “Women and Gender Equality in Engineering” course offered at UFG between 2017-2024 to discuss strategies for dealing with gender oppression in this higher education institution.

MATERIALS AND METHODS

The proposal to create a subject focused on reflections on the social representation of work at EECA emerged in 2017, organized by a group of teachers interested in addressing the demands of female students in the academic environment of engineering. In response to the limitations of traditional training, which often overlooks didactic-pedagogical studies, Alves and Brancher (2020), Dantas (2014), Pena (2018), Pires (2019), Siewerdt and Rausch (2012) and Silva et al. (2021), the subject entitled “Women and Gender Equality in Engineering” was created. This curricular component is open to any student at the Federal University of Goiás (UFG) in the first semester of each year and adopts a pedagogical approach based on the collective construction of knowledge. This methodology aims to challenge the traditional hierarchical model of teaching by fostering a horizontal learning environment in which both teachers and students actively engage in the teaching-learning process.Having a limit of 30 places, the course proposes an interactive and reflective dynamic, using different didactic strategies to deepen the understanding of gender issues in society, focusing on technological and engineering areas. Among the activities developed throughout the semester, the course plan includes:

- Lectures with external guests, who address key issues such as gender relations and women's reproductive rights, women in science and engineering, black feminism, sexual and moral harassment, among others. These meetings provide a direct dialogue with experts and activists, allowing students to broaden their perspectives and connect theoretical content with concrete realities.
- Thematic seminars, in which students choose and present topics related to feminism and gender equality. Several groups are formed, which carry out research on a chosen topic under the supervision of one of the teachers. This activity encourages research, critical debate and the exchanging experiences between participants.
- Final practical action, organized by the students themselves, aiming to encourage a broad reflection within the academic community on the gender inequalities still present in Brazilian society. Actions are proposed by students based on their skills and interests. This activity can take different forms, such as awareness campaigns, artistic interventions, conversation circles or other initiatives that encourage collective engagement.
- Evaluation of the course, in which students and teachers present their impressions of the course, the impact of practical action and suggestions for future classesinformally and without any data collection

Through this active and collaborative methodology, the course aims not only to provide a theoretical foundation on gender issues, but also to encourage students to participate critically and act to build a fairer and more equal society.

RESULTS

Throughout 2017-2024, the subject had an average of 26 students per semester (Figure 1). There has been a reduction in the number of students over the years, which may be related to the rate of permanence and completion in the public and private higher education network in the state of Goiás (24.3%), according to the 15th Map of Higher Education (Semes Institute, 2025). Of the 209 students who have taken the course to date, 171 are women and 38 men (Figure 1).

The students belonged to a wide range of undergraduate courses, but there was a predominance of students from UFG's engineering courses (Figure 2). A fair number of students from Architecture and Urbanism, Nursing and Dentistry attended the course. In addition to these, the subject occasionally extends its activities to other courses in other academic units (Administration, Agronomy, Biotechnology, Law, Ecology and Environmental Analysis, Physical Education, Food Engineering, Production Engineering, Materials Engineering, Transport Engineering, Forestry Engineering, Chemical Engineering, Physics, Geology, Nutrition,

Pedagogy, Psychology, Public Relations and Theater Studies). This breadth of the subject shows the importance of discussing gender in the context of higher education institutions.

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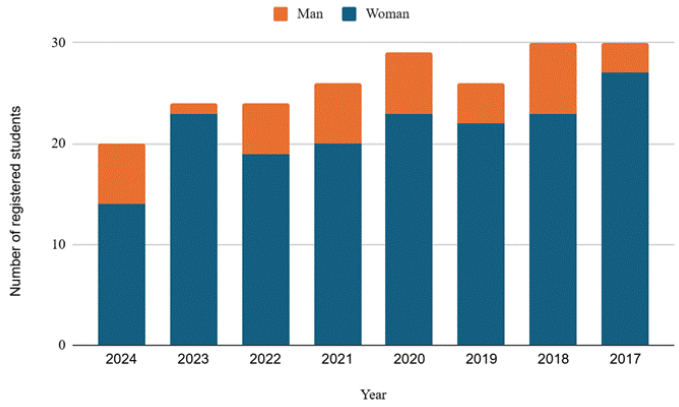

Figure 1 – Number of female and male students who took the subject, by year. Source: authors.

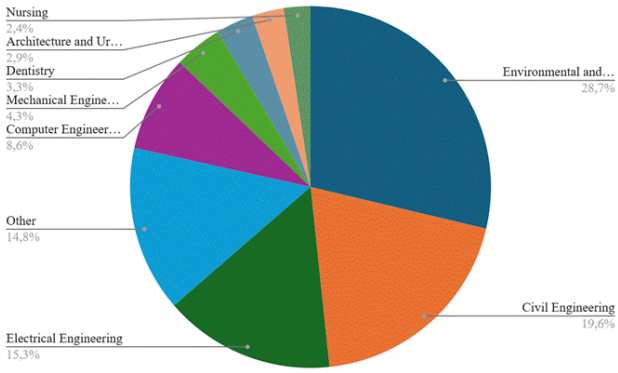

Figure 2 – Courses of the students who took the subject. Source: authors.

Over the years, the subject has left its mark through the various practical actions carried out, such as an exhibition on gender, creating content for Instagram (@meninasengenheirasufg), creating a mural with feminist themes and even building a reception room for mothers. In addition to these milestones, it also has an important legacy, as the last two directors of EECA/UFG (2019-present) were lecturers who taught the subject and one of the administrative technicians collaborating with the subject completed a master's degree in education in the area of gender and race.

From informal conversations at the end of the course, it is clear that the subject broadens students' understanding of gender equality and related topics. In addition, students consider it an important space to discuss topics that permeate their academic experience.

CONCLUSIONS

The “Women and Gender Equality in Engineering” subject highlights the importance of theoretical and practical actions that encourage diversity and equity in engineering courses at UFG. The data shows that there is a clear under-representation of women, especially black, indigenous and *quilombola* women, in the field, which reveals that there are structural problems that impact academic permanence and success. This is a complex and multifaceted challenge that extends beyond access to the university. The pedagogical approach, focusing on dialogism and horizontal interaction, provides a space for critical and in-depth reflection on gender, race and class relations in higher education. The experience report points to the need for effective policies for permanence after inclusion. It therefore corroborates the importance of affirmative action, but also of educational practices that take diversity and social transformation into account. The expansion of initiatives committed to a more just and equitable society is essential for deconstructing hegemonic practices of belonging and citizenship, fostering spaces for full development for all, without distinction, in the exact sciences. Regarding future research, a broad study on the benefits of the subject for EECA-UFG and EMC-UFG is recommended, in addition to a systematic evaluation based on the perception of the students who took it.

ACKNOWLEDGEDMENTS

We would like to thank the School of Civil and Environmental Engineering (EECA) at UFG for supporting the actions taken in the subject since it was created. We would like to thank the Research Support Foundation of the State of Goiás (FAPEG/GO) and the National Council for Scientific and Technological Development (CNPq) for funding the research on gender and the productivity grant for one of the authors.

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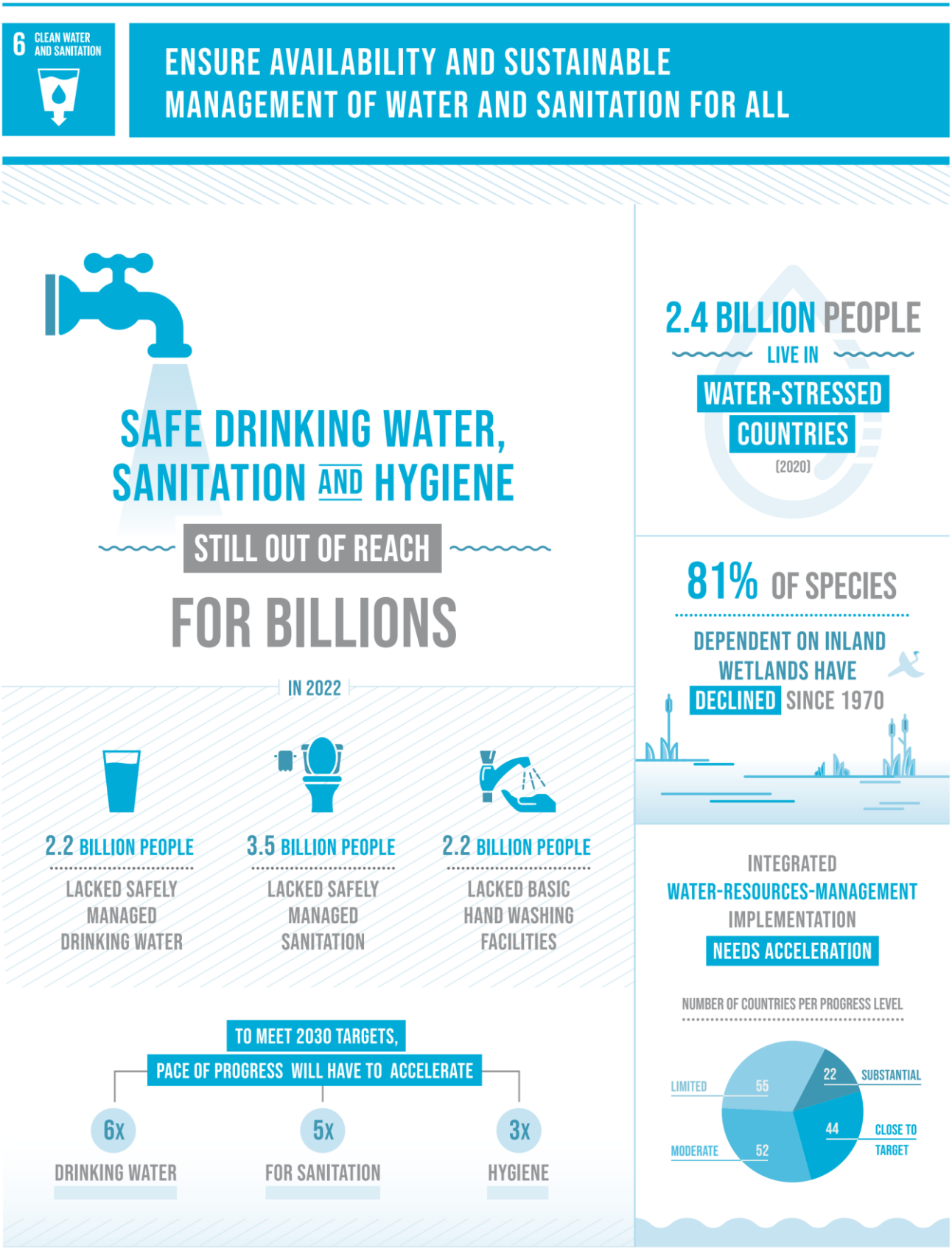
GOAL 6: ENSURE AVAILABILITY AND SUSTAINABLE MANAGEMENT OF WATER AND SANITATION FOR ALL



Source: UN's The Sustainable Development Goals Report 2023 – Special Edition

IDENTIFICATION AND REMOVAL OF BACTERIAL MULTIDRUG RESISTANCE IN WASTEWATER TREATED MICROALGAE

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ABSTRACT

Bacterial multidrug resistance is a global concern aggravated by poor sanitation in Brazil, which favors the spread of antibiotic-resistant bacteria and increases the risk of infections. The aim of this study was to identify the presence of total coliforms and *Escherichia coli* that are multi-resistant to five antibiotics (penicillin, amoxicillin, ceftriaxone, azithromycin and ciprofloxacin) in wastewater from Bauru wastewater treatment plant, treated by a microalga in a high-rate algae pond (HRAP). The bacteria were isolated and subjected to antimicrobial susceptibility testing using the agar diffusion method, following the guidelines of the European Committee on Antimicrobial Susceptibility Testing (EUCAST, 2024) and Clinical and Laboratory Standards Institute (CLSI, 2020). The results showed that both bacteria were resistant to multiple antimicrobials and the HRAP was partially effective in removing the microorganisms.

Keywords: Bacterial multidrug resistance; Basic sanitation; Microalgae photobioreactor; Wastewater; Antibiotics.

INTRODUCTION

Since the beginning of the 20th century, initiatives to increase access to drinking water have been essential in reducing waterborne diseases, marking the beginning of basic sanitation in Brazil and globally [1]. Despite these advances, the lack of adequate effluent treatment has contributed to the degradation of urban water bodies. Today, the country still faces serious challenges in the management and disposal of liquid waste, mainly from urban areas and health institutions [2]. According to the World Health Organization, access to safe water and sanitation services is vital for public health, which reinforces the need for solutions that consider not only the efficiency of treatments, but also the regional, environmental and social aspects involved.

In this context, one of the most worrying effects of ineffective wastewater treatment is the spread of bacterial resistance. Although natural in the evolutionary process, this resistance has been aggravated by anthropogenic factors, such as the excessive use of antimicrobials, population growth and inadequate waste disposal. These elements intensify the selective pressure on bacteria, favoring resistant strains and increasing their genetic diversity. It is estimated that, left unchecked, antimicrobial resistance could cause up to ten million deaths a year by 2050 [3]. Understanding its origins and the factors that drive it is key to containing its spread and reducing the impacts on human health and aquatic ecosystems.

Resistant bacteria such as *Escherichia coli*, *Staphylococcus* spp. and *Enterococcus* spp. are often found in wastewater, even after conventional treatments [4]. The presence of these microorganisms in domestic and hospital effluents represents an environmental and health risk, especially in inefficient treatment systems. Innovative technologies, such as microalgae photobioreactors, are gaining prominence as sustainable alternatives. These systems use microalgae, which through photosynthesis help to remove nutrients, contaminants and stabilize organic matter [5]. However, given the increase in antibiotics and resistant microorganisms in effluents, it is essential to evaluate the effectiveness of these technologies in controlling antimicrobial resistance, as well as investigating the presence and behavior of bacterial multidrug resistance throughout the treatment process.

MATERIALS AND METHODS

The raw wastewater was collected at the entrance to the Bauru Effluent Treatment Plant (WWTP), before any treatment stage. During the period from August to September 2024, 10 samples (210 liters) were collected, stored under sterile conditions and transported to the laboratory [6] for subsequent microbiological and physicochemical analysis. The samples were used to feed a HRAP (High-Rate Algal Pond) system made of fiberglass (125 cm × 60 cm × 40 cm, operating volume 150 L), maintained under controlled temperature and lighting conditions. An inoculum of microalgae, corresponding to 10% of the pond's volume (15 L), was added to the wastewater. The performance of the photobioreactor was monitored through daily analyses of dissolved oxygen, pH, temperature, turbidity, chemical oxygen demand (COD), total nitrogen, total phosphorus and total suspended solids (TSS).

For the isolation and identification of resistant bacteria, the samples were cultured on specific selective media: HiCrome Chromogenic Coliform Agar for *Escherichia coli* and total coliforms. Sowing was carried out using techniques such as Pour Plate and membrane filtration, depending on the target bacteria. After incubation, the colonies were transferred to Mueller-Hinton Agar culture medium, used for antibiotic sensitivity tests.

Bacterial resistance was assessed using the agar disc diffusion method, following the guidelines of EUCAST (2024) and CLSI (2020). The isolated bacteria were exposed to disks impregnated with selected antibiotics. After incubation at 35°C for 16 to 18 hours, resistance was determined by measuring the inhibition halos around the discs and comparing the results with the standardized values in the reference manuals.

RESULTS

The data on the physicochemical parameters monitored during the study are in line with the characteristics of sewage treatment by HRAP (Table 1). There was an average removal of total coliforms of 94% and 0.50 log, and *E.coli* = 67% and -3.07 log, which corroborates the results of preliminary studies [7] [8]. The results of the monitored data for each parameter with the mean and standard deviation for the HRAP pond are shown in Table 1.

Table 1 - Mean and standard deviation of the physical and chemical parameters of the HRAP.

Parameter	Unit	Average±standard deviation
Liquid temperature	°C	27.6±2.7
Luminous intensity	µmol m^{-2} s^{-1}	501.24±149.34
pH	-	8.4±1.2
DO	mg L^{-1}	10.3±2.9
Turbidity	NTU	148.5±13.2
TSS	mg L^{-1}	257.4±1.7
COD	mg L^{-1}	131.98±79.46
Total phosphorus	mg L^{-1}	45.10±2.30
Total nitrogen	mg L^{-1}	10.55±6.01

DO: dissolved oxygen; TSS: total suspended solids; COD: chemical oxygen demand.

Figures 1 and 2 show the antibiotic sensitivity results for the total coliform and *Escherichia coli* isolates. As can be seen from the total coliform results, it can be seen that the isolates for penicillin and amoxicillin with 100% resistance are ineffective when compared to azithromycin, which showed sensitivity of 80%, and the other antibiotics - ceftriaxone and ciprofloxacin - also showed an antibacterial profile. The most apparent case of antibiotic ineffectiveness can be seen for *Escherichia coli* when the isolates were tested for the antibiotics

most commonly used among individuals, such as penicillin, amoxicillin and ciprofloxacin, as 100% showed resistance to these antimicrobials, which demonstrates multidrug resistance. These bacterial isolates are considered multidrug-resistant according to CLSI (2020) and WHO (2019) because they are resistant to more than one antibiotic. Similar studies in Brazil have reported similar results for *E. coli* isolates in HRAP pond sludge samples [9].

Figures 1 and 2 - Resistance profile (frequency) of total Coliforms and *E. coli* to antimicrobials of clinical origin collected for analysis of the antibiotic sensitivity test. PEN, Penicillin; AMO, Amoxicillin; CRO, Ceftriaxone; CIP, Ciprofloxacin; AZI, Azithromycin;

CONCLUSIONS

The results indicate that the microalgae photobioreactor operated efficiently, guaranteeing significant removal of pathogens and maintaining the appropriate physicochemical parameters. Therefore, the presence of multidrug-resistant bacterial isolates reinforces the need for continuous monitoring and strategies to mitigate the spread of antimicrobial resistance in the environment.

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VARIATION IN THE WATER QUALITY OF AN URBAN RIVER USED FOR THE DILUTION AND TRANSPORTATION OF WASTEWATER

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ABSTRACT

Urban rivers are intensely modified and impacted by urbanization and population growth. Monitoring the quality of surface water in urban areas is a strategic tool for managing and ensuring water security. The Bauru River is an important river in the Brazilian city of Bauru and is used intensively to dilute domestic and industrial effluents. The monitoring of 9 water quality parameters (pH, temperature, turbidity, conductivity, dissolved oxygen, biological oxidation demand, total nitrogen, total phosphorus, total coliforms and total residues) and the calculation of a Water Quality Index (WQI) at 12 points in the river basin over a period of one year made it possible to find out which watercourses are most affected (Água Comprida and Vargem Limpa Streams) and how the parameters correlate with each other (turbidity and total coliforms; temperature and biochemical oxygen demand) ($p<0.001$).

Keywords: Urban river; Water quality; Sanitation; Sewage.

INTRODUCTION

Currently, around 55% of the population resides in urban areas, and by 2050, 2.5 billion people could be added to these areas, due to the increased urbanization and population growth [1]. In addition to the growing demand for water in urban areas, climate change could impose a decrease in water availability, exposing populations to water scarcity [2]. Superficial water bodies in urban areas are utilized in different manners such as tourism, recreation, water supply and also as outlets for wastewater discharge, which may cause contamination by pathogens, heavy metals and other polluting substances. Thus, other than environmental issues, the presence of contaminated urban rivers can impose a threat to communities and disruption in public health systems, due to the higher probability of diarrhoeal diseases and cancer diagnosis, related to the presence of pathogens and heavy metals on water [3]. In order to describe and understand the process of degradation and recovery of an urban river (Bauru River, São Paulo, Brazil) intensely contaminated with domestic and industrial wastewater, ten physico-chemical parameters (pH, temperature, turbidity, conductivity, dissolved oxygen, biological oxidation demand, total nitrogen, total phosphorus, total coliforms and total residues) were monitored and a water quality index was calculated. The aim was to provide a theoretical framework for the planning and management of intensely impacted urban rivers.

MATERIALS AND METHODS

STUDY AREA

The municipality of Bauru is located in the state of São Paulo/Brazil and is part of the Tietê/Batalha and Tietê/Jacaré river basins. The urban area is almost entirely within the Tiete/Jacaré river basin and is permeated by the headwaters and tributaries of the Bauru River, which cuts through the entire urban area of the city.. It has an area of 667.684 km² and a population of 381,706 inhabitants, resulting in a population density of 570 inhabitants/km² [4]. The urban population accounts for 98% of the total population. Only 4% of the municipality's population has access to domestic sewage collection and treatment. The amount of

untreated effluent in the municipality is discharged into surface waters, significantly impacting the Bauru River and downstream rivers.. The low quality of the Bauru River's water is reflected in its classification according to Brazilian regulations - Class 4. Water of this class can only be used when there is no direct contact: navigation and landscape harmony, with use for supply, recreation and irrigation being vetoed. Twelve monitoring points were chosen along the Bauru River, including tributary rivers and points of interest due to intense use and occupation. The location of the points can be seen in Figure 1.

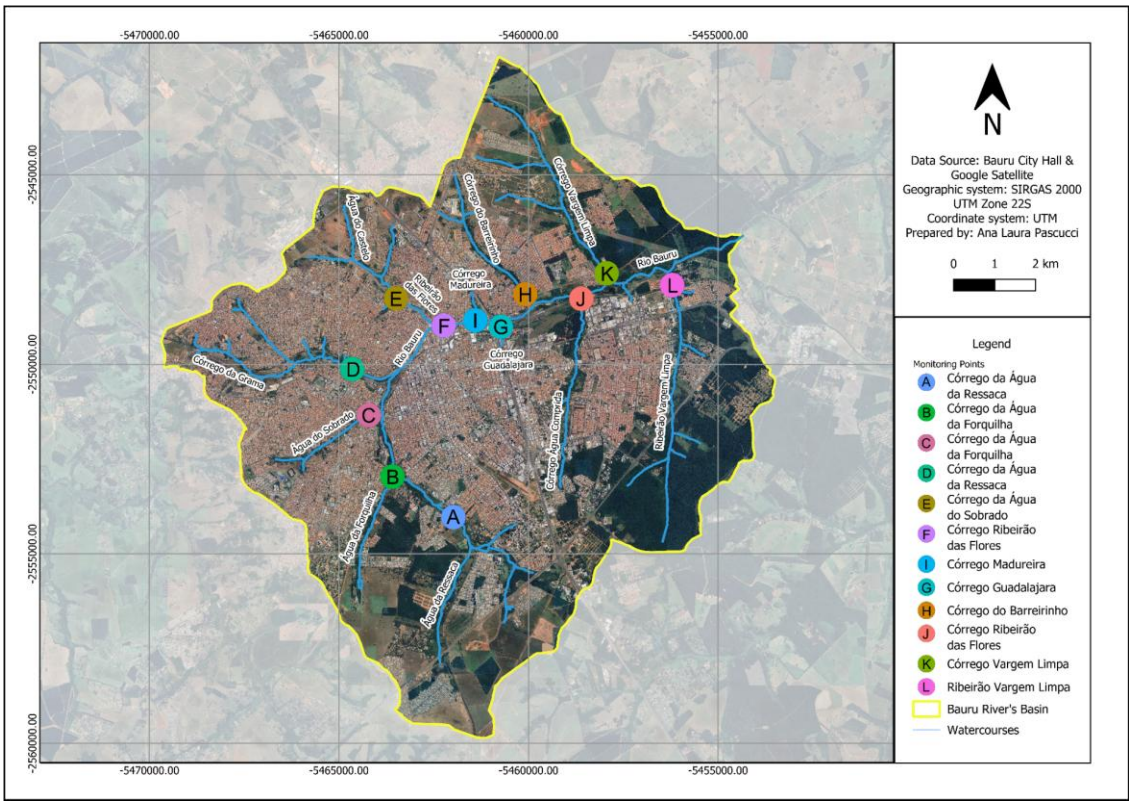

Figure 1 – Bauru River Basin in São Paulo Brazil and the 12 monitoring points.

SOURCE AND COLLECTION OF DATA

Data from one year (from February 2024 to January 2025) of monitoring the Bauru River and tributaries was obtained from the Pappa Waters Project (Projeto Pappa Águas - https://www.pappa-aguas.fundato.org.br/). This project is coordinated by the Toledo Teaching Institution (ITE) and the Toledo Foundation (FUNDATO) and supported by the São Paulo State University “Júlio de Mesquita Filho” through a Public Notice 507/2022 of the Bauru City Council. All the monitoring data is available for public access on the website: https://www.pappa-aguas.fundato.org.br/ [5]. The project conducted monthly collections of 12 monitoring points (Figure 1) determining the following parameters: pH, Turbidity (NTU), River Temperature (Temp) (◦C), Conductivity (Sm-1), Dissolved Oxygen (OD)(mg DO L−1) , Total Coliforms (TC) (UFC 100mL-1), Biochemical Oxygen Demand (BOD) (mg DO L−1) Total Phosphorus (TP) (mg P L-1), Total Nitrogen (TN) (mgN L-1) and Total Residue (TR) (g L-1) . Water Quality Index (WQI) data was also obtained from the project website, calculated according to the São Paulo State Environmental Company (CETESB) [6].

STATISTICS

The normality of each parameter was determined using the Shapiro-Wilk test and the correlation between the parameters was determined using the Pearson or Spearman test. All the tests were processed using Microsoft Excel® 2021 with Real Statistics Resource Pack Software (Release 7.6) [7,8]and R® with the package Hmisc [8,9f]

RESULTS

WATER QUALITY INDEX AND PARAMETERS CORRELATION

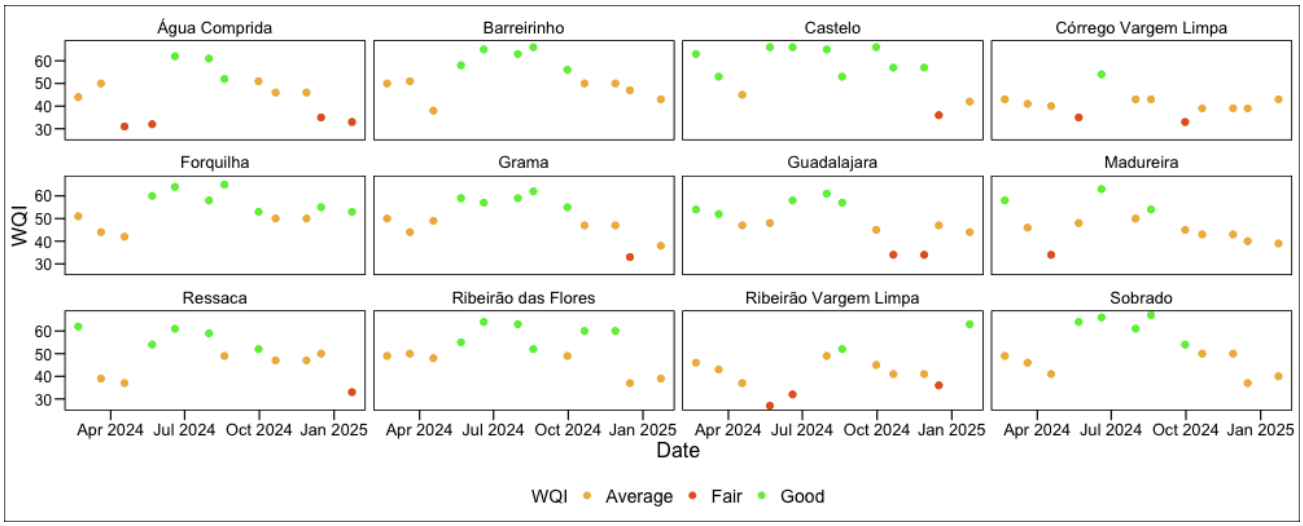

Figure 2 – Water Quality Index (WQI) values for the 12 monitoring points in the Bauru River basin.

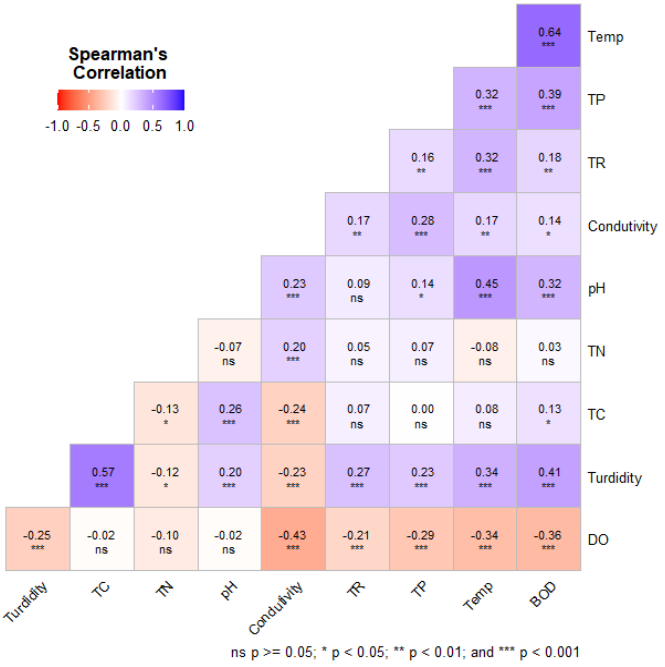

Figure 3 – Spearman's correlation between parameters monitored in the Bauru River. DO: Dissolved Oxygen; TC: Total Coliforms; TN: Total Nitrogen; TP: Total Phosphorus; TR: Total Residue; Temp: River Temperature, Conductivity, Turbidity and pH.

The WQI of the Bauru River and its tributaries was good, average and poor (Figure 2). The rivers with poor quality (WQI<50) were: Água Comprida and Vargem Limpa streams, the first stream having an intensely occupied catchment area and the second receiving a high load of domestic effluents. There are no previous records of water quality determinations in the Bauru River basin. In the Basic Sanitation Plan for the Municipality of Bauru, Product 3 [10], data is presented only for the main rivers that receive domestic sewage (mainly the Água Comprida River and the Bauru River) and the efficiencies of the municipality's treatment plants, which still contribute to the degradation of surface water quality. Other Brazilian urban rivers present similar realities, such as Ribeiro Ubá in the state of Minas Gerais and Ribeirão Jardim in the state of São Paulo,

with a high rate of domestic and industrial sewage along their course, with poor water quality, making all other uses of the river unfeasible [11,12].

Recent studies have identified monitoring and correlation between surface water quality variables as important tools for managing and managing water resources, making it possible to: *i.* identify the most critical points, where wastewater treatment systems and land use and occupation control should be improved; *ii.* control and prevent environmental degradation events; and *iii.* expand regulatory norms [13].

Spearman's correlation test showed a significant and strong correlation between urbanization and the concentration of total coliforms and temperature and biochemical oxygen demand. The average TC concentration in the watershed was 2.15 1.72, indicating contamination by domestic effluents throughout its length (Figure 3).

CONCLUSIONS

In this study, the variation of the WQI and the determination of the correlation of 9 water quality parameters were determined for the Bauru River Basin. One year of monitoring made it possible to determine seasonal variations and the main watercourses impacted. In addition, a strong correlation was observed between parameters such as turbidity and total coliform concentration, reinforcing the fact that easily monitored parameters such as turbidity can be used to easily and quickly monitor and indicate the quality of surface waters in urban areas.

ACKNOWLEDGEDMENTS

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DECENTRALIZED SANITATION FOR SOCIAL EQUITY AND ENVIRONMENTAL JUSTICE IN INFORMAL SETTLEMENTS

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ABSTRACT

Poverty represents a multidimensional challenge encompassing inadequate living conditions and limited access to basic services. In Brazil's informal settlements, marginalized populations - particularly women, ethnic minorities, and low-income residents - face disproportionate sanitation deficiencies that exacerbate health risks and economic vulnerabilities. For this case, traditional centralized systems remain impractical due to high costs and infrastructure demands. This study proposes a nature-based decentralized wastewater treatment system (DEWATS) integrating septic tanks and constructed wetlands to address these challenges. Beyond technical performance, the model emphasizes social equity through gender-inclusive training programs and community-led maintenance structures. Environmental benefits include pollution reduction and urban greening in densely populated favelas. The proposal contributes to ongoing policy discussions around Brazil's National Sanitation Plan and offer transferable insights for similar contexts in the Global South.

Keywords: Decentralized wastewater treatment system; gender equality; wastewater treatment; favelas.

INTRODUCTION

The global sanitation crisis remains one of the most pressing challenges of our time, with approximately 60% of the world's population lacking access to safely managed sanitation services [1]. This deficit disproportionately affects vulnerable groups, including women, low-income populations, and ethnic minorities living in informal settlements, where inadequate sanitation perpetuates cycles of poverty, gender inequality, and public health crises [2], [3]. In Brazil, rapid urbanization has led to the proliferation of favelas - densely populated informal settlements where conventional sanitation infrastructure proves economically and technically unfeasible due to topographic constraints and land tenure issues [4], [5].

This study focuses on a hybrid decentralized system that combines septic tanks and constructed wetlands to simultaneously address technical, social and environmental challenges. Beyond technical efficacy, the solution creates tangible social impact through gender-inclusive employment opportunities generated by community training programs in system maintenance and operation. Environmentally, the nature-based approach provides dual benefits: constructed wetlands not only treat wastewater effectively but also enhance urban green spaces.

By bridging the gap between engineering innovation and social empowerment, this approach offers a replicable model for achieving Sustainable Development Goals 6 (clean water and sanitation) and 11 (sustainable cities) in informal settlements worldwide.

MATERIALS AND METHODS

DEWATS PROPOSED TECHNOLOGIES

For system design parameters, the target area was defined as informal settlements in Brazilian urban areas, using São Paulo as a case study. Each module of the proposed system was designed to serve up to 30

residents. While this configuration was optimized for local conditions, the technology remains adaptable for implementation in other global communities through modular replication or scaling.

SEPTIC TANKS

Septic tanks are simple, decentralized wastewater treatment systems particularly suitable for areas lacking conventional sewage networks [6]. They require post-treatment and present some limitations like occasional odors and incomplete nutrient removal [6], [7]. Despite these constraints, their operational simplicity and adaptability have enabled important innovations in developing contexts. A notable example is Brazil's Basic Rural Sanitation System, which integrates septic tanks with subsequent biofiltration and chlorination stages to create a complete, low-maintenance treatment [6] –[9].

CONSTRUCTED WETLANDS

Constructed Wetlands (CWs) are recognized nature-based solutions (NbS) that effectively treat wastewater through natural processes with minimal operational requirements [10]. These systems are classified into subsurface flow (SF) and free water surface flow types, with SF-CWs being particularly advantageous for urban applications due to reduced odor emissions and insect proliferation [11].

COMMUNITARY MANAGEMENT IN SLUMS

In many slums in São Paulo the population is already organized in groups for communitary management so called as Residents' Associations (RA) with a corresponding Community Leader (CL). The idea is to take advantage and improve such existing structures, making them more inclusive.

RESULTS

PROPOSED SYSTEM

The lack of adequate sanitation in informal settlements exacerbates poverty and inequality, a persistent challenge in urban centers worldwide. DEWATS can provide a viable solution by combining affordability, technical efficiency, and community participation. The proposed system (Figure 1) integrates septic tanks with CWs, creating a compact, low-cost solution that is simple to install and operate.

Successful implementation depends on several community conditions: (1) urban location with tropical climate, (2) existing wastewater collection points, (3) available space, and (4) established organizational structures (particularly residents' and women's associations). While these factors optimize performance, their absence only requires system adjustments rather than preventing implementation.

Key to the system is its emphasis on community ownership, with local residents trained in both construction and maintenance to ensure long-term sustainability. This approach not only addresses critical sanitation needs but also empowers marginalized populations through direct engagement. Initial implementation focused on São Paulo's informal settlements, but the technology's modular design allows for global application in similar underserved communities.

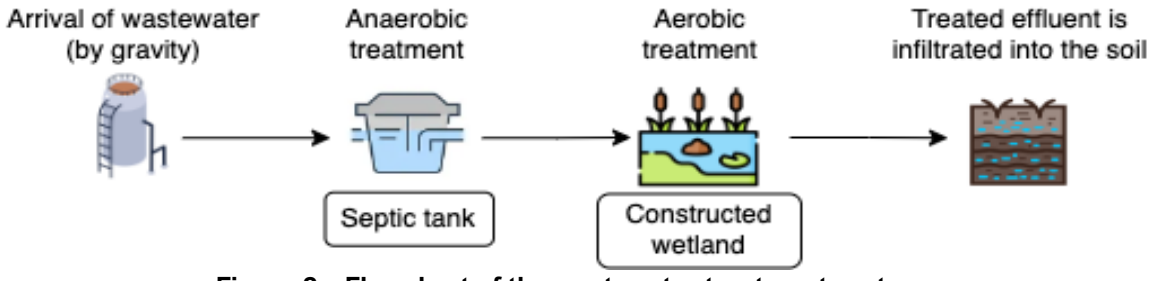

Figure 2 – Flowchart of the wastewater treatment system.

BEYOND TECHNICALITIES, REDUCING GENDER AND RACIAL DISPARITIES

The proposed system serves not just as sanitation technology but as a tool for social organization, environmental education, and reduction of gender and racial disparities while creating jobs. It incorporates Nature-based Solution (NbS) principles of inclusive, transparent governance through collaborative planning and implementation. The approach follows a human rights-based framework that actively involves historically marginalized groups in decision-making [1].

Successful implementation requires respecting each community's unique needs. Resident involvement in all stages ensures project viability while transforming perceptions of women's roles, where CL and RA will determine optimal system locations and assign roles through two working groups: one for construction/implementation and another for operation/maintenance, prioritizing women and non-white residents. When communities understand and exercise their rights through participatory decision-making, they can better ensure their needs are met, especially for vulnerable groups [1].

The project's success depends on both technical design and community training. An environmental education program will include: (1) seminars on system importance, function, and wastewater treatment concepts; and (2) Technical training for operations staff.

Experts will initially lead workshops for RA members, who will then train others. As trained personnel gain experience and potentially move to other jobs, new community members will fill their roles, creating a sustainable cycle of education and employment.

ADAPTATION FOR OTHER REALITIES

For the implementation of the proposed system some minimum requirements were acknowledged. To facilitate the process, a checklist that summarizes the main items needed is presented, and that must be applied to each community. However, the absence of one or more items does not imply the impossibility of implementing the project, and it only means that that requirement must be developed before the execution of the system itself or that the project must be adapted to the specific conditions of the community, with small modifications.

Informal settlement characteristics – Checklist including Community located in urbanized area, Location with humid tropical climate (or similar), Absence or deficit of wastewater treatment system, Existence of wastewater collection pipes in dwellings, Availability of enough area for system implementation, Existence of a residents' association, Existence of community women's organization

CONCLUSIONS

To ensure the proper functioning of the installed system, periodic maintenance and proper operation must be performed. The objective of this project is to ensure community involvement in the entire wastewater treatment process, from its construction to its maintenance. Therefore, the idealized system is simple to implement and operate, and the local residents, after simple technical training, are able to build and operate it.

ACKNOWLEDGEDMENTS

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METHODOLOGIES FOR MONITORING THE GROUNDWATER AQUIFER IN SOLID WASTE DISPOSAL AREAS: A SYSTEMATIC REVIEW

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ABSTRACT

Solid waste generation is inevitable due to consumption habits and short-lived products, with expected growth in coming decades. While proper waste management is essential to protect human health and the environment, inadequate disposal at waste disposal sites risks soil, air, and groundwater contamination—primarily through leachate. Monitoring groundwater near such sites is critical to detect and address pollution. A systematic review of nine studies identified Principal Component Analysis, Cluster Analysis, electrical resistivity tomography, and artificial sweeteners as contamination markers as the most frequently used techniques. Combining these approaches provides a deeper understanding of contamination patterns and supports better mitigation strategies. The findings underscore the need for tailored solutions and innovation in monitoring to safeguard groundwater resources globally.

Keywords: Groundwater contamination; Waste disposal sites; Environmental Monitoring; Landfill.

INTRODUCTION

The generation of solid waste is an inevitable consequence of consumption practices and the existence of short-lived products, with a projected increase in coming decades. The manner in which waste disposal is conducted can result in harmful impacts to society and the environment, such as soils, air and water contamination. Groundwater contamination occurs predominantly through leachate percolation, a liquid effluent resulting from the decomposition of organic waste components. This reality makes groundwater monitoring essential for assessing spatial water quality distribution relative to potential point sources of contamination, dispersion mechanisms, and vulnerable receptors [1]. Globally, monitoring wells remain the primary investigative tool mandated by environmental agencies for continuous groundwater contamination assessment [2]. Given the critical importance of groundwater monitoring near waste disposal sites for environmental protection, this study systematically examines current techniques for aquifer contamination assessment, with particular attention to their scientific basis and practical applications in different methodologies and contexts.

MATERIALS AND METHODS

STUDIES SELECTION

This study conducted a systematic review of scientific articles from the Scopus platform. With the objective of identifying and analyzing methodologies for groundwater monitoring in waste disposal sites, the following keywords were selected for the search: "landfill", "groundwater" and "monitoring" (String: “landfill AND groundwater AND monitoring"). The article selection criteria included only: peer-reviewed research articles, publications from 2014 to 2024 and english or portuguese language articles.

ANALYTICAL FRAMEWORK

The Bibliometrix package in RStudio was used to analyze the research data [3]. Studies were selected based on the recurrent application of similar methodologies. To refine the results, the Keywords Plus "plume" and

"environmental monitoring" were included. Articles unrelated to the topic were excluded according to inclusion and exclusion criteria, disregarding studies not related to aquifer monitoring and review articles. The most frequent themes were identified, and their corresponding articles were analyzed.

RESULTS

SELECTED STUDIES: OVERVIEW

The search in the Scopus database, using the selected keywords, resulted in 461 articles, which were narrowed down to 49 with the addition of the Keyword Plus. Using the Bibliometrix package, the countries of origin of the studies were analyzed, highlighting China, India, the United States, and Brazil, since most of the studies originate from countries that are also among the largest producers of solid waste. The most recurrent themes among the 49 articles involved: Principal Component Analysis (PCA) and Cluster Analysis (CA); Electrical Resistivity Tomography (ERT) and Artificial Sweeteners.

Table 1 – Selected articles and respective countries of origin. Source: authors.

References	Theme	Authors	Date	Country
[4]	PCA e CA	Djogo, A., *et al.*	2017	Serbia
[5]	PCA e CA	Zhang, X., *et al.*	2023	China
[6]	PCA e CA	Yadav, S., *et al.*	2023	Índia
[7]	Resistivity	Ling, X., & Zhang, W.	2019	China
[8]	Resistivity	Helene, L., Moreira, R., & Bovi, R.	2020	Brazil
[9]	Resistivity	De Borba, D. D., *et al.*	2022	Brazil
[10]	Sweeteners	Roy, J. W., Van Stempvoort, D. R., & Bickerton, G.	2014	Canada
[11]	Sweeteners	Stefania, P., *et al.*	2019	Italy, Switzerland
[12]	Sweeteners	Propp, R. J., *et al.*	2022	Canada

SYNTHESIS OF KEY THEMES

PRINCIPAL COMPONENT ANALYSIS AND CLUSTER ANALYSIS

The three studies investigated groundwater contamination in areas impacted by the disposal of municipal solid waste (MSW), employing multivariate statistical techniques, specifically Principal Component Analysis (PCA) and Cluster Analysis (CA). Djogo *et al.* [4] applied these methods to physicochemical data from leachate and groundwater samples, aiming to identify potential sources of pollution at an uncontrolled landfill site in Serbia. Zhang *et al.* [5] conducted a statistical comparison across five open dumping sites — two receiving exclusively MSW and three that also accepted industrial waste — to assess the impacts of co-disposal practices. Yadav *et al.* [6] analyzed groundwater samples collected near an uncontrolled municipal landfill in Bandhwari, India, and, through the application of PCA and CA, identified zones of high, medium, and low contamination associated with inadequate management of MSW leachate.

All three studies share the objective of improving groundwater monitoring programs in areas impacted by waste disposal, using multivariate analyses to identify the most significant parameters for pollutant detection. However, each study adopted specific approaches: Djogo *et al.* [7] focused on identifying potential pollution sources; Zhang *et al.* [8] aimed to comparatively assess the effects of co-disposing industrial and municipal waste; and Yadav *et al.* [9] prioritized the spatial identification of contamination areas at varying levels.

ELECTRICAL RESISTIVITY TOMOGRAPHY

The studies applied electrical resistivity tomography (ERT) to identify contamination plumes in waste disposal sites. Ling and Zhang [7] observed leachate plume movement in saturated surface sediments, indicating groundwater quality degradation up to 500 meters downstream from the Chang'an landfill in China. Helene, Moreira, and Bovi [8] monitored a waste cell in Brazil for three years, detecting leachate percolation beneath the geomembrane and a gradual increase in resistivity, linked to changes in leachate production and dispersion. Similarly, Borba *et al.* [9] identified resistivity anomalies in a landfill in Rio Grande do Sul, Brazil, revealing contamination in the lower areas of the site, near cells lacking geomembrane lining, suggesting leachate infiltration.

All three studies confirmed the effectiveness of ERT in identifying and monitoring leachate contamination in landfills. Despite methodological differences, they emphasized that ERT, especially when combined with chemical analyses, is a valuable tool for mapping contaminated areas.

ARTIFICIAL SWEETENERS

The articles on artificial sweeteners investigate the use of these compounds as markers of contamination in groundwater in waste disposal areas. Roy *et al.* [10] conducted a study at 15 landfills in Canada, detecting the presence of sweeteners even in sites that had been deactivated for decades. In older landfills (pre-1990), saccharin was predominant, while acesulfame was more commonly detected in more recent landfills. Stefania *et al.* [11] used artificial sweeteners as chemical tracers to identify sources of groundwater pollution from a sanitary landfill of household and sewage waste in Italy, located downstream from an old unlined landfill. The analysis suggested that the leachates in the area originated from two main sources: one associated with a leachate spill from the lined landfill's collection system, and the other originating from the old unlined landfill. Propp *et al.* [12] conducted a study in the urban creek region of Barrie, Ontario (Canada), adjacent to three historical landfills that lacked a leachate collection system, aiming to distinguish areas contaminated by leachates from historical landfills or by residual waters. The use of this set of artificial sweeteners proved effective in assessing the impact of leachates on groundwater affected by sources from historical landfills, evidenced by significant concentrations of saccharin and cyclamate.

These three studies demonstrate the effectiveness of artificial sweeteners as markers for monitoring and tracking groundwater contamination from landfill leachates. While they share the use of advanced detection and analysis methods, the differences in geographical, historical, and methodological contexts highlight the versatility of these markers in environmental investigations. Each study provides insights into the persistence of contaminants, flow dynamics, and the importance of multi-methodological approaches to understanding the complexity of groundwater contamination associated with waste disposal areas.

CONCLUSIONS AND FUTURE DIRECTIONS

The systematic review of recurring topics related to aquifer contamination monitoring proved essential for understanding the distribution of studies worldwide and highlighting the need for a broader expansion of the subject on a global scale. In general, the methodologies of the analyzed articles combined the main themes with sample collection and characterization of water parameters, demonstrating the indispensability of monitoring using wells. Furthermore, the analysis of the nine studies revealed a diversity of approaches and contexts for which the methods were proposed, even among those grouped for applying similar methodologies. It was also evident that a range of methodological approaches was integrated into studies monitoring contamination in aquifers of waste disposal areas, with the aim of understanding the complexity of groundwater pollution. Finally, the importance of these studies is emphasized, not only for expanding

scientific knowledge in the field but also for the implementation of effective strategies for managing and mitigating environmental and public health impacts, thus ensuring the protection of water resources at landfill sites and the well-being of surrounding populations affected.

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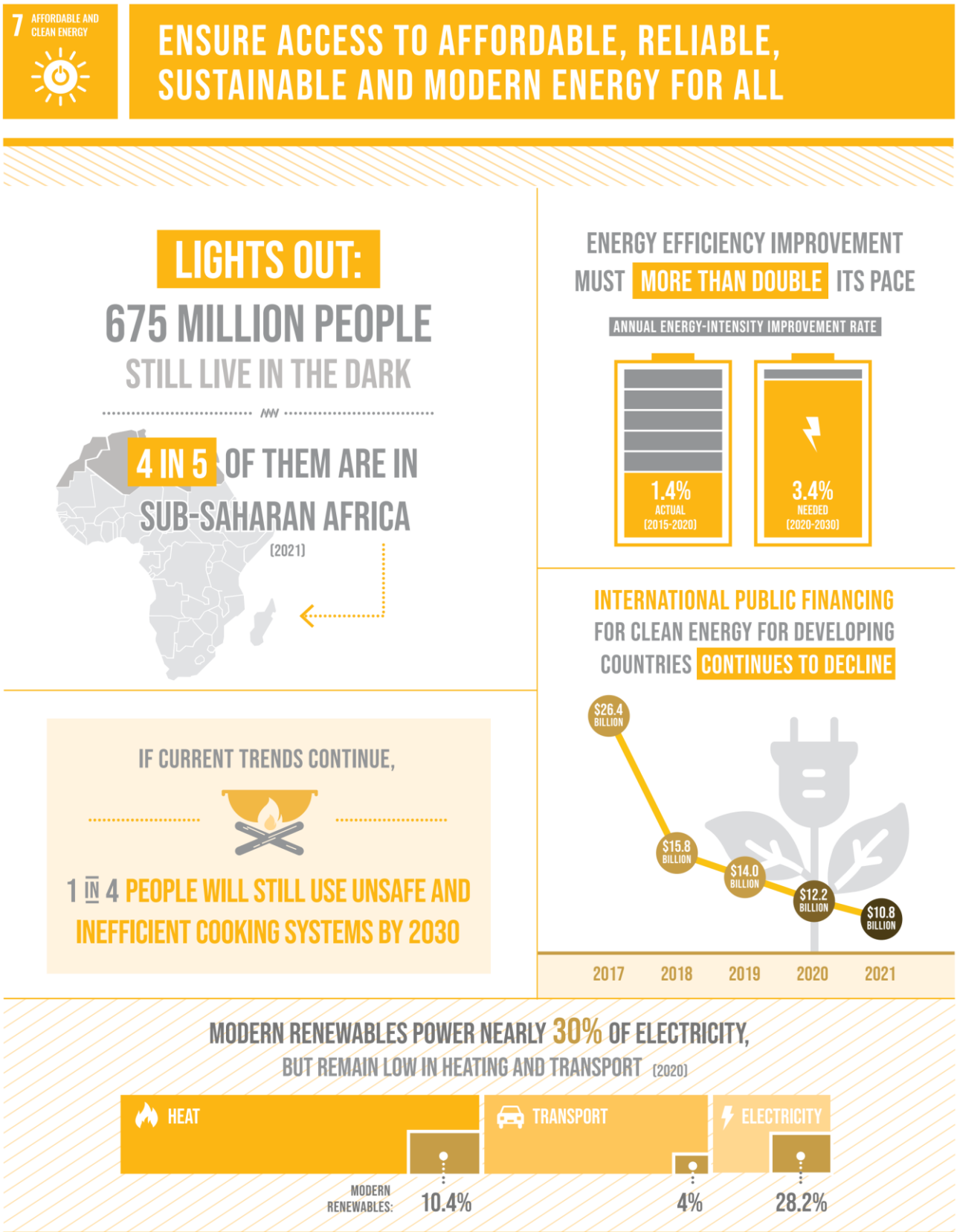
GOAL 7: ENSURE ACCESS TO AFFORDABLE, RELIABLE, SUSTAINABLE, AND MODERN ENERGY FOR ALL



Source: UN's The Sustainable Development Goals Report 2023 – Special Edition

ANALYSIS OF THE DR. CONGO ELECTRIFICATION SCENARIO FOR THE REDUCTION OF WOOD ENERGY IN THE ENERGY BALANCE USING MAED

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ABSTRACT

Energy planning is a crucial tool for analyzing the energy future of countries. In the Democratic Republic of Congo (DRC), energy demand is rising amidst challenges like wood fuel dominance, economic growth, and environmental concerns. This study uses the Modeling Analysis Energy Demand (MAED) to explore electrification's potential in reducing wood energy use by 2050. It focuses on integrating household electrification and renewable energy, particularly hydroelectricity, to meet growing demands while minimizing environmental impacts. The methodology involves selecting a modeling tool, establishing a reference year, and projecting demand. Results indicate that achieving 100% electrification in urban areas and 40% in rural areas could significantly reduce wood energy dependence under 60% and avoid up to 1,640 Mt CO_2 emissions by 2050, aligning with Sustainable Development Goals and climate commitments. Electrification could help decarbonize the DRC's energy balance and alleviate forest pressure.

Keywords: Energy planning, DRC's electrification, MAED, CO_2 emissions, energy transition.

INTRODUCTION

Like most developing countries, the DRC is faced with the problem of growing demand and consumption of energy in all its forms. The issue of energy in the DRC is set against a backdrop of other realities facing the country: the predominance of wood fuels, the 520 dynamic of economic growth seen in recent years, structural changes, liberalization of the electricity sector, demographic dynamics, the reduction of deforestation and climate change, poverty and inequality, and so on. This explains the fact that the DRC ranks 131st in terms of energy consumption in Africa, with an equivalent use of 389.33 kg of oil per capita. Biomass is the main energy source in the country, and 94% of basic energy consumption is based on biomass (charcoal and firewood) [1]. Electricity therefore represents a small share of total energy use, even though the hydropower potential of the country is around 90,000 MW spread over 575 sites and represents around 13% of the world's potential [2]. Electricity consumption is dominated by the industrial sector, concentrated in the southern part of the country where the mining industry is booming. To meet all these challenges, the country needs a substantial supply of energy. The next revisions of the National Energy Policy (NEP) [3], as well as the implementation of sectoral strategies within the framework of the Long-Term Strategy, will require solid energy planning tools. Energy system simulation models are widely regarded as effective tools for supporting governments and decision-makers in the design of long-term decarbonization policies.

MATERIALS AND METHODS

DESCRIPTION OF MAED

The MAED tool is designed to provide a systematic framework for mapping trends and anticipating changes in energy requirements in different economic sectors and consumer activities [4]. It allows energy consumption patterns to be disaggregated using country-specific representation, which can help identify the most promising energy efficiency options and support the development of sustainable energy policies and

programs [4]. The MAED uses a set of corresponding equations (Eq.1) and (Eq.2) to calculate energy consumption by each end-use group [4]. These equations, which all have the same form, are used to perform this calculation. The Energy Demand (ED) for a specific year in the future is evaluated by multiplying the driving factor for that future year by the Specific Energy Consumption (SEC), using the unit Driving Factor (DF) or the Energy Intensity (EI) for future years. Energy demand in year t is given by :

$$\boldsymbol{ED_t = SEC_t * DF_t} \qquad \text{(Eq.1)}$$
$$\boldsymbol{ED_t = SEC_t * GDP_t} \qquad \text{(Eq.2)}$$

One of the driving forces behind this model is the changing structure of the Gross Domestic Product (GDP) formation. The structure of total GDP by sector, expressed as a percentage of the contribution of each sector's value added to GDP formation, is specified directly as a scenario parameter. The final energy demand (Eq. 3) of a specific energy source is given by the product of the inverse of the efficiency of the process (output) where the energy is used, the market penetration of the given type of energy source and the final useful energy demand. To carry out a deep analysis of energy demand trajectories, it is necessary to consider the evolution of socio-economic factors, in particular GDP and population growth, identified as the main drivers of future energy demand.

$$ED_{final} = \frac{1}{efficiency} * Market\ penetration * ED_{used} \qquad \text{(Eq. 3)}$$

The MAED tool has found application in several developing countries, including Nepal [5], Nigeria, Tanzania, etc. Its use has made it possible to explore and anticipate trends in energy consumption across different economic sectors and according to various scenarios. To model energy demand for DRC up to 2050, we used a 3-step methodology: (i) Energy consumption in the reference year; (ii) Drawing up economic, social and technological development scenarios; (iii) and Analysis of scenario-based energy demand projections. The scenario developed determines an energy trajectory which is compared with the reference energy policy currently applied.

KEY ASSUMPTIONS

The year 2018 is taken as a reference because it is the last year for which a complete, reliable and disaggregated national energy balance sheet is available. Subsequent years show significant gaps in sector coverage and data quality. The energy intensities used in the modeling are taken from the DRC's 2018 energy balance [6]. The aggregated information in this balance has been disaggregated using potential sources such as the Central Bank of Congo (BCC), and other sources. The study modelled two scenarios: the Business As Usual scenario (BAU) focused on the current NEP, and the electrification scenario (HYDRO) that focus on valorization of hydropower potential.

In the electrification scenario, we considered the following assumptions:

I. Implementation of an ambitious electrification action plan, with a target of 100% electrification in urban areas and 40% in rural areas. This assumption is justified by the government's desire to restructure its electrification policy for the country.
II. Increased priority given to renewable energy sources, specifically hydropower, and electrification, with massive deployment of existing and innovative technologies to reduce greenhouse gas emissions.

RESULTS

ELECTRIFICATION SCENARIO

The electrification scenario analyzed produced the results shown in the figures below. Emphasis is placed on the total quantity of energy consumed, according to the form of energy, the demand for electricity, the impact of electrification on energy consumption in the residential, industrial and service sectors, and the reduction in emissions from cooking as a substitute for wood energy (traditional fuel). The energy balance, regarding

the traditional fuel end use, ranges from 50 Mtoe (71%) by 2022 under BAU scenario, to 6 Mtoe (17%) by 2050 under HYDRO scenario (figure 1). Total final demand for electrical energy in the DRC by 2050 (figure 2) will be around 17 GW-years, of which 11.9 GW-years (70%) will be for the residential sector, 4.4 GW-years (26%) for the industrial sector, and 0.7 GW-years (4%) for services. In terms of CO_2 emissions (figure 3), the electrification scenario shows a potential reduction by 2030 of 423.23 Mt CO_2e emissions, compared with the DRC's national climate change adaptation plan, which forecasts a potential reduction of 120.34 Mt CO_2e.

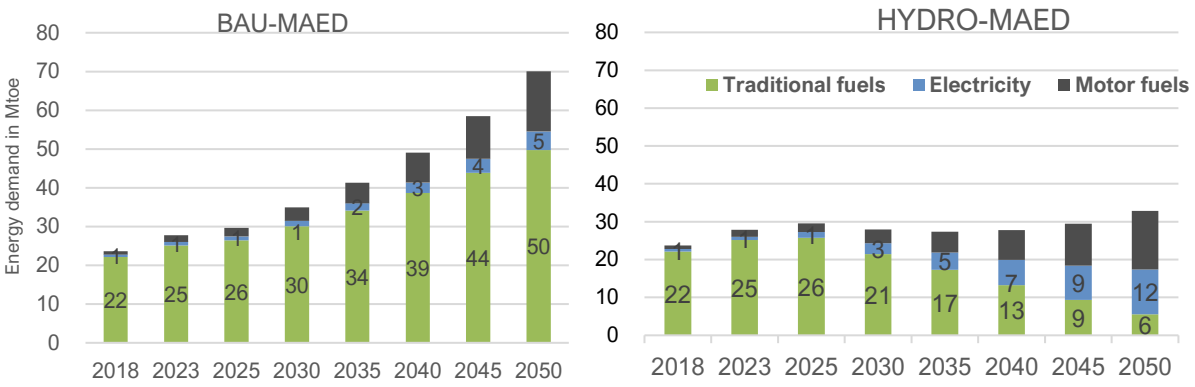

Figure 1 – Final energy demand by energy form. Source: authors

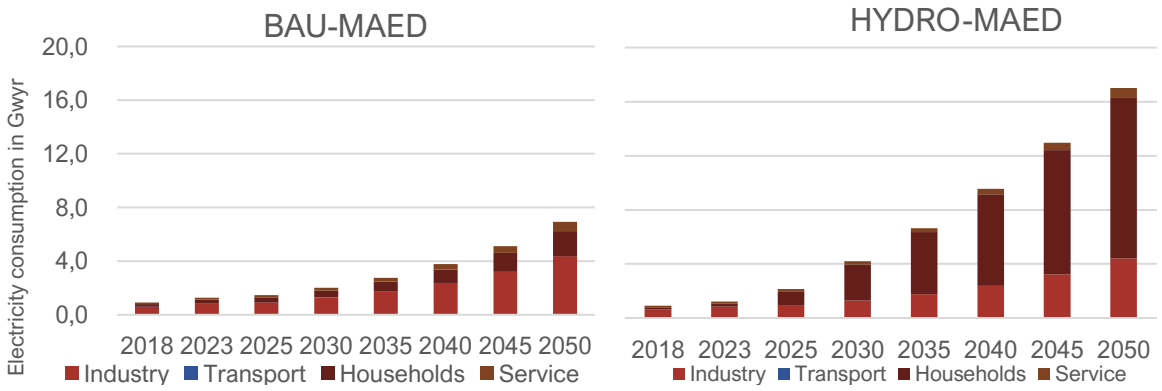

Figure 2 – Trend in final electricity demand by sector of activity. Source: authors

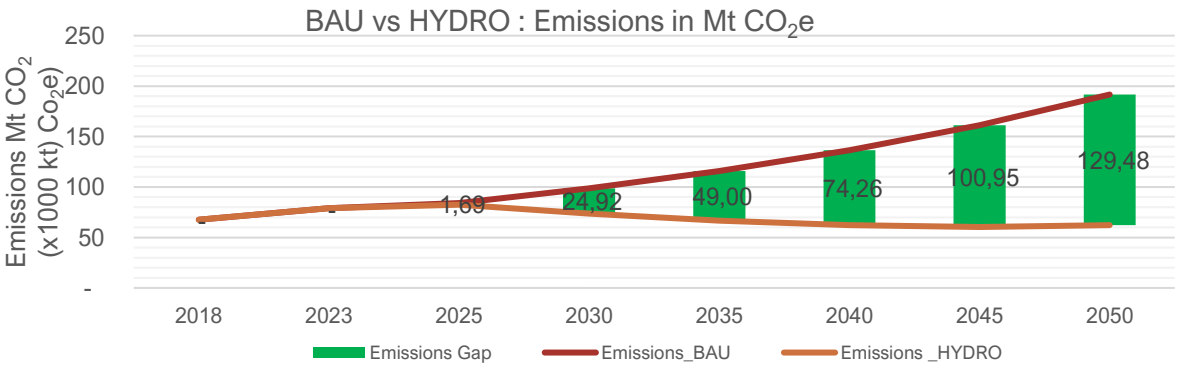

Figure 3 – CO_2 emissions gap in the residential sector. Source : authors

DISCUSSIONS

The HYDRO scenario's electrification policy significantly reduces the use of wood energy and promotes clean cooking through electric cookers for domestic or productive use. It lays a solid foundation for a race to national

electrification with greater ambitions, demonstrating the need to reduce the use of wood energy for heating and cooking which make the DRC losing more than half a million (500 000) hectares of primary forest every year [7], and meet the expectations of the Government in the conservation of the forest by reducing deforestation from 1.2 million hectares under BAU to 0.12 million hectares under HYDRO by the year 2050. The energy demand projected represents the target to be achieved by the Government's objectives in the energy sector for the guidance of policy decisions corresponding to the available energy supply, respectful of the environment and in phase with the century's motivations on the reduction of CO_2 emissions.

CONCLUSIONS

The aim of our research was to carry out a quantified analysis of the DRC's energy future, starting with current demand (2018) to identify future demand (2050), future impacts and redefine new options for energy development in line with the objectives of socio-economic development that respects the environment for the benefit of future generations. The basic scientific discipline for such an analysis is energy planning which, in this age of accelerated computerization, exploits "energy modelling" offering many facilities for the elaboration of energy demand scenarios. This study forms the scientific basis for the orientation of the energy policy still sought in the DRC.

These results show that if we project the DRC's energy trajectory by focusing on the country's electrification and presenting electricity as an alternative to wood energy, reducing wood energy use would be a solution to decarbonizing the energy balance and reducing pressure on the forest.

ACKNOWLEDGEDMENTS

We would like to thank Mr Jean MUGANZA ANUNU ASWIBA, for his assistance and encouragement in research to provide the Democratic Republic of Congo with an energy policy that matches the Government's ambitions. We would also like to thank the entire team at the International Energy Agency (IEA) for their support in mastering energy modeling tools.

The author used ChatGPT to check grammar issues and to improve readability. After using this tool, the authors reviewed and edited the content as needed and take full responsibility for the content of the publication.

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MANUFACTURE OF NA-ION SOLID-STATE ELECTROLYTES FOR BATTERIES

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ABSTRACT

During the past decade, solid-state batteries (SSB) have attracted scientific interest due to their anticipated superiority from the perspective of energy density and safety when compared to conventional Li-ion batteries. Na-ion batteries require an abundant natural resource on the earth and lower toxicity, therefore, is considered as a potential candidate to replace Li-ion battery which their disposal is toxic, it can contaminate water supplies and ecosystem. Even though significant improvements have been made, particularly in solid-state electrolytes, fundamental challenges remain in manufacturing time, ionic conductivity, pellet press production in industry, among others. This study works towards shortening the manufacture time of NASICON (Sodium (Na) Super Ionic CONductor) pellets sintered at 1180 °C. The production of NASICON by a solid-state method is done by ball mill, pellet press, calcination, hand grind and sintering procedures.

Keywords: NASICON; solid-state; electrolytes; manufacture.

INTRODUCTION

Batteries are part of our everyday life, they provide backup power, store energy from renewable sources, and is increasingly being used in the automotive field, portable electronics etc. The electromobility is definitely a developing field worthy of expanding and comprises hybrid and fully electric vehicles [1] with the aim to support sustainable development by reducing greenhouse gas emission and support the use of renewable energy particular for off-grid applications. Li-ion batteries are typically used in EVs and grid storage which have a flammable liquid electrolyte that are not stable at high temperatures, can lead to a thermal runaway and subsequent explosion or fire can occur [2].

A solid-state battery (SSB) is a battery technology in which all the components that compose the electrolyte in the battery are solid. An SSB consists of an anode, a cathode, and an electrolyte which provide the completion of the reactions occurring at the surface of these two electrodes. An illustration of the components of a battery can be seen in figure 1, and it is important to highlight that the solid-state electrolyte acts as physical separate between the cathode and anode, and the electrolyte is only a medium that conducts the electric current movement of the ions. Solid-state electrolytes overcome the safety problems presented by volatile liquids and have potential for higher energy density compared with liquid batteries [3]. To overcome limitations in material supply sodium is used instead of lithium.

In this research we investigate a solid state electrolyte based on sodium metal $Na_3Zr_2Si_2PO_{12}$ (NASICON) [4] and focus on two manufacturing routes in order to reduce the manufacturing time and cost.

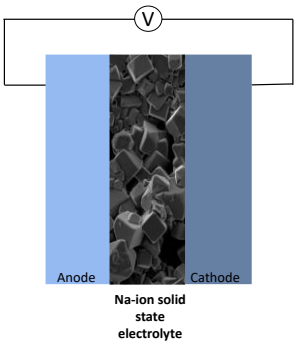

Figure 1 – Structure of a solid-state battery. Source authors.

PRECURSOR MATERIALS

All chemicals used in this research were used as purchased without further purification. For the NASICON solid-state manufacturing process, chemicals such as Sand white quartz ≥ 99.995% trace metals basis; Zirconium (IV) oxide 5 μm 99% trace metals basis, and Tri-sodium phosphate dodecahydrate were purchased from Sigma Aldrich, UK. And the solvent used in this study is 2-propanol (IPA) which was also supplied from Sigma Aldrich, UK.

METHOD

Na-ion solid-state electrolyte manufacture was adapted based on Jalalian-Khakshour et al., [5]. Initially, stoichiometric amounts of ZrO_2, SiO_2 and $Na_3PO_412H_2O$ precursors were placed in ZrO_2 grinding bowls. Two pellets were prepared with different manufacturing processes as seen in the tables below:

Longer manufacturing
•Ball mill •Dry oven 80°C (16.5 hours) •Pellet press •Calcination 400°C (5 hours, air) •Hand grind •Pellet press •Tube furnace 1100°C (16 hours, Argon) •Hand grind •Ball mill •Dry oven 80°C (16.5 hours) •Pellet press •Tube furnace 1180°C (16 hours, Argon)

Shorter manufacturing
•Ball mill •Dry oven 80°C (16.5 hours) •Pellet press •Calcination 400°C (5 hours, air) •Hand grind •Ball mill •Dry oven 80°C (16.5 hours) •Pellet press •Tube furnace 1180°C (16 hours, Argon)

RESULTS

XRD measurements were performed to determine the crystalline phases present in the prepared longer and shorter manufactured pellets using a Bruker D8 Discover – Tachi. As seen in figure 2.a) the diffractograms of the pellet before and after calcination at 400°C are similar. The XRD peaks obtained can be associated with the peaks of the precursor materials labelled as monoclinic ZrO_2 (m), SiO_2 (s) and sodium phosphate (P). It shows that no-reaction has happened between them at this temperature. After sintering the longer manufacturing pellet at 1100°C NASICON phases crystalises (COD 1530659 and COD 1529608, labelled as *). However, the presence of impurities and unreacted materials can still be detected. A second sintering

process at 1180°C helped to improve the crystallisation of NASICON peaks and highly reduced the presence of impurities (Figure 2.b). When comparing the diffractograms of the longer and shorter manufacturing pellets, no significant differences were observed with respect to NASICON presence. As seen in figure 2.c) similar results were observed for the Raman spectra (Renishaw inVia Raman microscope, laser with an excitation wavelength of 532 nm), where NASICON (*) and secondary phase monoclinic ZrO_2 (m) are detected for the shorter and longer manufactured pellets. In figure 3, the surface morphologies of NASICON pellets are observed at 1000 and 3000 magnifications for the longer and shorter manufactured pellets. Most of their grains present a typical cubic shape, with shorter manufacturing pellet presenting larger ones. Spiky crystals observed are related to NASICON secondary phases and EDS confirmed the presence of Na, Si, Zr, P and O but with a different stoichiometry than aimed. Ionic conductivity of 6.45 x 10^{-4} Scm^{-1} were obtained for the shorter manufacturing pellet using BioLogic VMP3 at frequencies range 1MHz to 100mHz, which is similar to the values expected for NASICON pellets [5].

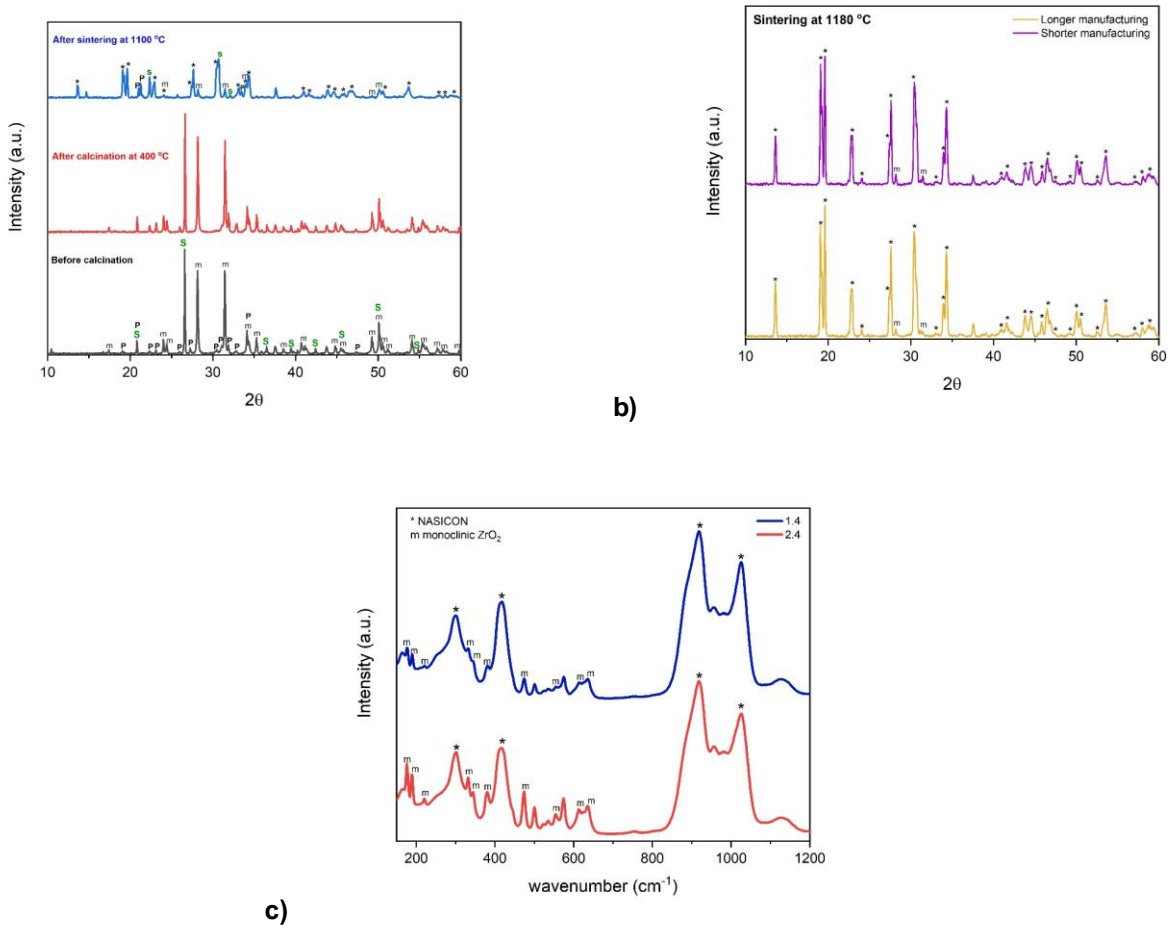

Figure 2 – a) XRD spectra at different stages during the longer manufacturing batch; b) XRD spectra of longer and shorter manufactured NASICON pellets; c) Raman spectrometry of longer and shorter manufactured NASICON pellets.

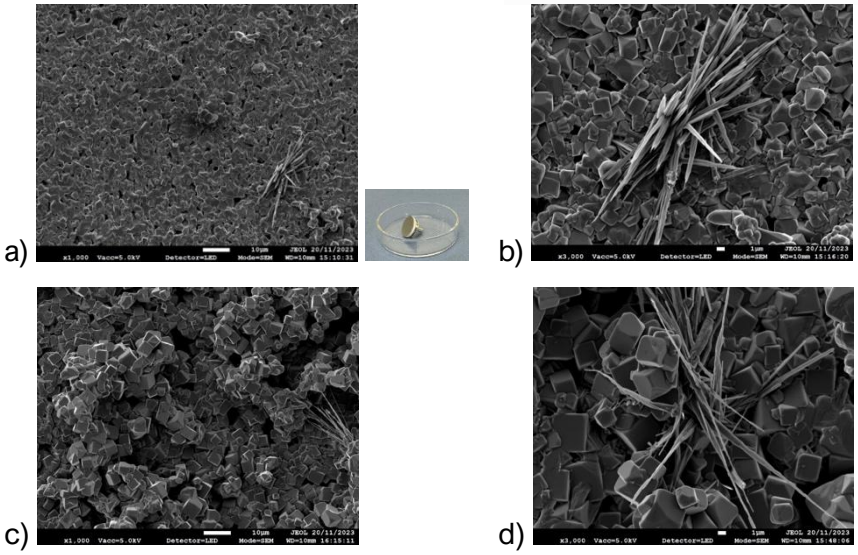

Figure 3 – SEM images a-b) longer manufacturing pellet and a photo of NASICON pellet on aluminium specimen stub after being coated with platinum, c-d) shorter manufacturing pellet.

CONCLUSIONS

In this work, we prepared NASICON using a solid-state synthesis method. This material was obtained after sintering its chemical precursors at 1180°C.

We reduced the manufacturing time of the NASICON pellets by omitting some preparation steps such as, the pellet press after the calcination at 400 °C, sintering at 1100°C for 16.5h and manual grinding before the second ball process. The XRD and Raman results show that there are no significant differences between processes (long and short manufacturing). The grain structure of the pellet with shorter manufacturing time presents better definition and slightly larger cubes than that of the longer manufacturing process. This could be related to the elimination of some production steps we carried out. No ionic conduction loss is observed for the shorter manufacturing method when compared to the expected values for NASICON at room temperature. This reduction in manufacturing time would potentially reduce the production costs of these NASICON pellets on an industrial scale.

Further work will include new measurements of the ionic conductivity of these pellets at different temperatures to confirm their potential as SSB electrolytes. Additional studies will also be conducted to quantify the presence of the ZrO_2 (m) phase (Rietveld refinement) and reduce its presence.

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POWERING PROGRESS: THE HUMAN-CENTERED JOURNEY TO AFFORDABLE AND CLEAN ENERGY

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ABSTRACT

Energy is fundamental to human well-being and economic development. As of 2024, over 650 million people still live without electricity, and 2.3 billion rely on polluting fuels for cooking. Although energy innovation has accelerated, affordability and equitable access continue to challenge developing nations. This article explores the multifaceted landscape of affordable and clean energy by analyzing decentralized systems, technological advancements, policy frameworks, and the socio-cultural impact of energy inclusion. With a focus on recent global developments and community-level insights, the study underscores the pivotal role of local innovation, cross-sector collaboration, and grassroots initiatives in realizing Sustainable Development Goal. Clean energy is now a catalyst for social justice, food security, education, and economic resilience.

Keywords: Clean Energy Access; Decentralized Energy Systems; Sustainable Development Goals (SDGs); Energy Equity; Technological Innovation in Energy

INTRODUCTION

Contemporary society confronts two interlinked energy challenges: universal access and sus- tainable production. Fossil fuels, once central to industrial progress, are now leading contributors to climate change, with over 70% of global greenhouse gas emissions linked to energy use [1]. At the same time, energy poverty continues to affect millions, manifesting in issues like unsafe cooking methods and limited digital access. The concept of affordable and clean energy extends beyond infrastructure deployment to include inclusive financial strategies, transparent policy-making, and resilient energy ecosystems. Achieving SDG 7 necessitates solutions grounded in everyday life—homes, schools, farms, and clinics—before scaling to national systems [2].

The research demonstrates significant quantitative impacts across multiple metrics. Decentralized energy systems achieved measurable improvements in rural electrification rates, with over 650 million people still lacking electricity access globally. Pay-As-You-Go models enhanced by blockchain technology expanded financial inclusion in underserved regions. Canada's energy profile shows 70% renewable electricity generation and 82% from non-GHG sources, with hydroelectric contributing 62%.

Comparative analysis reveals decentralized systems outperform centralized models by 37.7% in computation time reduction. Blockchain-based energy management prevented cost increases up to 17.6% from fraudulent activities. Electric vehicle registrations reached 10.8% of total vehicle registrations in 2023, representing nine-fold growth since 2017. These metrics validate decentralized energy's superior adaptability and efficiency.

The study employed thematic analysis and comparative case studies to examine decentralized energy systems across sub-Saharan Africa and South Asia. The methodology integrated multi-criteria assessment frameworks, utilizing Delphi method for expert consensus, Fuzzy Analytical Hierarchy Process (FAHP) for criteria weighting, and FPROMETHEE for alternative ranking under uncertainty. Sample selection focused on community-owned mini-grids, Pay-As-You-Go models, and blockchain-enhanced systems. Evaluation criteria encompassed health, education, food security, and economic inclusion metrics, with particular emphasis on cross-sectoral energy-water-food nexus linkages.

CRITICAL CHALLENGES AND LIMITATIONS

The research faced significant barriers including high capital costs for clean energy technologies, particularly in developing countries where perceived risk translates to higher cost of capital. Investment gaps persist with only 10% of announced green hydrogen projects securing committed capital despite $320 billion pipeline. Coverage challenges emerged across diverse technology areas and program components, necessitating theme-based case study approaches. Multi-criteria evaluation complexity required fuzzy logic to address uncertainties in expert judgments and alternative performance quantification.

KNOWLEDGE CONTRIBUTION

This study addresses critical gaps by providing systematic evaluation of decentralized systems at community scale, contrasting with predominantly national/regional MCDA applications. The integrated methodology advances participatory approaches combining expert consensus with resident preferences, contributing to the $50 billion annual investment requirement for universal energy access.

MATERIALS AND METHODS

The methodology adopted in this study includes thematic analysis, where patterns in energy adoption, affordability, and policy mechanisms were identified. A comparative case study approach was employed to examine decentralized models, such as mini-grids and off-grid systems, in relation to policy outcomes and stakeholder impact [1]. To evaluate effectiveness, various impact metrics were applied, focusing on health, education, food security, and economic inclusion. Particular emphasis was placed on emerging technologies such as solar PV, micro-hydro, and biogas; the integration of smart meters and mobile-enabled payments [9]; and the role of energy programs led by governments and community networks, especially in the context of cross-sectoral energy-water-food nexus linkages.

The results reveal that decentralized energy systems, particularly community-owned mini-grids, have significantly improved rural electrification in sub-Saharan Africa and South Asia [2]. The Pay-As-You-Go (PAYG) model, enhanced by blockchain technology, has further promoted financial inclusion in underserved regions [5]. Clean cooking solutions, powered by solar energy, are becoming increasingly viable in developing countries [3]. In parallel, smart technologies, including AI-driven forecasting models, are being integrated into microgrid operations for optimized energy management [4]. During emergencies, disaster resilience has improved due to blockchain-backed hybrid systems that maintain reliability and continuity of energy supply [6].

In terms of social development, education outcomes have improved where rural schools in Uganda and Malawi received electrification, enhancing access to digital learning tools and boosting student performance [2]. In healthcare, solar microgrids have strengthened maternal and emergency care in remote clinics [1]. Additionally, safety and mobility have been enhanced through AI-enabled microgrids that support electric mobility infrastructure [3]. Moreover, cultural participation has grown as digital hubs powered by renewable energy foster local innovation and community expression.

Several supporting sectors have emerged as crucial to energy access. In finance, rural entrepreneurs benefit from microfinance models and carbon credits, supported by blockchain-based energy tokens [6]. The technology sector is contributing through machine learning and blockchain innovations to optimize smart grid performance [3], [7]. Effective policy frameworks, especially those involving local governance, are essential for successful deployment of inclusive mini-grid solutions [1]. Furthermore, startups are leveraging IoT and blockchain technologies to scale up decentralized energy systems [5].

Lastly, the sustainable food landscape has benefited from energy-driven solutions that start at the grassroots. Irrigation systems powered by solar energy have enhanced crop yields and reduced operational costs [8]. Renewable-powered cold chains are minimizing post-harvest losses and bolstering food security [8]. In peri-

urban areas, biogas projects are decreasing dependence on polluting fuels [3]. Meanwhile, urban farming is experiencing a transformation through smart energy systems that enable efficient, hydroponic setups with minimal spatial requirements [7].

KEY RESULTS

The findings demonstrate that community-owned mini-grids have significantly improved rural electrification rates in sub-Saharan Africa and South Asia. Pay-As-You-Go models enhanced with blockchain technology have expanded financial inclusion in underserved areas. Solar-powered clean cooking solutions show increasing viability in developing countries, while AI-driven forecasting models optimize microgrid energy management. Educational outcomes improved in electrified rural schools in Uganda and Malawi, with enhanced digital learning access and student performance. Healthcare delivery strengthened through solar microgrids supporting maternal and emergency care in remote clinics. Agricultural productivity increased via solar-powered irrigation systems that reduced operational costs while improving crop yields.

DISCUSSION AND IMPLICATIONS

The research reveals that over 650 million people still lack electricity access, with 2.3 billion relying on polluting cooking fuels. The integration of blockchain, AI, and renewable technologies creates new optimization possibilities for decentralized systems. The study emphasizes that technical solutions require supportive policy frameworks and community engagement for successful implementation, treating energy as a public good that empowers communities holistically.

CONCLUSION

Affordable and clean energy forms the backbone of inclusive development. Amid growing climate challenges and persistent inequality, the transition to renewable energy must be inclusive, participatory, and rooted in local realities. Solutions—ranging from solar mini- grids to biogas systems—must be evaluated not only for their technical merit but also for their social impact. A holistic energy approach treats energy as a public good that empowers communities across all dimensions of life.

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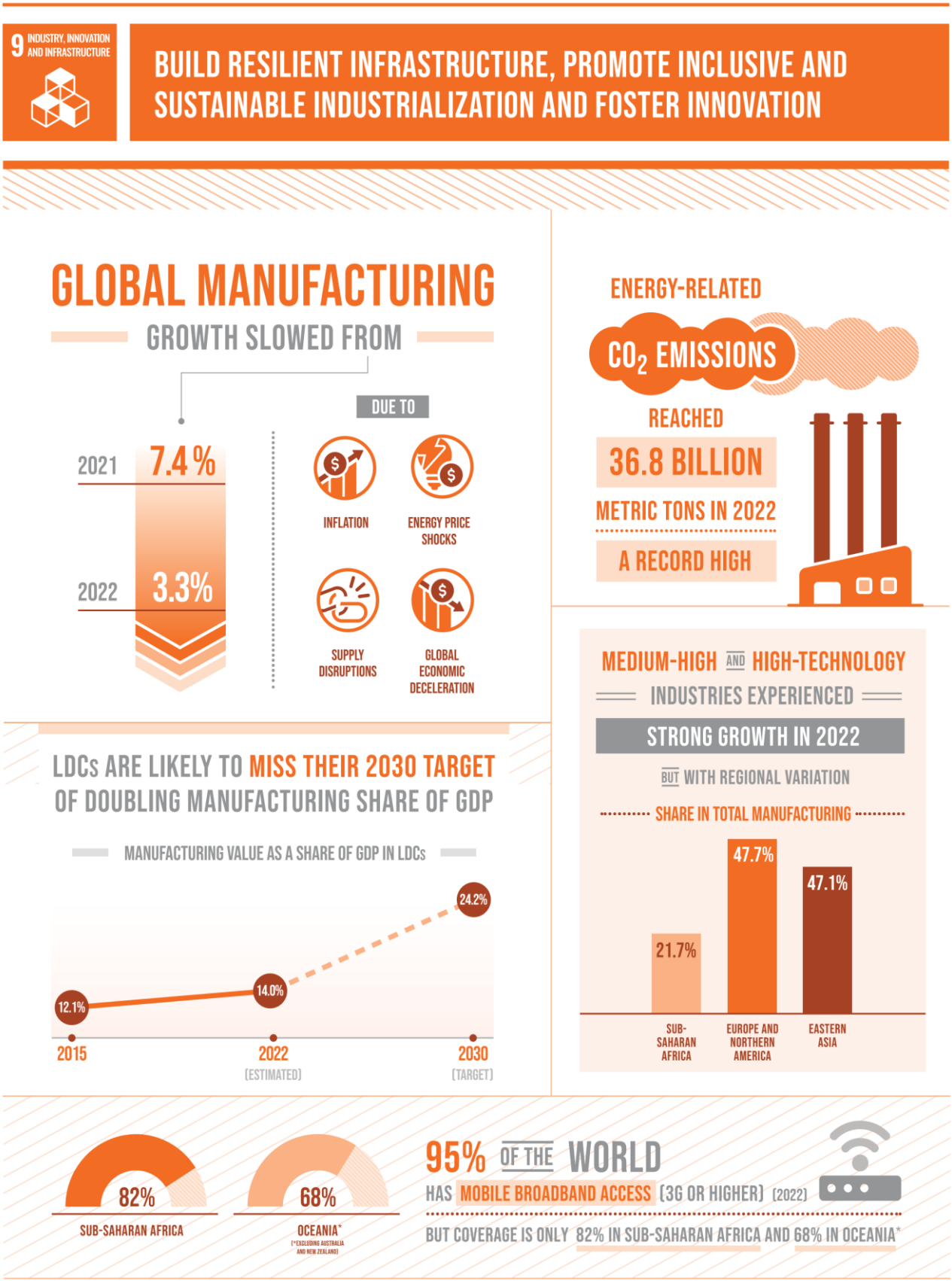
GOAL 9: BUILD RESILIENT INFRASTRUCTURE, PROMOTE INCLUSIVE AND SUSTAINABLE INDUSTRIALIZATION, AND FOSTER INNOVATION



Source: UN's The Sustainable Development Goals Report 2023 – Special Edition

ADVANCING SMART TRAFFIC INFRASTRUCTURE WITH AI-BASED VEHICLE DETECTION ACROSS COMPUTING CONFIGURATIONS

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ABSTRACT

Resilient, quality, sustainable and reliable infrastructure are dominant to enhance urban transportation as aligned with Sustainable Development Goals (SDG) 9 and 11 by promoting sustainable industrialization. Existing research merely focuses on evaluating the performance of detection models across different techniques and technologies. This study aims to examine the variations in deep learning model design and computational hardware in influencing vehicle detection performance. Several segmentation and detection models were trained and evaluated under different preprocessing techniques and Graphics Processing Units (GPU) environments. The results show that blurring irrelevant regions remarkably enhanced the detection performance while heavy augmentation increased the training time despite maintaining accuracy. Hardware advancements greatly reduced training time with only minor improvement in detection. The findings emphasize the importance of equipping computing configurations to build a more scalable and resilient traffic surveillance system that can support smart city initiatives through accurate and faster vehicle detection.

Keywords: Vehicle Detection; Deep Learning; Smart Traffic Infrastructure; Sustainable Urban Mobility

INTRODUCTION

Building a smart and resilient traffic infrastructure for a better smart city framework always requires innovative breakthroughs from multiple authorities to further improve the urban transportation system. In the alignment with SDG 9 and 11 which draws attention to promoting sustainable industrialization within the community, vehicle detection models that are powered by sophisticated technologies such as Internet of Things (IoT) come to be important in achieving these objectives across the countries [1], [2]. Having effective detection models is instrumental in building more responsive infrastructure which could power up infrastructure development. The integration of machine learning (ML) in vehicle detection could bolster the creation of smart city frameworks by making full use of the resource and improving energy efficiency [3], [4]. The advent of technologies such as Light Detection and Ranging (LiDAR) sensors technology also come hand in hand in boosting long-range detection performance due to its ability to provide 360-degree surveillance and generate 3D maps of subject areas which make them suitable for detecting vehicles under various traffic conditions [5]. Moreover, the use of infrared sensors combined with deep learning algorithms has shown great improvement in achieving higher detection accuracy [6]. Building powerful vehicle detection models in the automobile industry could have a great impact on several aspects, including development of Electric Vehicles (EV) and intelligent car driving [4], parking lot management, license plate recognition [7] and even traffic accidents scene reconstruction [8].

Upon literature research, the authors identified that there are indeed numerous studies that emphasize the techniques and technologies aiming to achieve more accurate and faster vehicle detection models by focusing on various algorithms, performance metrics, interdisciplinary technological collaborations and system deployment. However, there exists a lack of research on how both software and hardware settings could make an impact to the overall model efficiency and their suitability to contribute to a more resilient land transport infrastructure. In light of this, this study aims to investigate the impact of model variations and computational

hardware on the deep learning-aided vehicle detection for more scalable traffic surveillance focusing on You Only Look Once (YOLO) algorithm. The detailed analysis will focus on evaluating the capability of the trained models in assisting intelligent transportation systems by boosting vehicle detection accuracy.

METHODOLOGY

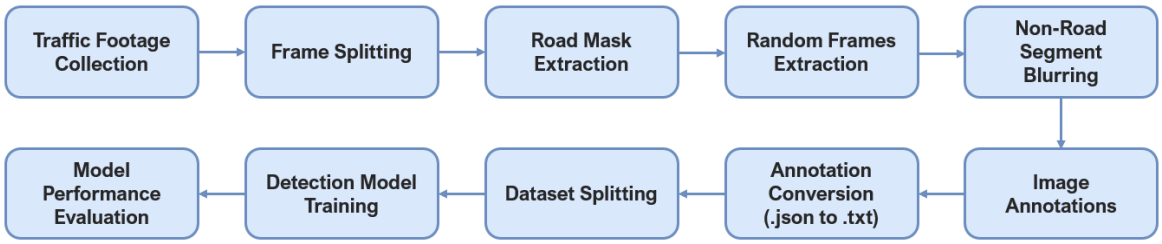

Figure 3 – Vehicle detection model workflow diagram.

DATA COLLECTION AND PREPROCESSING

The workflow diagram examining the performance of various vehicle detection models is presented in Figure 1. The development of vehicle detection model began with data collection, where traffic footages were captured from the Shah Alam Expressway (KESAS Expressway), a 37.5-mile highway in Selangor, Malaysia. 78 traffic footages were taken with Full High Resolution (FHD) from 23rd December 2024 to 13th January 2025 lasting for 21 days, and these footages covered various conditions including time of day (daytime to nighttime recordings), weather conditions (sunny, foggy, raining, clear and cloudy conditions), various levels of congestion and days of week (weekdays, weekends and public holidays) for the betterment of training and detecting the images.

With the objective of protecting privacy for both vehicles and pedestrians, all video and image processing were carried out offline using customized Python scripts for automating the processing procedures to completely eliminate any potential risks upon online processing. For frame extraction and annotation, open-source command-line tool *FFmpeg* was utilized for splitting frames based on the specified frame per second (fps), while graphical annotation tool *LabelMe* version 5.5.0 assisted the road segments extraction. Non-road areas were also blurred accordingly using Gaussian Blur to reduce background noise with its ability to provide gradual and smooth blurring and better edge preservation [9]. As a result, there was a total of 2208 images for annotations, which were then divided into 1545 training images, 444 validation images and 219 test images according to the ratio train:valid:test of 70:20:10. Polygon annotations have been a preferred choice to annotate object boundaries and segmentation masks as it allows the dataset to be used for both object detection and instance segmentation model training.

MODEL TRAINING AND EVALUATION

There were 6 different vehicle detection models trained for assessing the comparison in terms of both software factors – model types, dataset augmentation strategies and non-road segment blurring, as well as hardware factors – GPU performance. YOLO algorithm was selected with its excellent performance in both object detection and instance segmentation, and Google Colab Pro platform with Python 3.11.11 has been utilized for model training due to its efficiency in training large datasets. All 6 detection models were trained under the same configuration: 100 epochs with a batch size of 32. To evaluate the impact of data augmentation on model performance, horizontal flip, vertical flip and image gray-scaling were taken into consideration. These augmentation techniques were randomly applied to each image within the dataset. This resulted in 4753 images consisting of 3324 training images, 957 validation images and 472 test images. The performance comparison was evaluated specifically for mean Average Precision (mAP), precision, recall, F1-score and training duration to examine the ability of the model towards contributing to a smarter and responsive traffic

infrastructure. The details of each model trained are expressed as in Table 1. The bolded cells in the table indicate the variations where the model differs from the baseline. The baseline model was constructed with straightforward configuration: instance segmentation with blurred non-road regions, no dataset augmentation and T4 GPU. This setting serves as a minimal reference point for examining the subsequent variation in model architecture, preprocessing and hardware to ensure the performance is measurable and impactful.

Table 6 – Model training with software and hardware variations.

Model	Model Type	Non-Road Regions	Augmentation	Hardware	Remarks
1	Instance Segmentation	Blurred	No	T4 GPU	Baseline model
2	**Object Detection**	Blurred	No	T4 GPU	Software variations
3	Instance Segmentation	**Unblurred**	No	T4 GPU	
4	Instance Segmentation	Blurred	**Yes**	T4 GPU	
5	Instance Segmentation	Blurred	No	**L4 GPU**	Hardware variations
6	Instance Segmentation	Blurred	No	**A100 GPU**	

RESULTS AND DISCUSSIONS

The performance statistics of trained detection models were documented with the results categorized according to software and hardware variations as presented in Table 2.

Table 7 – Model training results visualization.

Model	mAP50	mAP50-95	Precision	Recall	Accuracy	F1 Score	Duration (Hours)
1	0.9620	0.7720	0.9123	0.9600	0.8789	0.9355	2.836
2	0.9620	0.7830	0.9051	0.9584	0.8709	0.9310	2.329
3	0.4020	0.2980	0.5210	0.6197	0.3948	0.5661	3.077
4	0.9600	0.7750	0.9119	0.9559	0.8746	0.9331	5.987
5	0.9610	0.7790	0.9157	0.9548	0.8777	0.9348	0.916
6	0.9600	0.7770	0.9138	0.9557	0.8777	0.9343	0.549

It was observed that the baseline model consistently outperforms other testing models across the performance metrics. A notable observation is that both segmentation and detection models achieved similarly high mAP50 scores when non-road regions were blurred, which means that reducing visual noise within the dataset could enhance the detection performance regardless of model type. While the detection model (Model 2) achieved slightly higher mAP50-95 than the segmentation model (Model 1), the overall differences in precision, recall, accuracy and F1-score were minimal. In this context, segmentation models still remain a strong option, especially for tasks that require concise boundary detection such as lane markings or multi-class traffic monitoring. Apart from that, the applied dataset augmentation strategy appeared to have a subtle impact in a way it maintained high performance, but it incurred almost double the training duration (Model 4). This observation makes us question whether having heavy data augmentation operation is worth the extra time it requires when it comes to implementing in real-world settings where faster model training time is preferred.

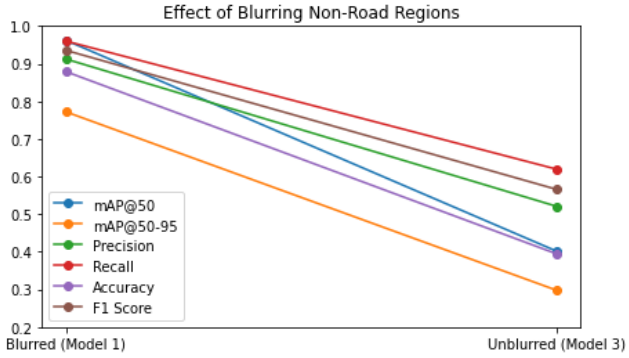

Figure 4 – Effects of blurred and unblurred non-road regions

As depicted in Figure 2, non-road region handling serves as one of the important metrics in evaluating the effectiveness towards smart traffic infrastructures. Model trained with non-relevant areas, focusing on only vehicle-labeled regions, achieved drastically higher performance (Model 1) across all examined metrics compared to those trained with unblurred images (Model 3). Blurring irrelevant areas could help improve accuracy while also reduce computational costs during training.

In terms of hardware impact, moving from a T4 GPU to an L4 (Model 5) or A100 (Model 6) showed only slight increment in terms of mAP50-95, but it resulted in drastic reduction in training duration especially for A100 GPU. While the model accuracy plateaus to a certain extent, having advanced and decent hardware could speed up the training which is an important factor when frequent model updates are needed in urban settings. Overall, the findings show that deep learning-based vehicle detection could effectively contribute to the advancement of smart traffic infrastructure by having more accurate and faster vehicle counting, traffic flow prediction or even congestion management.

CONCLUSIONS

This study explored the impact on both model variations and computational hardware on AI-based vehicle detection for smarter traffic infrastructure. In balancing the trade-off between model performance and training duration, this challenge could be overcome by combining both software and hardware strategies to develop a highly effective model suitable to be deployed in real-world scenarios. For instance, combining dataset augmentation methods with an A100 GPU can offset the downsides of long training time while also boosting the detection performance. Paving way to contribute to an intelligent transportation system, future work could focus on deploying the model into broader traffic applications such as a traffic prediction system or a traffic surveillance framework to analyze traffic condition within a specific region. The model performance could also be further investigated in future research with more decent hardware configurations such as Tensor Processing Units (TPU). All in all, this research lays the foundation of having accurate and faster vehicle detection framework, which can lead to informed decisions for researchers and urbanists about the future infrastructure planning to ensure the roads and transportation systems are designed to meet future needs.

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A MAPPING OF DIVERSITY IN INNOVATION COMMUNITIES: AN EVALUATION OF DIVERSITY PROMOTION IN THEIR ECOSYSTEMS

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ABSTRACT

The study of diversity within startup communities and ecosystems has gained relevance as it is intrinsically connected to innovation. In this context, this research aims to analyze the relationship between innovation and diversity, exploring its benefits and how it can be promoted within startup communities. The study adopts a qualitative case study approach, utilizing documents and interviews as data collection sources. Content analysis techniques, considering frequency and categories, were applied. The results demonstrated that diversity is a key factor in driving innovation. Additionally, it was found that community leaders recognize the positive impacts of diversity on society, the community, and the ecosystem, considering its implementation as beneficial.

Keywords: Diversity, Innovation Communities, Entrepreneurial Ecosystems.

INTRODUCTION

The startup ecosystem has played a central role in promoting technological innovation, disrupting traditional business models, and accelerating organizational changes on a global scale (Spigel, 2017; Nambisan, 2017). However, although these organizations often position themselves as environments open to creativity, recent research points to the persistence of exclusive dynamics and the reproduction of social inequalities in these contexts (Breslin; Jones, 2020; Ruebottom; Toubiana, 2021).

Particularly, diversity, equity, and inclusion (DEI) have emerged as central dimensions for understanding the challenges and opportunities within the startup environment. Studies demonstrate that diverse teams can foster innovation and expand the capacity for solving complex problems (Østergaard; Timmermans; Kristinsson, 2011), but they also face structural barriers that limit the full participation of underrepresented groups, especially regarding gender, race, and age (Huang et al., 2020).

The academic literature on diversity in startups is still incipient and fragmented, although it is expanding (Marques; Silva, 2022; Smith et al., 2018). Research in the fields of management, organizational psychology, and gender studies has contributed to understanding implicit biases in recruitment practices, decision-making processes, and the distribution of financial and symbolic resources (Marques; Silva, 2022; Smith et al., 2018). Gaps remain concerning the intersectional analysis of inequalities and the understanding of how diversity policies are implemented (or neglected) in environments under high pressure for performance and scalability (Marques; Silva, 2022; Smith et al., 2018).

The increasing complexity of the topic of diversity, equity, and inclusion (DEI) in the startup environment demands an in-depth approach, demonstrating that, the more text and discussions are generated on the subject, the more nuances and challenges emerge. This review aims to consolidate this vast literature, highlighting how DEI has become a strategic and ethical imperative for innovative ventures, far from being a superficial concept.

MATERIALS AND METHODS

RESEARCH PROBLEM AND OBJECTIVE

Research Question: How can diversity be perceived in innovation community contexts within ecosystems, and what actions are being developed to promote diversity?

General Objective: To understand the relationship between diversity and innovation in startup communities and their ecosystems across five municipalities in the Southeastern region of Brazil.

Specific Objectives:

- To understand the perception and relevance of diversity within communities.
- To identify how diversity is perceived in these communities.
- To understand how diversity is promoted and explored within innovation communities.

THEORETICAL FRAMEWORK

A business ecosystem is an economic community supported by the interaction between organizations and individuals within the business world (MOORE, 2006). A startup community is a group of people committed to helping entrepreneurs succeed, based on shared interests, objectives, identity, and camaraderie (HATHAWAY, 2020). Diversity refers to the differences between individuals, considering how people distinguish themselves from one another. Humanity is naturally diverse, as we possess various cultures, identities, and expressions (TOTVS, 2021).

METHODS

The present study followed a descriptive and qualitative research methodology, utilizing a case study strategy. The qualitative approach was chosen as it facilitates inductive theorization based on a case intentionally selected, i.e., theoretical sampling (Eisenhardt, 1989). Descriptive research was chosen as it allows for a more exploratory and descriptive approach, focusing on depicting a reality. The qualitative research approach was selected because it enables the study of monitoring characteristics. The case study method was chosen for its capacity to provide in-depth analysis and the study of individuals or groups (Eisenhardt, 1989).

The data collection procedure was based on the triangulation of secondary data (documents) and primary data (interviews). The documents analyzed included reports from the Brazilian Association of Startups (2021) and the "Playbook de Comunidades: Edição 2.0" (Carrillo et al., 2020), which provided descriptive information about communities in the Southeastern region and diversity data within these environments.

Semi-structured interviews were conducted with leaders of startup communities in five municipalities in the Southeastern region of Brazil, selected through purposive sampling. The criteria for selecting interviewees included their leadership position and their direct involvement with diversity promotion initiatives within the ecosystem. Purposive sampling was employed to ensure that participants possessed in-depth and relevant knowledge about the studied phenomenon, aligning with the objectives of qualitative research.

For data analysis, content analysis techniques were employed, with a focus on the identification of thematic categories and the frequency of occurrence of specific terms and concepts related to diversity and innovation. Given the qualitative and exploratory nature of the study, which sought an in-depth understanding of perceptions and practices, complex multivariate statistical tools, such as linear regression, discriminant analysis, or cluster analysis, were not utilized. The validation of categories and inferences was carried out through cross-referencing data from different sources (documents and interviews), aiming for the robustness of the analysis.

RESULTS

The first specific objective was achieved through documents and interviews, revealing that diversity plays a significant role within the communities and holds great relevance for them, as well as for the entire ecosystem. For the second specific objective, it was found that diversity is indeed seen as an important pillar for innovation within the community, and contrary views on this point are not welcomed in this context. For the third specific objective, it was concluded that there are numerous possible actions to promote diversity, including organizing events to attract more diverse individuals, maintaining active and strategically positioned social media to engage diverse people, and implementing affirmative leadership training and recruitment processes.

The study further emphasizes the importance of diversity for communities and ecosystems and demonstrates how adapting to this new scenario is increasingly necessary, evident, and encouraged. Additionally, the study highlights how more diverse communities have advantages in terms of innovation, impacting the ecosystem and society as a whole.

Among the study's limitations, it is noted that the research was focused solely on the Southeastern region, with no perspectives from participants in other innovation communities. Moreover, the results should be interpreted with caution, as they are based on a sample from these communities. Future research is proposed to explore inclusion initiatives more thoroughly, investigate how equity and inclusion programs can enhance early diversity movements, and examine how ecosystems can reach higher maturity levels through diversity efforts. Additionally, future studies should explore the intersection between the six ecosystem competencies and diversity pathways.

CONCLUSIONS

The first specific objective revealed that diversity plays a significant role within the communities and holds great relevance for them, as well as for the entire ecosystem. For the second specific objective, it was found that diversity is indeed seen as an important pillar for innovation within the community, and contrary views on this point are not welcomed in this context. For the third specific objective, it was concluded that there are numerous possible actions to promote diversity.

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DRIVING TECHNOLOGY ADOPTION: DIGITAL TOOLS TO DRIVE NON-PROFIT ORGANISATIONS' EFFICIENCY

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ABSTRACT

Non-Profit organisations (NPOs) are typically a crucial aspect to fostering sustainable cities and communities, bringing quality of life to the society through their services, social impact and positive economic impact. However, they're known to have an inability in adopting and integrating digital technologies due to their special characteristics. In recent years there have been an increasing number of studies around the barriers in NPOs technology adoption process, but most of them remain narrow in scope and lacks practical applicational suggestion. This study aims to explore the underlying overarching factors influencing digital adoption in non-profit sector. A mixed method approach informed by established framework will be used to identify common inhibitors. The findings will contribute by providing both theoretical understanding and practical applications, enabling NPO leaders to utilize technology more efficiently to continue building sustainable communities.

Keywords: Digital adoption strategy; Non-profit; Technology adoption framework; Sustainable communities.

INTRODUCTION

Organisations commonly overlook learning and innovation, failing to understand that these two capabilities may be an essential part of pursuing market sustainability. In the growing generation of technology, organisations can embrace innovations to streamline their operation, providing the market with improved services and goods whilst maintaining their competitive advantage [1]. However, the context of information systems and digital transformation may not be well researched, stemming from an inadequately characterised industry ecosystem [2]. A digital transformation is defined as "a fundamental change process, enabled by the innovative use of digital technologies accompanied by the strategic leverage of key resources and capabilities, aiming to radically improve an entity* and redefine its value proposition for its stakeholders." with an entity being classified as an organisation, industry or business network [3].

It is also seen through literature that non-profit organisations (NPOs) have previously been underexplored in the aspect of digital/ technology adoption. Emphasising NPOs is critical as they are crucial in fostering the environment of a civil city, enhancing social capital, economic growth and the general well-being of communities. They often undergo continuous challenges as crises occur, leading to an increase in societal demand. NPOs may function similarly to other organisations, but they are distinctly different due to their emphasis on non-financial results and the lack of incentive to boost production, leading to enduring their unique challenges when adopting technology [2]. NPOs continue to struggle with the integration and deployment of emerging technologies, even in leading countries, despite the availability of cutting-edge technologies and skillsets the challenge of its integration persists [4].

A thorough scoping review of the existing literature revealed a distinctive gap in understanding the barriers to digital transformation in non-profit organisations (NPOs). Most studies have been limited by narrow scopes, focusing on specific countries, subsets of NPOs, or small sample sizes, therefore unable to capture the broader challenges faced by the sector holistically. So, this research aims to address this gap by identifying common barriers to digital transformation across NPOs, to create strategies and app design prototypes in supporting an efficient technology adoption process. This study will follow the below research questions:

- What are the key factors influencing technology acceptance and adoption in non-profit organisations, and how do these relate to commonly identified barriers in digital transformation?
- Which methodology is the most suitable to explore the gaps and solutions identified through the literature review?
- What are the primary barriers to technology adoption identified through data collection?
- What features and functionalities are critical for a mobile app to address the needs of non-profit organisations?
- How can user-centred design improve technology acceptance and usability in non-profits?
- How effective is the developed hi-fi prototype in addressing the identified barriers to technology adoption?

MATERIALS AND METHODS

PRISMA, FOUR PHASES

This scoping review follows the Protocol for Scoping Review and employs the Prisma Extension for Scoping Reviews Checklists to select articles in the existing body of literature [5]. From March to April 2025, three databases including Web of Science, Scopus and Science Direct were utilised in this research. Specific search strings and phrases were used across all three databases to ensure consistency: Digital OR Technology OR Non-profit. There were no limitations in the first selection as the area of digital/ technology adoption has been severely underexplored with a limited number of literature available. The diagram of the results is inserted in the results section, please refer to that section for the diagram.

IDENTIFICATION PHASE

At this stage, the search mentioned above was conducted across the databases, and 6,393 papers were found, most of them from ScienceDirect. These results were then exported to EndNote to remove any duplicates, 83 results were found that existed across the three databases, therefore removed from the selection range. A total of 6310 papers were included for the next round.

SCREENING PHASE

In this phase, journal articles were assessed according to the titles and information within the abstract. The exclusion criteria include misalignment of the research area, publication type, time interval of paper published from 2010 onwards, and language used. In reference to the research area, results were eliminated when it is not relevant to the topic of interest, technology, many papers from ScienceDirect were health-related when the search query of “non-profit” was used. The publication type of the selection result was limited to peer-reviewed journal articles only, book chapters and industry web sources were all eliminated. A filter for publication time of 2010- 2025 was applied as reviewing significant older research was unnecessary. More recent research is likely to have built upon the body of literature, addressing previously identified limitations, and analysing a more recent understanding of the non-profit sector. Furthermore, the papers that were able to move onto the next phase had to allow full access to all text in English, the studies that did not meet these criteria were automatically excluded. This review has been conducted by single author search and documented. The result obtained for this section is 21.

INCLUSION PHASE

The final phase follows some inclusion criteria to elect the suitable papers that will be included in this research, the results have all been filtered through by research area, language, article type and open access. Full-text screening was completed to ensure the 13 articles included are closely aligned with the inclusion criteria, focusing on digital technology adoption in the non-profit sectors.

DESIGN THINKING FOR APP

This stage of the study is yet to commence, it will adopt a design thinking approach to produce a functional prototype. The prototype will be tested and evaluated with key stakeholders across non-profit organizations (NPOs). Design thinking, defined as "a methodology that imbues the full spectrum of innovation activities with a human-centered design ethos" [6]. It has been proven in the body of literature that it is an effective methodology which can be used in information systems design, creating innovative uses of technology [7].

The design thinking process is broken down into three aspects, inspiration, ideation and implementation [6]. These stages are further expanded into human centered focus, strategy and goals, innovation approach, altruism, collaboration approach, technology usage, user involvement, prototype usage, test, experimentation, and resources need [7]. This development process ensures that the final digital product is not only innovative but contextually appropriate for the special demographic of NPOs, which is hopeful to help NPO leaders to adopt technology more efficiently, to support organizations in creating a more sustainable community. Previous research insights alongside the design thinking approach will help guide key features in the hi-fi prototype mobile app created to address specific barriers faced by NPOs in technology adoption, which will require the employment of tools like Figma or Adobe XD. A usability test will also be carried out with representatives from the NPOs to validate the development with organizational goals and community impact.

RESULTS OF PRISMA

The results captured from the PRISMA scoping review inclusion criteria was 13 papers and they were analysed in detail for this research. The research question *"What are the key factors influencing technology acceptance and adoption in non-profit organisations, and how do these relate to commonly identified barriers in digital transformation?"* was formulated through an extensive review of the existing body of literature. The analysis of the included studies revealed three major themes: the unique organisational characteristics of non-profit organisations, the critical role of leadership in driving digital innovation and the lack of digital expertise among individuals within NPOs. Additional barriers were also identified; however, they appeared less prominent across the literature.

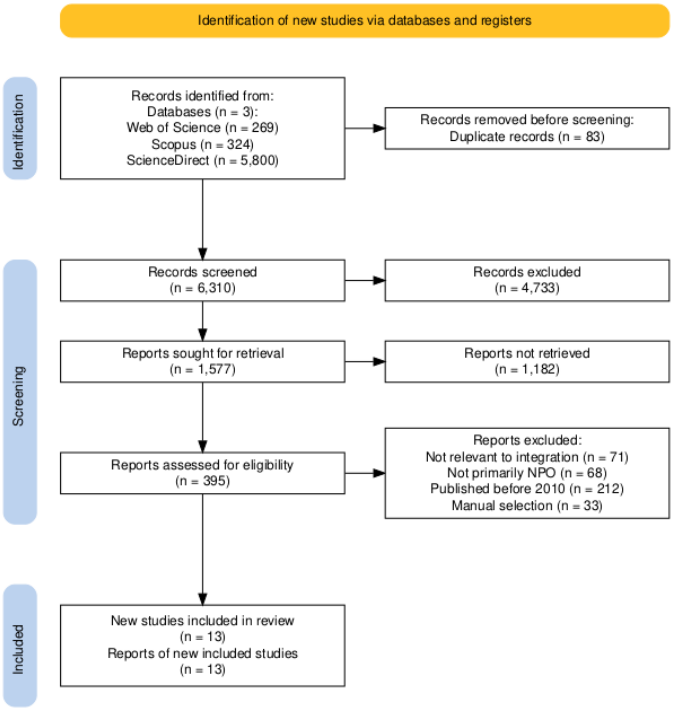

Figure 5 – PRISA flow chart for this study.

CONCLUSIONS

The scoping review following the PRISMA extension discovered three significant barriers for digital adoption in Non-profit organisations (NPOs) including the role of leadership, skill gap of individuals and the financial challenges in the adoption of technologies [5]. Despite the growing recognition for the benefits of digital tools, NPOs still face major structural and resource-based obstacles, restricting their ability to undergo significant transformations [4]. Innovation is often restricted by NPOs' unique challenging characteristics of mission driven governance, decentralised decision making and restricted finance. Similar to Non-government

organisations (NGOs), NPOs strive to adopt new cost effective technological tools to adapt to new target audiences in ensuring their mission can be delivered appropriately [8].

The findings from the literature review suggests that successful technology adoption requires more than just the availability of technology, it is critical to develop actionable insights for NPOs to be digitally transformed. If this matter is not addressed in the coming years, it will prevent NPOs from further growing and its ability to contribute to sustainable communities and society. This study will address its challenge through the design thinking stage of the project followed by the prototyping of mobile application in tailoring to the NPOs needs. In supporting the transition of technology adoption, NPO leaders can consider assessing their own digital readiness, invest in targeted upskilling initiatives for staff and volunteers and engaging strategic partnerships with technology providers.

ACKNOWLEDGEDMENTS

The author would like to thank Dr Amara Atif, her research supervisor, for the continuous guidance, feedback and encouragement throughout the course of this study and the future of this study. The support was invaluable in shaping the direction and quality of this research. She would also like to dedicate her appreciation to the University of Technology Sydney and the Faculty of Engineering and Information Technology for the constant support and providing the resources needed to conduct this research.

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GOAL 11: MAKE CITIES AND HUMAN SETTLEMENTS INCLUSIVE, SAFE, RESILIENT AND SUSTAINABLE

Source: UN's The Sustainable Development Goals Report 2023 – Special Edition

STRATEGY IMPLEMENTATION OF A STORMWATER MANAGEMENT PLAN IN PETRÓPOLIS (BRAZIL)

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ABSTRACT

Stormwater management practices (SMP) are very important tools to prevent flooding and overflows. SMP are techniques capable of improve rainwater infiltration and flow control. In developed countries, several cities have their own guidance to implement SMP, while developing countries are still suffering with floodings, like Petrópolis in Brazil. Due to the largest number of tragedies caused by rainwater, this paper aims to create a plan with the SMP that best fit the hydrological aspect of the city, based on practices already spread in the world. This plan serves to make the city safe, resilient, and sustainable (SDG 11), by the capacity of disaster risk reduction. The techniques suggested involves maximization of infiltration and control of streams flows.

Keywords: stormwater management; flooding; overflows; rainwater.

INTRODUCTION

Over the years, urbanization and human development have increased, significantly impacting water quality and management. Cities concentrate impervious surfaces, increasing surface runoff and reducing rainfall infiltration, which leads to higher peak flows and floodings [1]. The alteration of natural environments, occupation of flood-prone areas, and modification of streams further intensify these issues [2].

Floods represent public health risk, causing material losses, diseases, and infrastructure damage. In combined drainage systems that carries both wastewater and stormwater, they also contribute to soil and water contamination [3]. Additionally, reduced rainwater infiltration disrupts the water cycle, decreases groundwater recharge, and affects ecosystems [1].

Developed countries have adopted stormwater management practices (SMP) to control runoff, enhance infiltration, and mitigate floodings by reducing the amount of water in rivers and streams in rainfall events [4]. Besides the floodings mitigation, such approaches also provide more environmental benefits, such as creation of green space, better air quality, improvement of biodiversity, and mitigation of urban heat island effects [3].

Although rainwater management has gained global attention, it still undervalued in developing countries, like Brazil [2]. With a tropical climate and a high rainfall level, Brazil faces significant challenges in stormwater management. A national survey in 2022 showed that 60,9% of the cities have faced severe hydrological events in the past 5 years, and 4,3% of houses at flooding risk [5]. These numbers highlight the need for implementing SMP in Brazilian cities to mitigate flooding and hydrological risks.

Petrópolis, in Rio de Janeiro - Brazil, is one of the thousands of cities affected by floodings. In 2024, it took the first place among the cities in Brazil with more occurrence of landsliding and floodings [6]. The severity of these events can be bigger due to the lack of coordination among municipal stormwater management agencies and the absence of strategic SMP implementation plan [7]. Given the importance of effective rainwater management, this paper proposes a strategic plan for implementation SMP in the Quitandinha watershed.

MATERIALS AND METHODS

In a first step, a geological and hydrological characterization of the city of Petrópolis was conducted to access the topography and the watershed information. Besides the general characterization of the city, Quitandinha watershed have received a focus due to high occurrence of flooding. The analyses were carried out at the software QGis, that uses data from different sources, like ALOS, IBGE and MapBiomas.

Then, a plan for implementation of stormwater management was develop based on practices used by counties reported on legislations, papers, studies and stormwater manuals around the world. The selection of techniques to create the plan was based on worldwide techniques that better fit to the city's characteristics.

RESULTS

CHARACTERIZATION OF THE CITY

The Figure 6 shows the limits of Petrópolis and Quitandinha watershed. The watershed hydrograph map represents how surface drainage behaves in the basin, it means the courses that the water follows until it reaches the main drainage system. In addition, the hydrography of the basin with the rivers that compose it.

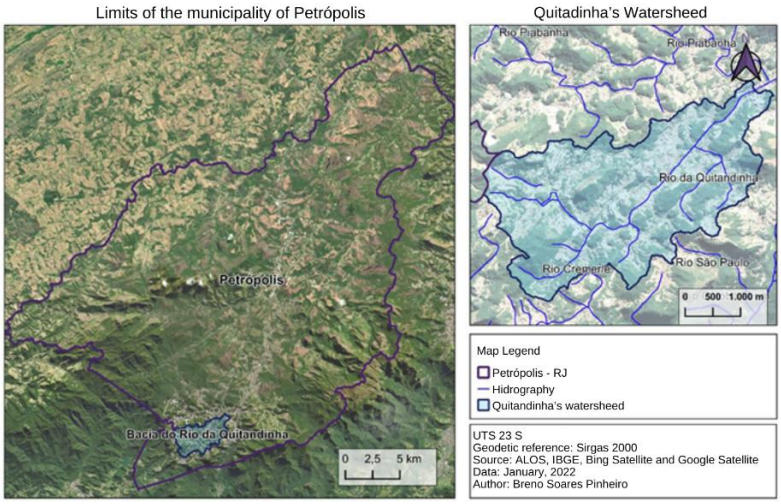

Figure 6 - Petrópolis Municipality limits and Quitandinha watershed

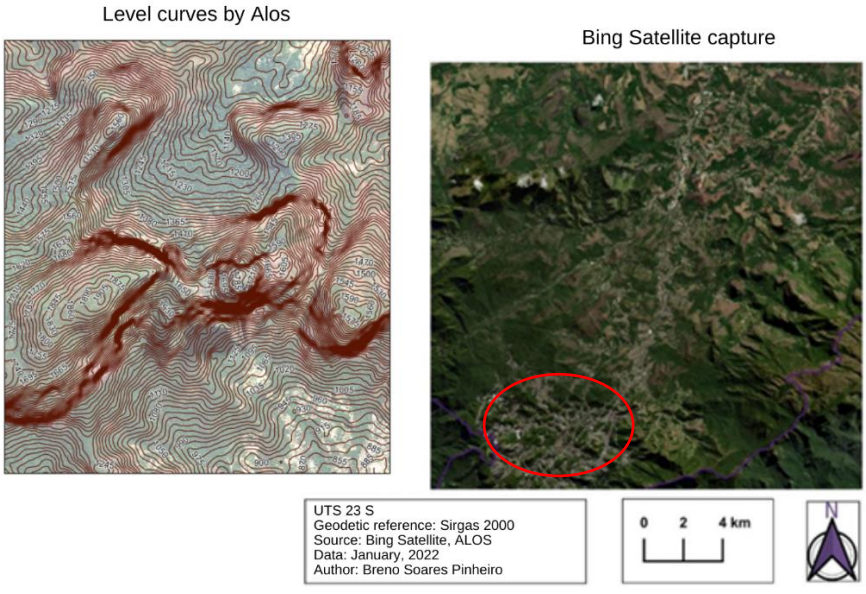

Figure 7 - Level curves and satellite capture of Petrópolis (Quitandinha watershed in red circle)

Through the Figure 7, it is possible to analyze two important factors that influence the flooding occurrence: soil slope and urbanization. The soil slope influences the rainwater infiltration into the soil. Due to the gradient, most of the water runs off toward rivers in the lower parts of the watershed in a very fast way instead of being absorbed into the ground. Urbanization also influences the amount of water conveyed to the streams and sewage pipes, since it reduces the pervious surface and create more runoff volume. As analyzed through the satellite capture, the watershed studied has a high urbanization level concentrated in the lower parts, which increases the risk of flooding and losses by the stormwater in peak events flow.

Urbanization also influences the amount of water conveyed to the streams and sewage pipes, since it reduces the pervious surface and create more runoff volume. As analyzed through the satellite caption, the watershed studied has a high urbanization level and concentrated in the lower parts, which increases the risk of flooding and lasses by the stormwater in peak events flow.

PROPOSED STORMWATER MANAGEMENT PLAN

By the risks represented for the geological and climate characteristics of the city, it is necessary to develop tools to enhance infiltration and control the runoff conveyed to the streams. Figure 8 was created as a guide for the most proper tools to help in the municipality plan for stormwater management.

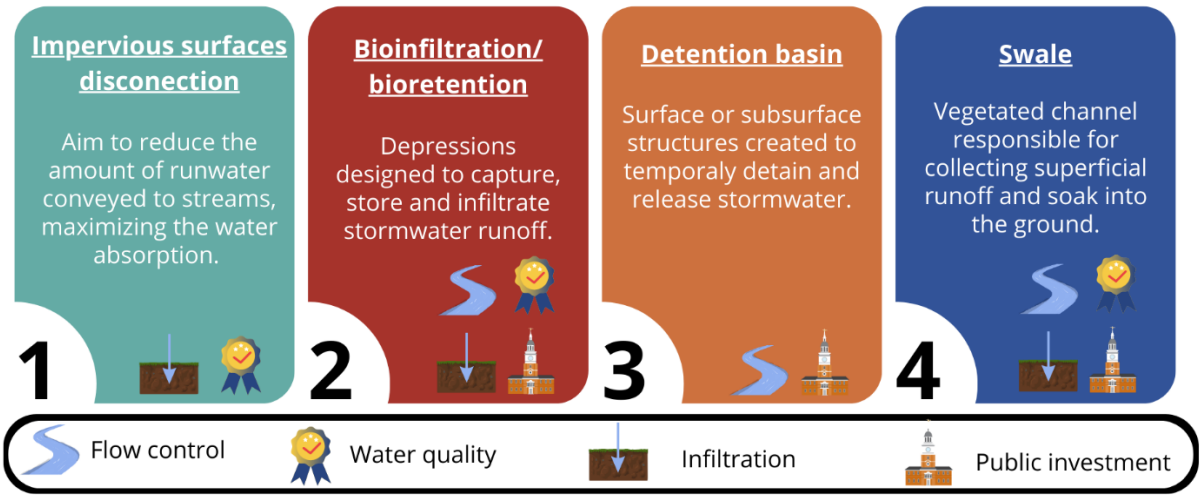

Figure 8 – Stormwater Management tolls to be implemented. Adapted from [8], [9] and [10].

As seen in the previous analyses, the watershed studied has a very urbanized area, increasing the impervious surfaces represented by roofs and streets. Besides that, Petrópolis is a planned city built in the 19th century, which represents it was not designed to accommodate the high rate of urbanization in some areas. The tools selected to create the plan was based on these factors. They explain the recurrence of overflows, since both help to increase the amount of water in streams and drainpipes and also reduce the soil capacity for infiltration.

The disconnection of impervious areas means to convey the rainwater from roofs and roads to pervious surface. This action reduces the amount of runoff carried to streams and rainwater pipes, avoiding overflows by the infiltration of water. Disconnection of roofs can be done in each property, directing the runoff of the roof to the pervious areas, so it was chosen as the first phase due to the easy implementation. To implement it, the municipality might create legislations and inspect constructions.

The bioinfiltration/bioretention are the SWM tool with highest-preference in the Philadelphia Stormwater Management Manual [8] due to the high-performance and cost-effectiveness. This tool uses vegetated depressions to improve infiltration by filtering runoff through a vegetated soil. The implementation of the technique can represent the control of the flow and reduction of runoff for the watershed studied, but to apply

the technique the municipality should make a relatively low investment and make some urbanization changes to fit rain gardens over the public space.

Detention basins function like tanks, temporarily storing water during peak flow events to reduce the volume entering streams and prevent overflows [9]. After the rain event, the stored water is gradually released in a controlled manner. Detentions basis are big constructions capable of store a high amount of water, then the construction is expensive and the location and implementation should be specifically designed. A previous study already suggested this tool, but the lack of interesting by municipality agents can prevent the implementation [11].

The last technique presented is the constructions of swales close to impervious surfaces, like roads and sidewalks. The runoff can be collected and drained to a vegetated swale, in order to infiltrate into the soil [10]. Swales are not complex tools to be implemented and it can mitigate overflows, since located strategically.

CONCLUSIONS

This work aims to study the hydrology of Quitandinha watershed and suggest a stormwater management plan from manuals already stablished in other countries to prevent overflows. In order to increase infiltration, the disconnection of impervious areas is the first act suggested. The following proposed tools enhance the infiltration and flow control by retention of runoff, represented by bioinfiltration/bioretention, detention basin, and swale. The techniques mentioned are used in developed countries and all of them have specifications and parameters to be followed, in order to guarantee security and the operation of the system.

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BUILDING A DATABASE FOR BRAZILIAN CONSTRUCTION SYSTEMS: AN APPROACH TO COST AND ENVIRONMENTAL IMPACT ASSESSMENT

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ABSTRACT

This study developed a comprehensive database of Brazilian construction systems for walls, roofs, and floors by integrating cost and environmental impact data from SINAPI and SIDAC. Costs and embodied CO_2e emissions (per m²) were computed for 32 wall types, 48 roof types, and 20 floor types, revealing significant variability across systems. For instance, the most expensive floor system, comprising a slab, thermo-acoustic insulation, subfloor, and granite, cost R$751.54/m² compared to R$75.02/m² for the simplest system, while wall systems showed CO_2e emissions ranging from 9.18 to 99.84 $kgCO_2e/m^2$. Moderate, positive correlation coefficients (0.54 for walls, 0.48 for roofs, and 0.43 for floors) indicated that higher-cost systems generally yielded greater emissions. However, the data also demonstrated that strategic reductions in material usage could simultaneously lower both costs and environmental impacts. These findings challenge the conventional premise that sustainable construction is inherently more expensive and underscore the necessity for context-specific, lifecycle-based assessments to optimize both economic and environmental performance in the construction industry.

Keywords: sustainable construction; CO_2 emissions; cost evaluation; data integration.

INTRODUCTION

The construction industry significantly impacts the environment, primarily through the production chain of its materials. Approximately 24% of the extracted global materials, 34% of worldwide energy demand, and 37% of global CO2 emissions are attributed to the construction sector [1]. Lifecycle assessment (LCA) indicators are used to evaluate environmental impacts across a material's lifecycle—from raw material extraction to final disposal [2]. A critical metric is embodied CO_2, which quantifies the CO_2e emissions generated throughout a material's lifecycle [3]. In Brazil, builders typically focus solely on lowering construction costs, often overlooking environmental impact assessments and assuming that sustainable products are more expensive [4]. Thus, this study aims to develop a database of major Brazilian construction systems, detailing acquisition costs, implementation services, and CO_2e emissions from raw material extraction to production, while questioning the notion that low-impact constructions necessarily incur higher expenses.

MATERIALS AND METHODS

This study builds on the list of Brazilian construction systems compiled by Oliveira et al. [5] in their thermal performance analysis of housing. It encompasses systems for walls, floors, and roofs. For walls, the systems include various core types—such as concrete blocks and ceramic blocks, with or without structural functions—and different plaster thicknesses. Floor systems consider variations like the presence of slabs, thermo-acoustic insulation, subfloors, and finishes in materials such as porcelain, granite, and wood. Roof systems vary in the use of slabs (e.g. solid and ribbed), ceilings (e.g. gypsum, wood, and PVC), tiles (e.g. concrete, ceramic, and fiber-cement), and thermo-acoustic insulation. In total, the database includes 32 wall types, 48 roof types, and 20 floor types, available in full via the provided link.

For cost and environmental impact assessments, values were obtained from two national sources: the National System for Construction Cost and Index Research (SINAPI) and the Construction Environmental Performance Information System (SIDAC). SINAPI provides monthly cost breakdowns for construction services across Brazilian states; this study used the December 2024 spreadsheets, analyzing costs specifically for the State of São Paulo, the most populous state in Brazil. This choice enhances the representativeness of the data while acknowledging regional variability. Additionally, due to time and resource constraints, it was not feasible to include all states in this study. SIDAC compiles CO_2e emission data from material extraction to production at a national level, and the emissions used here were based on the average of the reported ranges. Materials not covered by SINAPI—such as certain mortar thicknesses and masonry with horizontally laid bricks—had their prices approximated based on material similarity, consistent unit measures (m² or m³), and, if necessary, national market research. Similarly, for materials absent from SIDAC—like fiber-cement tiles, glass wool, and carpet—CO_2e figures were derived from the international Ecoinvent inventory. Ultimately, each construction system was assigned a cost and CO_2e value per square meter (R$/m² and CO_2e/m², respectively).

To incorporate the financial and environmental impacts of partition walls within the independent structural system, these walls were assumed to be reinforced concrete—a common practice in Brazil—following the methodology outlined by Mattos [6]. This approach establishes relationships to determine the superstructure's concrete volume, steel weight, and formwork area for budgeting purposes, and it was also applied to estimate the steel content in the solid concrete slab. For the other slabs (with EPS or ceramic blocks), the steel quantities provided by SINAPI were used. Since this methodology relies on the built area to compute the overall concrete volume, the study focused on the housing unit shown in Figure 1, which has a total area of 40 m², is single-family, and reflects a typology present in federal housing programs such as *Minha Casa Minha Vida*, which include a significant share of ground-level houses. This model was selected due to time and resource constraints.

Figure 9 – Assessed building (simplified schematic of the layout of the building envelope). Source: authors.

Using the formulations by Mattos [6], the total concrete volume ($V_{concrete}$) is calculated as the product of the built area ($A_{building}$) and an average thickness indicator of 14 cm (Equation 1). The steel weight (W_{steel}) is then determined by multiplying $V_{concrete}$ by an average steel rate of 86.5 kg/m³ (Equation 2). For cost estimation, an equal proportion of CA-50 reinforcing bars with diameters of 6.3, 8.0, and 10.0 mm was assumed. The formwork area ($A_{formwork}$) is computed by applying a rate of 13 m²/m³ to $V_{concrete}$ (Equation 3). Finally, by segregating the concrete volume of the slab from that of the beams and columns, the same calculations are repeated to account separately for the vertical elements (columns and beams in partition walls) and the horizontal element (solid slab).

$$V_{concrete}\,[m^3] = A_{building}[m^2] \times 0,14\,m \quad \text{Equation 1}$$

$$W_{steel}\,[kg] = V_{concrete}\,[m^3] \times 86,5kg/m^3 \quad \text{Equation 2}$$

$$A_{formwork}\,[m^3] = V_{concrete}\,[m^3] \times 13m^2/m^3 \quad \text{Equation 3}$$

RESULTS

The compiled cost and environmental impact data for all analyzed systems can be found at this link. Figure 2 displays the dispersion of cost and environmental impact values across wall, roof, and floor systems by area.

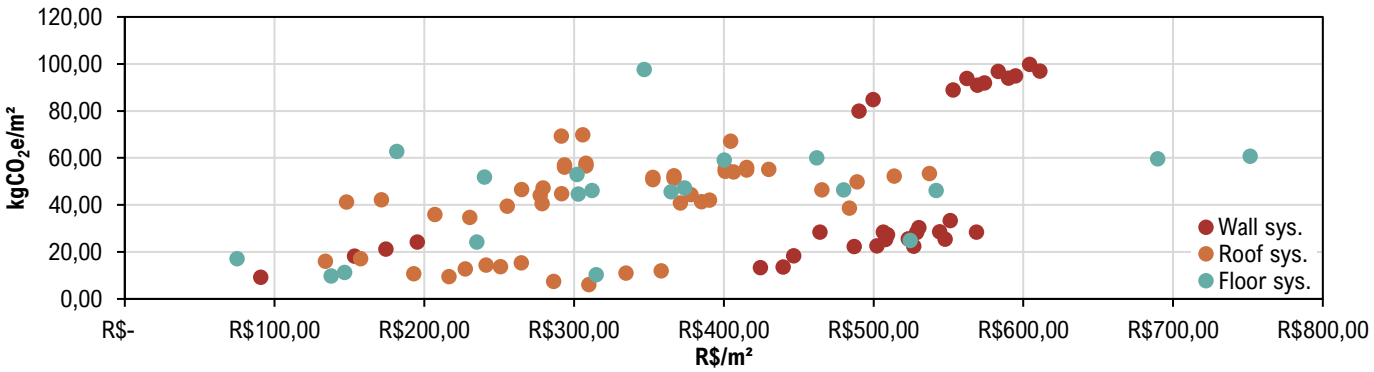

Figure 10 – Dispersion of the cost and environmental impact values of the analyzed systems. Source: authors.

As observed, there is significant variation in both cost and environmental impact among the construction systems analyzed. The most expensive floor system, comprising a slab, thermo-acoustic insulation (glass wool), subfloor, and granite, costs R$751.54/m², while the least expensive floor system—consisting solely of a subfloor and burnt cement—costs R$75.02/m². The wall system with the highest environmental impact was built with non-structural ceramic blocks (11.5 x 19 x 29 cm) laid horizontally and finished with a 2.5 cm plaster render, resulting in 99.84 $kgCO_2e/m^2$, whereas a wall composed solely of structural concrete blocks (14 x 19 x 39 cm) without a finish produced the lowest impact at 9.18 $kgCO_2e/m^2$.

Table 1 presents the cost (R$/m²) and environmental impact ($kgCO_2e/m^2$) values for the evaluated systems, highlighting significant variability. For instance, wall systems exhibit an average cost of R$482.96/m² (SD = 133.46) and an average impact of 47.13 $kgCO_2e/m^2$ (SD = 33.06). These high dispersions confirm a wide diversity of solutions, reflecting the differing quantities and types of materials used in each system.

Table 8 – Database statistics. Source: authors.

Metrics	Wall systems		Roof systems		Floor systems	
	R$/m²	$kgCO_2e/m^2$	R$/m²	$kgCO_2e/m^2$	R$/m²	$kgCO_2e/m^2$
Maximum value	611.06	99.85	537.30	69.90	751.54	97.59
Minimum value	90.75	9.18	133.98	6.17	75.02	9.83
Average	482.96	47.13	323.02	40.47	359.17	43.94
Standard deviation (SD)	133.46	33.06	95.99	18.02	172.88	21.51
Correlation coefficient	0.54		0.48		0.43	

The correlation coefficients—0.54 for walls, 0.48 for roofs, and 0.43 for floors—indicate a moderate, positive relationship between cost and CO_2e emissions, as observed in clusters of higher-cost, higher-impact systems (Figure 2). Although more expensive systems generally yield greater emissions, this correlation is not deterministic. In this study, higher-cost systems often include more material layers, which contributes to

increased embodied emissions. Still, data shows that reductions in material usage can simultaneously lower both costs and emissions, challenging the assumption that sustainable construction inherently incurs higher expenses. In practice, high-cost systems may reflect varied material combinations, resulting in diverse trade-offs. Therefore, each project must be evaluated within its specific context, taking into account the full material lifecycle and associated trade-offs, rather than relying on broad generalizations equating sustainability with increased cost.

CONCLUSIONS

In conclusion, this study developed a comprehensive database of Brazilian construction systems using data from SINAPI and SIDAC to assess costs and environmental impacts across walls, roofs, and floors. For example, the most expensive floor system cost R$751.54/m², compared to R$75.02/m² for the least expensive, while wall systems ranged from 9.18 to 99.84 $kgCO_2e/m^2$. The moderate, positive correlation coefficients—0.54 for walls, 0.48 for roofs, and 0.43 for floors—indicate that higher costs generally accompany greater emissions. However, strategic material reduction can simultaneously lower both costs and environmental impacts, challenging the notion that sustainable construction is inherently more expensive. This work underscores the importance of detailed, context-specific analyses for optimizing cost efficiency and environmental performance in the construction industry.

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The author used ChatGPT to check grammar issues and to improve readability. After using this tool, the authors reviewed and edited the content as needed and take full responsibility for the content of the publication.

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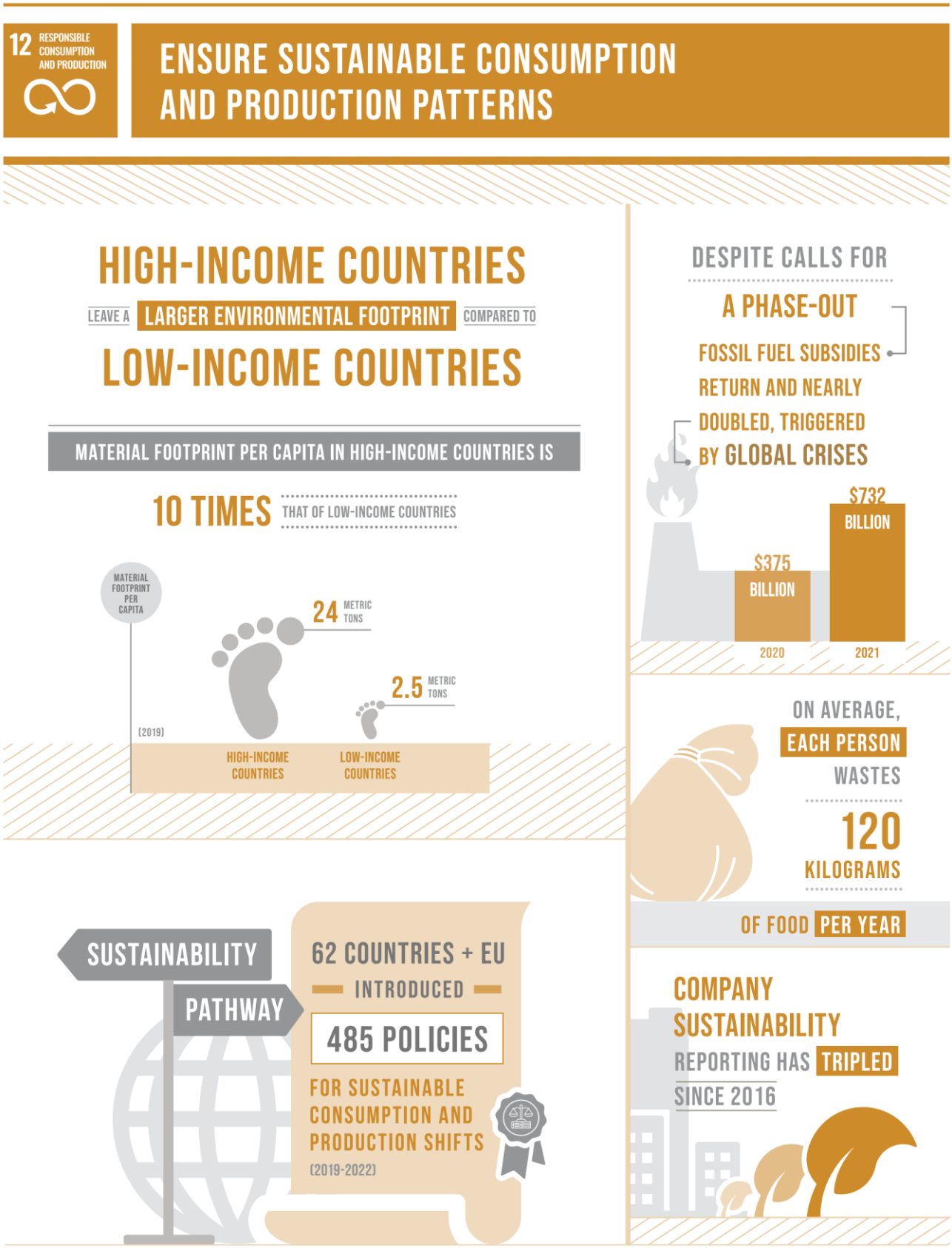
GOAL 12: ENSURE SUSTAINABLE CONSUMPTION AND PRODUCTION PATTERNS



Source: UN's The Sustainable Development Goals Report 2023 – Special Edition

USE OF WASTE AS RAILWAY BALLAST: A SYSTEMATIC REVIEW

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ABSTRACT

The extraction and processing of natural rocks for railway ballast generate severe environmental impacts, driving the search for sustainable alternatives. This article reviews the potential of solid waste as substitutes for traditional aggregates, analyzing their properties, performance, and environmental and economic feasibility. The systematic review (2014–2024) highlights tire rubber and steel slag as the most studied waste materials. The use of these materials enhances railway durability and reduces maintenance costs. The analysis concludes that incorporating waste into railway ballast can mitigate environmental impacts, lower costs, and strengthen the circular economy while ensuring adequate performance and safety for railway tracks.

Keywords: railway ballast; solid waste; recycling; environmental impact.

INTRODUCTION

Railways play a fundamental role in transporting goods and passengers over long distances, ensuring logistical and economic efficiency. However, railway infrastructure requires large volumes of ballast, a granular material responsible for track stability, drainage, and absorption of dynamic impacts [1]. Traditionally, railway ballast consists of natural rocks such as granite, basalt, and quartzite, whose extraction causes significant environmental impacts, including soil degradation, CO_2 emissions, and siltation of water bodies [2]. In addition, the high demand for railway ballast generates logistical and economic challenges, as track maintenance requires periodic replacements, raising operating costs and intensifying the exploitation of natural resources [3].

Given this scenario, the incorporation of recycled materials into railway ballast has been widely studied as a sustainable alternative. Industrial waste, such as steel slag, and polymeric materials, such as recycled tire rubber, are considered promising solutions due to their favorable physical and mechanical properties, as well as their contribution to the circular economy and the reduction of improper solid waste disposal [4, 5]. Studies indicate that using these materials can improve wear resistance, reduce degradation over time, and minimize the environmental impact associated with natural aggregate extraction [6].

Despite the environmental and economic advantages, the adoption of recycled materials in railway ballast still faces challenges, such as the lack of specific standardization, the need for experimental validation, and acceptance by railway concessionaires [7]. This study conducts a systematic review on the reuse of solid waste as a sustainable alternative, analyzing its technical performance, aiming to foster its application in the railway sector.

MATERIALS AND METHODS

The literature review was carried out between 1 and 20 December 2024, covering studies published between 2014 and 2024, focusing on the analysis of findings from the last 10 years. Brazilian Periódicos CAPES and Science Direct databases were used. The search was carried out in English and Portuguese, with the strings: ("waste" OR "residue" OR "tailings" OR "recycled aggregate" OR "by-product") AND (("railway" OR "railroad" OR "track") AND ("ballast" OR "track bed")). The selection of the papers occurred in three stages: reading of

titles and keywords, exclusion of duplicates, analysis of the abstracts to identify alignment with the objective of the study and, finally, complete reading of the selected articles. For a paper to be included, it had to present those previously mentioned terms in the title, abstract or keywords; and, upon reading its abstract, it had to address the use of waste as aggregate in railway ballast. Initially, 1,722 studies were identified, of which 31 were maintained after the final screening.

RESULTS

The studies found explore the combined use of materials, such as rubber and steel slag or even reuse ballast – that is, clean deteriorated ballast, shown in the Figure 1. In general, there is a growing interest in research that evaluates the application of industrial by-products in the railway sector. This increase is mainly driven by the high mechanical strength and durability of these materials, which have the potential to partially or totally replace natural aggregates, in addition to improving their technical properties.

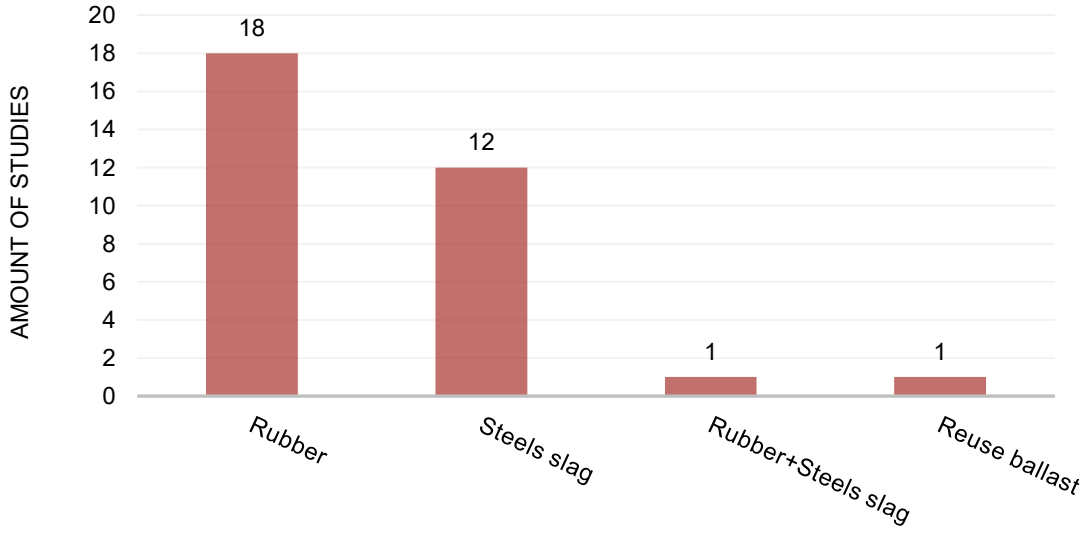

Figure 1 - Number of studies per residue. Source: Authors

Rubber is the most studied material for application in the ballasted layer, being addressed in 56% of the studies analyzed. This is due to its mechanical properties, wide availability and potential to improve ballast performance under repetitive loads. Steel slag appears in 34% of the surveys, driven by its favorable characteristics, environmental concerns about its disposal and the search for solutions to reduce this accumulation. Only one study did not investigate the use of slag or rubber, instead focusing on the reuse of previously employed aggregate waste in ballast after separation and granulometric adjustment. The main results are presented in Table 1.

Table 1 - Main characteristics in the use of waste as ballast, when compared to conventional ballast.

Material	Positive characteristics	Negative characteristics
Rubber	• Lower particle breakage; • Low Los Angeles Abrasion; • Increased track stability; • Greater lateral confinement; • Greater resistance to deformation; • Greater resistance to lateral displacement; • Reduction in vertical stress propagation; • Higher damping rate; • Vibration reduction;	• Reduction in structure stiffness; • Loss of efficiency over the years;
Slag	• Low Los Angeles Abrasion; • Lower permanent deformation; • Lower particle breakage; • Higher shear strength; • Reduced track deflection; • Higher damping rate; • Lower settlement; • Higher friction angle; • Lower permanent vertical deformation.	• Greater permanent axial deformation; • Volumetric expansion; • Higher density.
Recycled ballast	• Insignificant variations in results (mixtures containing up to 30% residue).	• Loss of angularity; • Reduces interlocking between particles.

Studies on steel slag highlight its potential as an effective alternative to crushed natural rock, meeting the physical and mechanical performance required for use as railway ballast. Authors such as [8], [9] and [10] emphasize the contribution of this alternative to the preservation of natural resources. However, none of the reviewed studies make a detailed environmental analysis of this use. In addition, economic viability is also a factor not addressed in the surveys, although it is a determining aspect for railway companies.

Studies on tire rubber confirm its viability as railway ballast, promoting positive impacts on the structural performance and durability of the system. In addition, geogrids made from recycled rubber have also shown promising results, increasing particle interlocking and reducing deformations and impacts, outperforming conventional solutions.

The results of [11] indicated that mixtures containing up to 30% of recycled ballast (produced with residues of the aggregate previously used in the ballast) have satisfactory mechanical performance, with variations considered insignificant in the results. However, higher proportions result in reduced shear strength and increased displacements. This drop in performance is attributed to the loss of angularity and smoothing of the surface texture of the reused material, which decreases the interlocking between particles in the reused ballast compared to the new ballast.

CONCLUSIONS

This study conducted a critical review of the performance of solid waste as alternative materials in the railway ballast layer. The literature review mainly identified studies on recycled tire rubber and steel slag. Comparing their performance with natural rock aggregate, most technical results were promising, although gaps remain

regarding economic and environmental performance. The findings indicate that reusing these waste materials is a promising alternative to reduce environmental impacts, minimize waste disposal, and promote sustainability in the railway sector, aligning with circular economy principles.

ACKNOWLEDGEDMENTS

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MINERALOGICAL AND CHEMICAL PROPERTIES OF SOIL AND RECYCLED CONSTRUCTION AND DEMOLITION WASTE FOR USE IN LANDFILL COVER SYSTEMS

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ABSTRACT

Landfill cover layers are largely composed of natural soils or mixtures of soils with waste, whose mineralogy directly influences their performance. Thus, the objective of this study is to identify the chemical/mineral components of soil and recycled construction and demolition waste (RCDW), considering their context of interest in studies on landfill cover layers. The chemical and mineralogical characteristics of the soil and RCDW were analyzed using X-ray fluorescence, and the qualitative characteristics and particle shape were analyzed using microscopic analysis. The results show that there are minerals in different degrees of weathering in the soil sample and that in the RCDW sample, the predominant minerals originate from the concrete materials processed for the production of the RCDW studied. It was concluded that the soil has the mineralogy of tropical soils and the RCDW has chemical elements from the materials processed for recycling.

Keywords: Minerals; chemical elements; microscopic analysis.

INTRODUCTION

Landfill cover layers can be conventional or alternative. The latter aims to repurpose waste from other industries, contributing to sustainable development in accordance with SDGs 11 [1] and 12 [1], the latter being relevant as it includes specific targets for proper waste management. They are indispensable structures, as they maintain a balance between the interaction of municipal solid waste (MSW) and the external environment, reducing greenhouse gas (GHG_S) emissions, such as methane (CH_4) and carbon dioxide (CO_2), in accordance with the premises of SDG 13, and controlling the infiltration of rainwater that can generate water pollution and counteract the objectives of SDG 6 [1,3].

The cover layer can be composed of soil or mixtures of soil and waste, whose chemical and mineralogical characteristics influence its performance and affect crucial properties such as water retention, permeability, and contaminant adsorption capacity [2,3]. The predominance of certain minerals can increase the capacity to retain liquids and decrease the flow of leachate formed [3]. Thus, chemical/mineralogical characterization and microscopic analysis are essential for the selection of materials that meet the technical and environmental criteria for landfill operation [3]. Therefore, this article aims to characterize the chemical and mineral components of soil and construction and demolition waste (RCDW), given their relevance to studies focused on landfill cover systems.

MATERIALS AND METHODS

MATERIALS

The soil used for the research comes from a private landfill located in the municipality of Guapó-GO and was collected in accordance with NBR 9604 [4]. Recycled construction and demolition waste (RCDW) is processed at a recycling plant that receives construction and demolition waste (CDW) from Goiânia-GO and Aparecida de Goiânia-GO and processes the materials using fixed jaw equipment. It should be noted that for this work, a RCDW called gray sand was chosen, which is the result of the processing of concrete materials with a finer

grain size, aiming to obtain essential characteristics (low suction and reduced permeability) for a material applied in landfill cover layers, whose main functions are to mitigate gas emissions and reduce rainwater infiltration. The RCDW collections were carried out in accordance with NBR 16915 [5] and NBR 10007 [6].

METHODS

In order to understand the physical-chemical and mineralogical properties of the soil and RCDW used, chemical analyses were performed by X-ray fluorescence (XRF) to identify major and trace elements, as well as microscopic analysis (MA) to observe qualitative characteristics and particle shape. 200 g and 100 g of the total deformed sample prepared according to NBR 6457 [7] were prepared for the XRF and MA tests, respectively. The Rigaku ZSX Primues IV spectrometer was used for XRF analysis for larger elements (oxides), a calibration curve was constructed according to natural rock and mineral standards and the results were represented as a percentage (%), and for smaller elements (traces), the GeoTrace 3 calibration curve was used, and they are represented in parts per million (p.p.m.). For MA, a U500X digital microscope with a 1 mm scale was used.

RESULTS

CHEMICAL AND MINERALOGICAL CHARACTERIZATION

The results of chemical and mineralogical characterization showed that silicon oxide, known as quartz (SiO_2), predominates in the soil, followed by aluminum oxide (Al_2O_3) and iron III oxide (Fe_2O_3). The presence of these oxides is a peculiarity of weathered soils, especially aluminum oxide, which results from the weathering process of soils that have potassium feldspar as their primary mineral [9]. Feldspar is an aluminosilicate that undergoes partial hydrolysis and forms kaolinite, a compound that contains aluminum oxide in its structure, which reacts with water to form gibbsite, a form of aluminum hydroxide [9, 10]. Gibbsite is common in tropical soils because it results from the alteration of kaolinite, a clay mineral with low expansion potential [2, 9]. Thus, the presence of kaolinite favors water retention and is recommended for impermeable barriers and cover layers because it reduces percolation and the risk of groundwater contamination [15], which is compatible with SDG 6.

The predominance of SiO_2 (quartz) and the presence of TiO_2 were expected, as these oxides are stable and common in tropical soils [10,11]. Quartz makes up the majority of the granulometric fractions (sand, silt, and clay) of the analyzed material. The presence of Fe_2O_3 is indicative of tropical soils, since this compound is responsible for the concretions present and the characteristic coloration, which is consistent with studies by Almeida and colleagues [12] who studied soils in the Metropolitan Region of Goiânia. The loss on ignition (LOI) index indicated low organic matter content and refers to tropical soils [10]. In RCDW, there is a predominance of silicon oxide (SiO_2), calcium oxide (CaO) and aluminum oxide (Al_2O_3), which are materials present in the region's sands that are used to make concrete materials, which compose the RCDW, except for Al_2O_3, which indicates the presence of red ceramic-type material residues and soil that may be the result of traces of other types of materials recycled by the plant.

As for minor elements, strontium (Sr), barium (Ba) and chromium (Cr) are the most abundant elements found in RCDW, being related to the chemical elements present in Portland cement, used to manufacture concrete materials [13]. Vanadium (V), zirconium (Zr) and chromium (Cr) are the elements found in the highest quantities in the soil, and the presence of these minerals in the soil is related to the lithology found in the region, formed by intrusive bodies of Piracanjuba type granites and metamorphic rocks, which, even under extreme weathering conditions, is the most influential in the formation of these elements [14]. Mineralogical analysis is essential because minerals influence water retention, permeability, and aggregation, which are indispensable characteristics for efficient performance of cover layers [2].

MICROSCOPIC ANALYSIS

Figure 1 shows the soil (a) and RCDW (b) samples, respectively. In Figure 1.a shows that the soil sample contains rounded, reddish grains, which is characteristic of the type of soil studied: tropical soil. Heterogeneous particles can also be seen, suggesting a well-graded soil particle size distribution. Figure 1.b shows the RCDW particles in detail, and it can be seen that there are rounded and angular grains, a characteristic shape due to the material processing process. As for the grayish color, it is attributed to the predominance of concrete materials, but there are particles that have a color similar to that of soil (detailed in the arrows), which may be indicative of the presence of soil or ceramic materials, suggesting that before processing, these materials may have adhered to the crushing equipment and/or been contaminated during collection, since it was carried out manually using tools such as shovels and hoes.

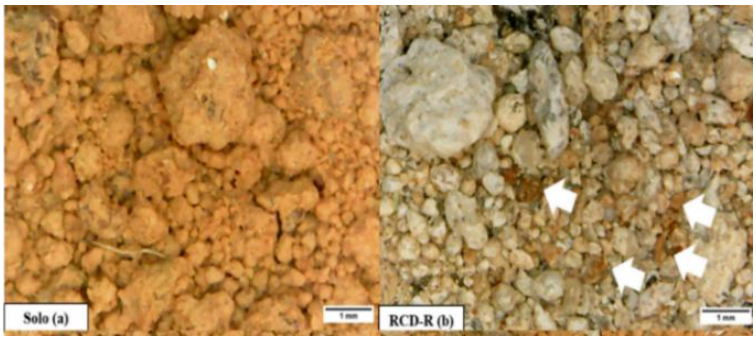

Figure 1 – Images obtained by digital microscopy: (a) natural soil and (b) recycled construction and demolition waste (RCDW) [8].

CONCLUSIONS

Chemical and microscopic analyses conclude that the soil has characteristics of tropical soils and that the RCDW has a composition consistent with the materials used during its processing. Therefore, analyzing the mineralogy of the materials to be used in the cover layers is essential, as they influence the hydraulic performance in terms of geotechnical characteristics, stability, and chemical reactivity of these layers, which are essential characteristics for efficient cover layers, especially those that apply alternative materials, as in the case study of RCDW. These aspects are fundamental to ensuring the proper functioning of cover systems in landfills, contributing to the protection of groundwater quality (SDG 6), the promotion of more sustainable cities and communities (SDG 11), the encouragement of responsible use of resources, waste recycling (SDG 12), and mitigating environmental impacts associated with climate change (SDG 13).

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FEASIBILITY STUDY OF RECYCLING 3D PRINTED COMPOSITES FOR CIRCULAR ECONOMY APPLICATIONS

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ABSTRACT

This study explores the integration of 3D printing with circular economy principles by evaluating the feasibility of recycling composite 3D-printed materials. There are three types of filaments that were used to produce 3D-printed specimens, which are virgin Polylactic Acid (PLA), PLA reinforced with wood (PLA – Wood), and Acrylonitrile Butadiene Styrene reinforced with carbon fiber (ABS – CF). The after-use filaments were shredded, mixed, and extruded to make the new filaments. Mechanical strength analysis revealed degradation occurred in the recycled filaments, especially for PLA and PLA-Wood, which exhibited brittleness. The results suggest that recycling 3D-printed composites is technically feasible but requires necessary enhancements such as adding plasticizer and moisture control to improve filament quality for future trials. The study provides practical insights to improve recycling workflows in additive manufacturing and supports the shift from linear to circular production models.

Keywords: 3D printing; circular economy; PLA; filament recycling; natural fiber composites.

INTRODUCTION

Additive manufacturing or 3D printing has appeared as a primary enabler of the circular economy since it has an inherent ability to enhance resource efficiency and minimize material wastage. Furthermore, 3D printing technology can support sustainable production by enabling the use of materials precisely when needed, limiting overproduction, and helping local or in-house manufacturing [1]. As a digital production method, 3D printing has a key role in advancing circular economy practices, and digitalization is viewed as one of the main drivers of such a transition [2]. It enables several circular strategies, including the use of recycled feedstock, repair and remanufacturing components, and recycling material during the end-of-life of a product [3]. These abilities position 3D printing as a key technology for the development of closed-loop manufacturing systems and the advancement of long-term economic and environmental sustainability.

Polylactic Acid (PLA) and Acrylonitrile Butadiene Styrene (ABS) are the most used thermoplastics in 3D printing technology. These 3D printing filaments have also been reinforced with other reinforcements to become composites, increasing the strength and stiffness of the printed materials. As an example, the ABS with carbon fiber, PLA with carbon fiber and PLA with wood [4] [5]. By recycling 3D-printed components will add value and produce quality products through circular economic approach as shown in Figure 1, protecting nature [6] [7]. The circular economic approach emphasizes the 3Rs - reduce, reuse, and recycle, as highlighted by recent studies [8] [9].

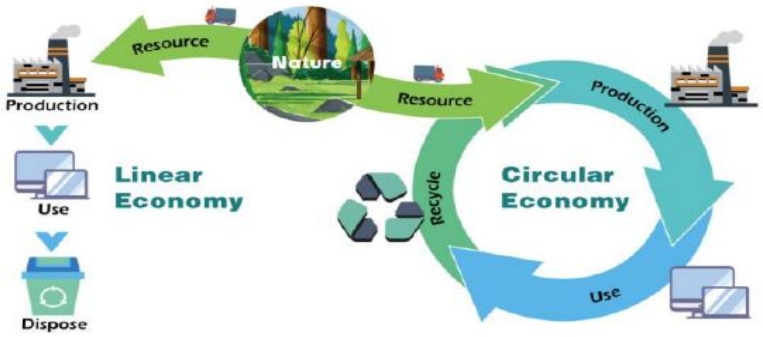

Figure 1: Transition from linear economy to circular economy [9].

MATERIALS AND METHODS

The process of making the filament from recycled 3D-printed filament consists of four main steps: shredding, blending, drying, and extrusion. The experiment began with the 3D printing of ASTM D638-IV standard tensile specimens using PLA, PLA-Wood, and ABS-CF filaments as in Figure 2. The PLA-Wood filament utilized in this study is a commercially available product from Sunlu, comprising PLA blended with approximately 10 – 15% wood powder where the types of wood used in the filament was not disclosed by the manufacturer. While for the ABS – CF filament used in this research is also commercially available in the market consist of ABS reinforced with short carbon fibers. The post-use specimens were re-shredded into small pellets and remixed to give a homogeneous mixture using a sigma blade mixer. The pellets were then dried using a vacuum oven and extruded using a single-screw extruder to form the recycled filament. Then, the filament quality was assessed, and their ultimate tensile strength was measured to compare the mechanical strength before and after the recycling process. The specimens were re-printed using a Prusa i3 MK3S+. Figure 3 shows the processes involved in making the recycled 3D printing filaments.

(a) (b) (c)

Figure 2: a) PLA-Wood specimen; b) PLA specimens; c) ABS-CF specimens

(a) (b) (c) (d) (e)

Figure 3: Process of making the recycled 3D printing filament, which includes: (a) shredding of post-use 3D printed parts into pellets, (b) mixing for homogeneity using a sigma blade mixer, (c) extrusion of recycled filament using single screw-extruder, (d) 3D printing of test specimens, and (e) mechanical testing.

RESULTS

The stress-strain curves of recycled and virgin filaments for PLA, PLA-Wood, and ABS-CF are shown in Figure 4. Based on the results, recycled PLA had the highest ultimate tensile strength (UTS) of around 19.71 MPa at a strain of about 0.06 mm/mm. In contrast, virgin PLA showed a consistently higher stress response due to their good ductility and structural integrity. The decrement of performance for the recycled PLA is primarily attributed to thermal degradation during reprocessing when exposed to elevated temperatures and leads to the disruption of microstructure and reduction in molecular weight [10] [11]. The recycled PLA-Wood filament recorded a peak stress of 13.22 MPa with a relatively stable plateau between 0.05 and 0.10 mm/mm, suggesting effective energy absorption attributed to the presence of natural wood fibers.

In contrast, ABS-CF had a maximum stress of 16.83 MPa at roughly 0.05 mm/mm strain but had a rapid and notable decline in stress right thereafter. This is possibly due to the brittle mechanical behavior and lower elongation capacity under tensile load which make the sudden drop to low ductility behavior. This contrasts with virgin ABS, which showed a higher strength profile and smooth stress distribution. These comparative curves clearly demonstrate that while recycled PLA retains high tensile strength, it experiences a reduction in mechanical strength. PLA – Wood offers a balance between strength and deformation even the ultimate tensile strength is the lowest, while ABS – CF, despite its initial high strength suffers a poor elongation and sudden failure under tension. Based on the observations, the PLA filament tends to degrade after recycling compared to other filaments, and the addition of virgin PLA during mixing improved the quality of the PLA filament. This is evident the mechanical degradation occurs during recycling when the typical ultimate tensile strength for the virgin PLA was approximately recorded at 53 MPa [10] [11].

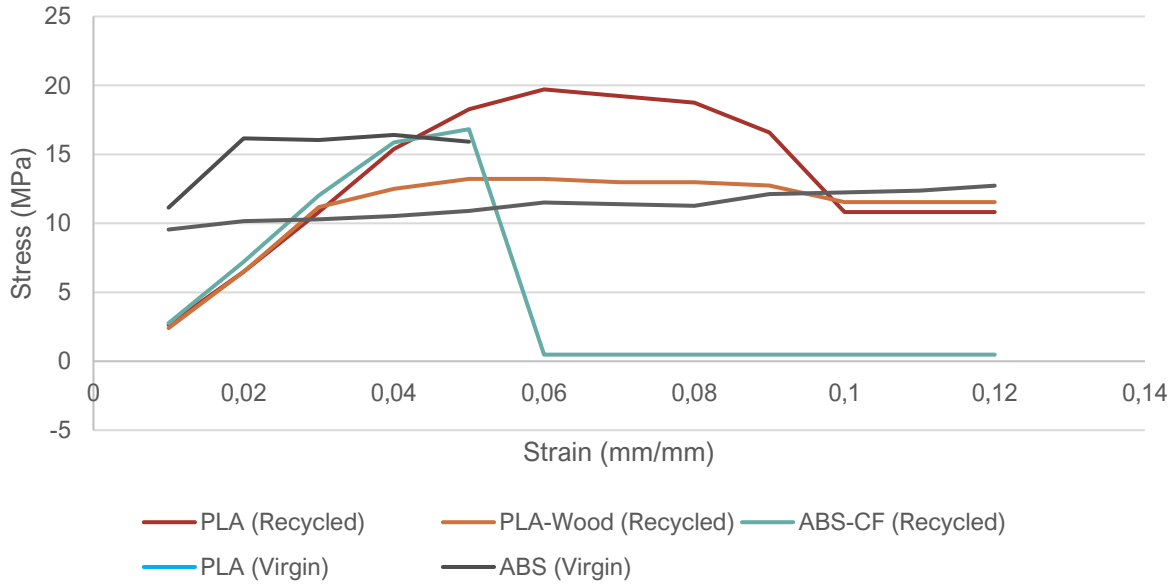

Figure 4: The comparison of mechanical strength for the recycled 3D printing filament.

CONCLUSIONS

This study confirms that recycling 3D-printed composite parts into usable filament is feasible but requires optimization within a circular economy framework. The brittleness of PLA-based recycled filaments highlights the need for improvements such as blending with virgin polymers, controlling the moisture and adding plasticizers such as polyethylene glycol to restore ductility and enhance printability of the recycled filaments [11][12]. Future work will explore the suitable additives to optimize the quality and durability of recycled composite filaments and the findings from this study support the integration of addition manufacturing into

circular economy frameworks, enabling sustainable reuse of materials in prototyping and production to support sustainable additive manufacturing.

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