Development of an Artifact to Enhance the Resilience of Low-Carbon Decentralized Energy Solutions in Remote Regions

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This study aimed to assess the development of an artifact that supports the resilience of decentralized low-carbon energy generation solutions. We applied the Design Science Research (DSR) method to guide the construction of the artifact, considering the resilience of decentralized low-carbon energy generation solutions, local vulnerabilities, and social technologies. In this context, this research sought to characterize the stages of artifact construction and align them with Sustainable Development Goal (SDG) 7, which aims to ensure access to clean and affordable energy.
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The energy transition has emerged to promote changes in the energy matrix by increasing the participation of renewable sources such as solar and wind [1]. One of the challenges of this movement involves expanding electricity supply infrastructure, as access to electricity is a parameter for social inclusion, especially considering that 785 million people still lack access to electricity [2,3].

Moreover, in many regions, electricity supply is precarious, especially in remote areas [4]. To ensure a continuous energy supply in these locations, it has been identified that generation systems must be resilient. According to the Intergovernmental Panel on Climate Change (IPCC), resilience corresponds to a system's capacity to meet the principles of prevention, adaptation, resistance, and recovery [5,6].

In areas where transmission networks are inefficient or nonexistent, decentralized solutions such as off-grid systems and community microgrids have emerged as viable alternatives to ensure a reliable electricity supply [7]. Redundancy in supply can also be achieved through energy storage systems that complement generation systems [8]. Despite official recognition of the potential of these decentralized systems, there is still no consensus on the best strategy to adopt [3,9].

Because generation from renewable sources occurs intermittently due to their nature, advances in energy storage technologies are necessary, primarily to address this intermittency [10,11].

In addition to ensuring supply continuity, energy storage contributes to grid stability, particularly in areas with limited infrastructure or vulnerable to extreme weather events, thus enhancing energy resilience [10,11].

The primary objective of this research was to evaluate the development of an artifact that enhances the resilience of decentralized, low-carbon energy generation solutions, considering local vulnerabilities and social technologies.

Material and Methods

The research aimed to develop an artifact that supports the resilience of decentralized, low-carbon energy generation solutions in remote regions with limited electrical infrastructure. To achieve this objective, the Design Science Research (DSR) method was applied, which guided the construction of the artifact considering the specificities of local energy chains and the intermittency of renewable sources. DSR was chosen because it is suitable for complex situations, such as this study, which involves multiple factors, including technical, social, and economic issues

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[12]. Figure 1 illustrates a schematic draft of the methodological steps for artifact construction.

Results and Discussion

The research focused on evaluating the development of an artifact to support the resilience of decentralized low-carbon energy generation solutions. The choice of this topic was motivated by its potential to contribute to the energy transition and promote social inclusion. The DSR method was chosen to guide artifact development through a sequence of steps that consider the contextual specificities.

DSR proved appropriate due to its structured approach and focus on developing practical solutions, enabling the definition of a path for artifact construction that aligns with the specific challenges of remote regions and renewable energy sources.The method enabled the integration of technical and social aspects of the solutions, facilitating the adaptation of the artifact to local communities.

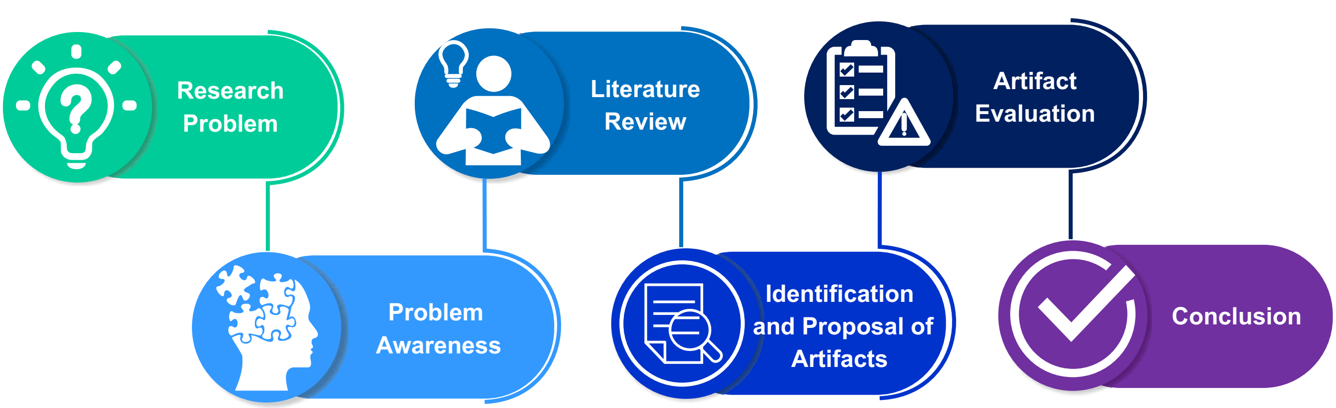
As part of the development process, a theoretical foundation is being established for the construction of an analysis platform that will support decision-making in scenarios with conflicting objectives, such as economic issues and specific topographic conditions at each location. This foundation encompasses the analysis of existing models and an examination of best practices in decentralized energy systems and renewable energy sources. The platform will be designed to suggest options and arrangements of energy generation systems tailored to regional characteristics. Thus, it will enable a dynamic evaluation of technological solutions, considering the varying conditions of each context.

However, the research has some limitations. The focus on remote areas and the simplification of certain elements, such as a detailed analysis of the intermittency of renewable energy sources and energy storage in these locations, were not addressed in depth. Additionally, the study defined the microgeneration threshold by Brazilian legislation. However, with minimal adjustments, the proposed method could be applied to other markets, provided there is knowledge of local regulations and topographical data.

Conclusion

This study developed a method to guide the construction of an artifact that supports the resilience of decentralized, low-carbon energy generation solutions. The proposed method contributes to the energy transition, social inclusion, and the creation of additional environmental and economic benefits by providing a solid foundation for building more adaptable and resilient solutions in remote regions. Although the artifact is still under development, the results obtained so far indicate that its

Figure 1. DSR methodological framework.



Source: Adapted from Dresch and colleagues and Ferreira and colleagues [13,14].

construction should consider critical factors such as the technical feasibility of the solutions, the specific characteristics of the regions where they will be implemented, and the ability to adapt to climate change. Future research should expand the analysis to other geographic areas, considering differences in local legislation and conditions, and deepen the assessment of the impact of renewable source intermittency and energy storage. Collaboration with local communities is also essential, as it will enable a deeper understanding of the specific needs and challenges of each region, facilitating the customization of solutions.

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