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Energy-Efficient Practices in Reinforcing Steel Activities During Construction

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Abstract

The construction sector is a significant consumer of energy worldwide, and reducing this consumption requires that each construction process is carried out in an energy-efficient manner. This paper aims to present the findings from an energy efficiency program implemented during the construction of a business complex in Mexico, with a specific focus on the processes related to reinforcing steel activities. The results of the study highlight that the appropriate use of equipment, coupled with effective coordination between engineers and workers, can significantly enhance energy efficiency during the construction phase. These improvements not only contribute to reducing energy consumption but also minimize material waste, demonstrating a dual benefit in both energy and resource management. However, the paper also discusses the challenges associated with integrating energy efficiency into the cleaner production framework. Identifying and estimating energy inefficiencies in the construction process is complex, particularly because much of the focus in energy efficiency studies tends to be on the operational phase of buildings rather than the construction phase. The construction phase typically consumes less energy over the building's life cycle, leading to a relative scarcity of research and evidence on energy efficiency during this stage. This paper seeks to fill that gap by providing practical insights and experiences that can serve as a valuable resource for construction professionals. By sharing these findings, the paper aims to offer a stronger foundation for making informed decisions about energy efficiency in the construction industry. Ultimately, it advocates for a more comprehensive approach to energy management in construction, emphasizing the importance of efficiency not only during building operation but also throughout the construction process.

Keywords: Energy Efficiency, Construction Process, Reinforcing Steel

JEL Codes: Q40, L74, O13

1. INTRODUCTION

Buildings represent a significant portion of the world's energy consumption, accounting for approximately 40% of global energy use (WBCSD, 2009). Several key factors contribute to this extensive energy demand, making buildings a focal point in efforts to improve sustainability and reduce overall energy consumption. Among the primary contributors are the location, building materials, and design of the structures. The location of a building plays a major role in determining its energy needs. Buildings in different climates and geographical areas experience varying demands for heating, cooling, and lighting. For instance, buildings in colder regions require more energy for heating, while those in warmer areas might consume more energy for air conditioning. Furthermore, the proximity of buildings to transportation networks, services, and workplaces can impact energy use by influencing commuting patterns and transportation energy consumption. The choice of building materials is another crucial factor. Materials with poor insulation properties, for example, lead to higher energy use for heating and cooling, as they allow heat transfer more easily. Conversely, using materials with superior thermal performance, such as high-efficiency insulation, energy-efficient windows, and reflective roofing, can significantly reduce a building's energy demand. Moreover, the use of sustainable or recycled materials can lower the environmental impact associated with resource extraction and material production, contributing to a building's overall sustainability.

Building design is also a critical determinant of energy consumption. A well-designed building can incorporate energy-efficient features such as passive solar heating, natural ventilation, and optimized lighting. Elements such as the orientation of the building, window placement, and the use of shading can minimize energy requirements for heating, cooling, and lighting. Additionally, integrating energy-efficient technologies, like smart HVAC (Heating, Ventilation, and Air Conditioning) systems and energy-saving appliances, can further decrease energy consumption. Green building certifications, such as LEED (Leadership in Energy and Environmental Design) or BREEAM (Building Research Establishment Environmental Assessment Method), often promote these design features as essential components of sustainable construction. Moreover, urban planning plays a complementary role, as the design of entire neighborhoods or cities influences building energy use. Dense, walkable communities reduce reliance on vehicles, thereby decreasing energy used for transportation, while integrated green spaces and energy-efficient infrastructure contribute to lower overall energy consumption. To address the energy demands of buildings, several innovative approaches are being pursued. These include the development of zero-energy buildings, which produce as much energy as they consume, typically through renewable energy sources such as solar panels. Similarly, smart buildings utilize advanced technologies

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to monitor and control energy usage in real-time, optimizing energy efficiency while maintaining occupant comfort. In the face of growing concerns over climate change, the focus on reducing the energy footprint of buildings is becoming increasingly important. Enhancing energy efficiency through improved building materials, location strategies, and intelligent design is not only critical for reducing global energy consumption but also essential for meeting sustainability goals, mitigating environmental impacts, and creating resilient communities (Chou et al., 2017). As urbanization continues to rise, making buildings more energy-efficient and environmentally friendly will play a key role in addressing the challenges of sustainable development on a global scale. One effective way to reduce energy consumption in buildings is to focus on improving the efficiency of every phase of the construction process, from sourcing raw materials to the final stages of demolition and waste management (Peláez Ramos, 2011). Each phase of the construction lifecycle presents opportunities for minimizing energy use and reducing the environmental impact of buildings. The first phase, which involves obtaining and processing raw materials, plays a crucial role in determining the overall energy footprint of a building. Sourcing materials locally can reduce the energy required for transportation, while using recycled or sustainably harvested materials can decrease the environmental impact associated with extraction and production. Additionally, selecting materials with lower embodied energy—such as those that require less energy to manufacture and transport—helps to reduce the overall energy consumption of the building even before construction begins.

During the construction phase, implementing energy-efficient practices can significantly reduce energy use. This includes utilizing energy-efficient machinery and equipment, optimizing construction schedules to minimize resource waste, and reducing energy use on-site by using temporary structures that are energy-efficient. Furthermore, incorporating sustainable construction techniques such as modular or prefabricated components can also contribute to energy savings by reducing construction time and material waste. Once a building is complete, its operational phase represents the largest portion of its energy consumption over its lifetime. By integrating energy-efficient technologies such as high-performance insulation, low-energy lighting systems, and smart HVAC systems, energy use can be dramatically reduced. Building automation systems, which monitor and optimize energy use in real-time, are also key to enhancing efficiency during this phase. Another critical consideration is the maintenance and repair phase. Regular maintenance using energy-efficient practices and sustainable materials ensures that the building remains energy-efficient throughout its lifespan. Preventive maintenance also reduces the need for energy-intensive repairs and replacements over time.

The demolition and waste management phase presents further opportunities for energy reduction. Adopting strategies such as deconstruction—the careful disassembly of a building to recover reusable materials—helps minimize energy use associated with producing new materials. Recycling and repurposing materials from demolished structures also reduce the energy required to manufacture and transport new materials for future construction projects. Additionally, proper waste management practices, such as sorting construction waste for recycling, help to minimize the energy associated with landfill disposal. By focusing on energy efficiency across all phases of the construction lifecycle—raw material sourcing, construction, operation, maintenance, and demolition—a significant reduction in energy consumption can be achieved. This holistic approach ensures that every stage of a building’s life contributes to a more sustainable, energy-efficient built environment. Such strategies are essential for addressing global energy challenges and creating a more sustainable construction industry. The purpose of this paper is to present the findings of a case study on reinforcing steel (rebar) activities in the construction of a business complex in Hermosillo, Sonora, Mexico, as part of a broader energy efficiency program. The study aims to explore how energy-efficient practices can be applied in specific construction activities to reduce overall energy consumption and enhance sustainability.

The paper is organized as follows: The next section provides a literature review on sustainability and energy efficiency in construction, as well as related topics such as energy-efficient materials and processes. Section three outlines the methodology employed in the study, detailing the data collection and analysis methods used to evaluate energy efficiency during the rebar activities. Section four presents the results of the case study, highlighting key findings and the impact of energy-efficient practices on the construction process. Finally, the last section offers concluding remarks, summarizing the study’s contributions to the field and suggesting potential areas for further research or practical applications.

2. LITERATURE REVIEW

Construction processes generate a wide range of environmental impacts, including the emission of greenhouse gases and other air pollutants (Zhang et al., 2014). To mitigate these impacts, it is crucial to integrate sustainable development principles into the construction sector (Passer et al., 2015). According to the Nordic Innovation institution (2014), the primary objectives of sustainable construction activities are to prevent the depletion of vital resources such as energy, water, and raw materials, while also preventing environmental degradation caused by the construction and operation of facilities and infrastructure throughout their entire life cycle. Sustainable construction focuses on minimizing the negative environmental impacts by employing energy-efficient practices, reducing waste, and using renewable or recycled materials. Additionally, sustainable construction aims to optimize resource use and improve the long-term performance of buildings, ensuring that they contribute to ecological, economic, and social sustainability. This holistic approach requires the adoption of green building technologies, improved design strategies, and environmentally conscious decision-making in every phase of the construction process, from planning and material sourcing to demolition and waste management. By incorporating these principles, the construction industry can play a key role in reducing its environmental footprint and advancing global sustainability goals.

Although the construction sector is often marked by frequent delays, budget overruns, and challenges in maintaining consistent quality (Nowotarski et al., 2016), the field of sustainable building construction has seen substantial growth in recent years (Wibogo et al., 2017). Despite this positive trend, the industry still lacks a comprehensive and well-structured framework for sustainability (Alwan et al., 2017). This absence of a standardized approach highlights the need for more thorough investigation and strategic development to align the construction sector more effectively with the overarching goals of sustainable development (Alsudairi, 2015). Without a robust sustainability framework, efforts to integrate environmental, social, and economic considerations into construction practices may remain inconsistent or superficial. Sustainable construction requires not only the adoption of green technologies and materials but also improvements in project management, design, and long-term operation to minimize negative environmental impacts. As such, developing a clear, industry-wide approach to sustainability is essential for driving more consistent and impactful outcomes, ensuring that the sector contributes meaningfully to global sustainability objectives. Further research and policy development are necessary to address these gaps and create standards that encourage sustainable practices across all stages of construction projects. Some of the key supporting activities for sustainable construction include strengthening technology innovation, improving standards and evaluation frameworks, establishing demonstration projects, and increasing public awareness (Chang et al., 2016). These activities are essential for fostering the growth of sustainable practices within the construction industry and encouraging the adoption of environmentally responsible methods. To achieve meaningful progress in sustainable construction, it is crucial to ensure strict supervision and enforcement of sustainable practices throughout the entire project lifecycle. This involves overseeing the meticulous application of construction planning, monitoring construction methods at each phase, and ensuring that the execution of all works adheres to recognized environmental standards (Kalfa and Kalogirou, 2017). By rigorously applying these principles, the construction sector can minimize its environmental impact, reduce resource consumption, and ensure that projects contribute positively to the goals of sustainable development.

In addition, continuous monitoring and evaluation against these standards are vital to ensure compliance and identify areas for improvement. Establishing demonstration projects serves as a practical way to showcase sustainable construction methods, highlighting the benefits and feasibility of eco-friendly designs, materials, and techniques. Publicity and awareness-raising efforts further help to spread knowledge about sustainable construction practices and encourage stakeholders across the industry to adopt these methods. This multifaceted approach is necessary to embed sustainability into the construction industry on a broader scale and drive long-term change. Particularly in developing countries, the construction industry often exhibits low levels of sustainability awareness, as these nations are only beginning to address the complex challenges associated with sustainable development (Tabassi et al., 2016). This presents a significant hurdle, as the responsibility for understanding and translating high-level strategic sustainability objectives into concrete, actionable steps at the project-specific level is critical (Ugwu and Haupt, 2007). However, this task is often underappreciated or not fully integrated into construction practices, leading to missed opportunities for creating genuinely sustainable outcomes.

A common misconception in the construction sector is that focusing solely on the early stages of a project, such as planning and design, or managing impacts through on-site practices, will automatically lead to sustainable construction outcomes. While these efforts are important, they are not sufficient on their own to ensure sustainability. As Ding (2007) notes, simply relying on early project steps or minimizing environmental impacts through appropriate on-site management does not necessarily guarantee that the project as a whole will meet sustainability goals. True sustainable construction requires a comprehensive approach that encompasses the entire project lifecycle—from design and material selection to construction, operation, and eventual decommissioning. It also necessitates continuous engagement with sustainability objectives at every stage, ensuring that strategic goals are consistently translated into tangible, project-specific actions. For developing countries, overcoming these challenges involves raising awareness of sustainability within the industry, building capacity for sustainable practices, and integrating these objectives into all phases of construction. This means fostering a deeper understanding of sustainability principles, improving education and training in the sector, and developing robust frameworks that can guide projects toward long-term sustainability, rather than relying on piecemeal efforts.

Advancing sustainability can be effectively achieved through energy efficiency, as it significantly contributes to reducing greenhouse gas emissions (Ganda & Ngwakwe, 2014). Buildings that are designed and constructed with high energy efficiency not only help mitigate environmental impacts but also lead to substantial economic savings in construction processes (Ladenhauf et al., 2015). This dual benefit—environmental protection and cost efficiency—makes energy-efficient building design a crucial component of sustainable development. To achieve this, it is necessary to develop a sustainable design model that focuses on the optimal combination of construction materials and energy-efficient strategies. During the construction phase, materials and equipment are primary contributors to carbon emissions, highlighting the need for careful selection and use of low-carbon alternatives. Proper planning, management, and efficient application of equipment are essential in reducing energy consumption. These practices not only lower carbon footprints but also contribute to reducing operating and maintenance costs in the long run (Choi et al., 2016; Zhang & Wang, 2016; Kirimtat et al., 2016). The sustainable design model should consider energy-efficient materials, such as recycled or renewable resources, alongside the use of advanced construction technologies that minimize waste and optimize resource use. Additionally, incorporating energy-efficient equipment and technologies, such as smart systems for lighting, heating, and cooling, can significantly reduce energy use during both construction and operation phases. By focusing on the life cycle of materials and equipment, sustainable construction practices can be embedded from the early planning stages, ensuring long-term energy savings and contributing to broader sustainability goals.

3. METHODOLOGY

An energy efficiency program was implemented in the construction of a commercial and business complex located in Hermosillo, northwestern Mexico, through a collaborative effort between the construction company and the Sustainability Graduate Program of the University of Sonora. The program followed the Cleaner Production-Energy Efficiency approach proposed by UNEP (2004), which comprises five key stages: planning and organization, pre-assessment, assessment, options evaluation, and implementation and continuity. The focus of the study was on the reinforcing steel (rebar) activities during the construction of one of the three buildings in the complex, covering the period from April 2016 to January 2017. This activity was selected due to its significant contribution to energy consumption and carbon emissions, given the intensive use of steel and machinery involved in the process. The methodology aimed to identify areas for improving energy efficiency and reducing greenhouse gas emissions throughout the construction phase. Data for the study were gathered from various sources, including technical specifications found in equipment and machinery labels, as well as user manuals. These resources provided critical insights into energy consumption patterns and equipment efficiency levels, which were then analyzed to identify potential improvements. The program's structured approach ensured that the evaluation of energy use was comprehensive, addressing all aspects of the reinforcing steel activities, from material handling to on-site machinery operations. By incorporating the Cleaner Production-Energy Efficiency framework, the project aimed not only to reduce energy consumption during construction but also to serve as a model for future projects in the region. The collaboration between academia and industry was essential for integrating sustainability principles into practical construction processes, contributing to both environmental and economic goals. The successful implementation of the energy efficiency measures in this project underscores the importance of continued collaboration between educational institutions and the construction sector to foster innovation and sustainable development practices in construction projects.

4. RESULTS

The first stage of the energy efficiency program, planning and organization, commenced with a meeting between the top management of the construction company and representatives from the Sustainability Graduate Program of the University of Sonora. The purpose of the meeting was to present the potential benefits of implementing an energy efficiency program within the construction industry. As a result of this meeting, a formal agreement was signed between both parties, marking the beginning of the collaboration. To facilitate the program, an energy efficiency team was formed, consisting of both company personnel and university members, which ensured a structured and organized approach to the tasks ahead. In the pre-assessment stage, the team created a process flow diagram detailing the material and energy inputs and outputs, which was crucial for identifying the primary activities within the construction process that could be targeted for efficiency improvements. This step provided a comprehensive overview of where energy was being consumed and what materials were being used. Walkthroughs of the construction site were conducted alongside the project manager and construction manager. These site visits helped the team gain a preliminary understanding of potential inefficiencies in the energy use, allowing them to develop an initial perspective on areas that required attention. The goal at this stage was to identify opportunities for improvement. One key issue that immediately stood out during the walkthroughs and team discussions was the long distance between the location where reinforcing steel activities were taking place and the final site of the concrete casting. This inefficient layout resulted in increased energy use for transporting the steel, presenting a clear area for improvement.

The assessment stage involved a more detailed characterization of the equipment used in the reinforcing steel activities. The team conducted an inventory of all equipment and analyzed its energy consumption. For instance, each steel cutter was found to consume 2 kW per hour and was used throughout the entire working day. The tower cranes used in the project consumed 324.4 kW per hour, while the all-terrain cranes used 20.90 liters of diesel per hour. The usage of both types of cranes varied based on the daily construction needs. To facilitate the identification of potential energy savings and reductions in greenhouse gas emissions, the construction process was divided into two main parts: steel cutting and the movement of steel structures. This division allowed the energy efficiency team to focus on these critical activities and determine where significant energy consumption and CO2-equivalent emissions (CO2-eq) reductions could be achieved. Through this structured and methodical approach, the program aimed to reduce energy consumption in reinforcing steel activities while minimizing the associated carbon emissions. The findings from the assessment laid the groundwork for identifying actionable steps that could lead to improved energy efficiency and more sustainable construction practices. This detailed evaluation of equipment use and process inefficiencies was a crucial part of ensuring that the construction project not only met its immediate energy-saving goals but also served as a model for future energy-efficient construction projects.

At this stage, the proposed options were evaluated through three key perspectives: technical, environmental, and economic. The technical evaluation considered the consumption of materials and energy, the time required to implement each proposal, and the impact these changes would have on the quality of the construction processes. The results showed that Proposal P01, which focused on improving the organization between workers and engineers during the steel-cutting process, would enhance production quality and help with the maintenance of equipment. This proposal would reduce the amount of steel waste and lead to a more efficient use of steel cutters, ultimately extending the lifespan of the equipment by reducing wear and tear. Proposal P02, which involved creating a dedicated cutting area, would streamline the process and minimize wasted time, improving overall efficiency. Proposal P03, centered on coordinating crane operators and engineers, would reduce the need for human labor and improve crane maintenance, leading to savings in crane repair costs. Finally, Proposal P04 aimed to reduce time wastage and improve future processes, which would lead to better production quality by refining workflow efficiency. The environmental evaluation focused on whether the proposals would contribute to reducing greenhouse gas emissions, fossil fuel consumption, and risks to construction workers. Common environmental and safety risks were also examined. Proposal P01, by improving organization in the steel-cutting area, would help reduce solid waste, thus decreasing the environmental impact of steel waste disposal. Proposal P03 was expected to reduce greenhouse gas emissions by enhancing the coordination of crane operations. Better scheduling and more efficient use of the cranes would result in fewer emissions by minimizing idle time and unnecessary fuel consumption. However, Proposals P02 and P04 did not offer significant environmental benefits. Their main focus was on improving time efficiency, rather than directly addressing environmental concerns. From an economic perspective, the proposals were evaluated based on potential cost savings and the reduction of operational expenses. Proposal P01 was likely to yield economic benefits by reducing steel waste and optimizing the use of equipment, which would lower material costs and reduce wear on machinery. Proposal P03, through improved coordination of crane operations, was expected to lower labor costs and reduce maintenance expenses, providing direct financial benefits to the project. While Proposals P02 and P04 were primarily focused on time-saving measures, these improvements in workflow and productivity could also lead to indirect economic gains by enhancing overall project efficiency.

The evaluation revealed that Proposal P01 and P03 offered substantial technical, environmental, and economic advantages, particularly in reducing steel waste and greenhouse gas emissions. These proposals would significantly enhance the overall efficiency and sustainability of the construction process. Although Proposals P02 and P04 did not have a major environmental impact, they contributed to time management improvements and higher production quality, offering benefits in terms of operational efficiency and long-term sustainability. Lastly, the economic evaluation considered the investment required for each proposal, including the potential impact on energy and material savings. Given the specific nature of the activities examined in this study and the practicality of the proposed solutions, the maximum investment needed for implementation was relatively modest, totaling less than four hundred US dollars. This low-cost investment made the proposals highly feasible, especially considering the potential long-term benefits in terms of energy efficiency and resource optimization.

An implementation action plan was created to outline the timing, tasks, and responsibilities for putting these proposals into practice. This plan prioritized implementation based on the availability of resources, ensuring that the most impactful changes could be made without overstretching the project's budget or workforce. The approval of the senior management was a crucial step in moving forward, and once secured, all proposals were implemented. One of the most significant outcomes was the reduction in process inefficiencies, particularly regarding the unnecessary use of cranes. By optimizing crane operations, the project achieved an estimated daily reduction of 18.613 kg of CO2-equivalent emissions. This demonstrates the potential environmental benefits of the proposals, as well as their contribution to making the construction process more energy-efficient and sustainable. The combination of technical, environmental, and economic improvements highlights the overall success of the energy efficiency program, underscoring the importance of small, practical changes in achieving broader sustainability goals.

5. DISCUSSION AND CONCLUSIONS

The construction industry has significant environmental and health impacts throughout its entire life cycle, including resource depletion, material waste, and high energy consumption. These issues are compounded by the industry's contribution to greenhouse gas emissions, which exacerbate climate change. From a sustainability perspective, energy efficiency is a critical factor to consider in this sector. By improving energy efficiency, not only can resource use be optimized, but greenhouse gas emissions can also be minimized, reducing the industry's overall environmental footprint. Addressing these challenges through energy-efficient practices is essential for promoting sustainability within the construction industry, as it directly influences both ecological preservation and climate change mitigation efforts. This study demonstrated that, despite the complexity of construction processes—characterized by multiple operations and the involvement of numerous individuals—there are still significant opportunities for improvement by targeting specific areas. For instance, focusing on reinforcing steel activities revealed substantial potential for enhancing energy efficiency and reducing environmental impacts.

By addressing these specific tasks within the broader construction process, meaningful changes can be implemented that contribute to overall sustainability goals, proving that even in a complex industry, targeted interventions can lead to impactful results. Particularly, the Cleaner Production-Energy Efficiency program proposed by UNEP (2004) proved to be an effective tool for identifying inefficiencies in operations such as steel-cutting and site structure transportation, where large equipment is involved. The results of the program revealed some short-term benefits in reinforcing steel activities, including minor reductions in operation time and modest resource recovery. These improvements contributed to an average daily reduction of 18.613 kg of CO2-equivalent emissions, demonstrating the potential for even small operational adjustments to make a positive environmental impact. While the immediate benefits may appear modest, the study highlights how targeted interventions in key construction processes can contribute to more sustainable outcomes over time. Nevertheless, the most significant potential benefits of the program are expected to be realized over the long term. As a result of the positive perception from top management regarding the outcomes of the program, it is anticipated that this approach will be extended to other construction activities on the site, such as concrete casting, steel structure insertion, and block wall construction. The Cleaner Production-Energy Efficiency approach offers additional value beyond immediate energy savings. Its implementation has the potential to not only enhance energy efficiency but also uncover opportunities in other important areas, such as occupational health and safety. By improving operational processes and reducing inefficiencies, the program can create safer working conditions, reduce waste, and contribute to a more sustainable construction model. Over time, these improvements can have a lasting impact on both environmental performance and worker well-being, making the program an essential tool for sustainable development within the construction industry.

Despite the numerous benefits that energy efficiency programs can offer, there are inherent challenges in applying such initiatives within the construction sector. Unlike more standardized industries, daily operations in construction are highly variable, making it difficult to measure and track energy efficiency improvements consistently. As highlighted by the OECD/IEA report (Tanaka, 2008), the dynamic nature of construction projects complicates data collection and slows the process of consistently tracking changes in energy use. Each construction site and project can have different variables, which adds complexity to evaluating energy consumption and assessing progress. Nevertheless, the implementations in this project provide clear evidence that adopting strategies such as effective material waste management and the efficient use of large equipment can deliver tangible economic and environmental benefits. Properly managing material waste reduces both costs and resource depletion, while optimizing the use of heavy machinery minimizes energy consumption and associated emissions. Despite the challenges in data collection and tracking, these practical interventions have proven to be effective in advancing sustainability goals within the construction industry. This suggests that even in a complex, non-standardized sector, targeted efforts toward energy efficiency can yield meaningful outcomes. Although this paper presents the results of a single case, it operates under the assumption that the construction industry exhibits similar behavior across the northern region of Mexico. As such, the findings from this study can serve as valuable insights for decision-makers and key stakeholders in the sector. The information provided could support more informed decisions aimed at significantly improving energy efficiency and reducing energy consumption in construction projects.

A final remark is the importance of adopting a more integrative approach to making the construction industry not only more energy-efficient but also more environmentally and socially responsible. Balancing these objectives while ensuring economic feasibility is crucial for enhancing the industry's overall performance. By incorporating sustainable practices at every stage—focusing on energy efficiency, reducing waste, and improving occupational safety—stakeholders can push the construction sector toward a more sustainable future. Ultimately, these efforts contribute to building a more sustainable world, where environmental stewardship, social responsibility, and economic viability coexist and reinforce each other.

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