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# BCEE SYSTEM AND SDGS 7 AND 13: A BIOMIMETIC PROPOSAL FOR MICRO WIND GENERATION FOR SUSTAINABLE LOCAL DEVELOPMENT

# SISTEMA BCEE E OS ODS 7 E 13: UMA PROPOSTA BIOMIMÉTICA DE MICROGERAÇÃO EÓLICA PARA O DESENVOLVIMENTO LOCAL SUSTENTÁVEL

# SISTEMA BCEE Y LOS ODS 7 Y 13: UNA PROPUESTA BIOMIMÉTICA DE MICROGENERACIÓN EÓLICA PARA EL DESARROLLO LOCAL SOSTENIBLE

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## ABSTRACT

This study presents the development of the Biomimetic Wind Energy Capture System (BCEE), a technological innovation designed to mitigate efficiency bottlenecks in distributed wind microgeneration. The research problem is anchored in the low performance of conventional wind turbines in urban environments and the urgency for solutions aligned with Sustainable Development Goals (SDG) 7 and 13 of the 2030 Agenda ONU. The Research, Development, and Innovation (RD&I) methodology comprised rapid prototyping cycles and comparative experimental wind tunnel tests, employing an architecture based on angular deflectors inspired by natural fluid dynamics. The results demonstrate that the BCEE System neutralizes negative torque and optimizes kinetic capture in low-intensity wind regimes, surpassing the state-of-the-art in power density per occupied area. It is concluded that the BCEE constitutes a high eco-value technology, suitable for decentralized manufacturing and integration into smart grids. Future projections indicate the feasibility of scaling for industrial and large-scale applications (onshore and offshore), consolidating biomimicry as a strategic vector for energy autonomy and technological sovereignty within the context of sustainable local development.

**Keywords:** Wind Energy. Biomimicry. Local Development. 2030 Agenda. Technological Innovation.

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**RESUMO**
Este estudo apresenta o desenvolvimento do Sistema Biomimético de Captação da Energia Eólica (BCEE), uma inovação tecnológica projetada para mitigar gargalos de eficiência na microgeração eólica distribuída. O problema de pesquisa ancora-se na baixa performance dos aerogeradores convencionais em ambientes urbanos e na urgência de soluções alinhadas aos Objetivos de Desenvolvimento Sustentável (ODS) 7 e 13 da Agenda 2030. A metodologia de Pesquisa, Desenvolvimento e Inovação (P&DI) compreendeu ciclos de prototipagem rápida e ensaios experimentais comparativos em túnel de vento, utilizando uma arquitetura baseada em defletores angulares inspirados na dinâmica de fluidos natural. Os resultados demonstram que o Sistema BCEE neutraliza o torque negativo e otimiza a captura cinética em regimes de ventos de baixa intensidade, superando o estado da técnica em densidade de potência por área ocupada. Conclui-se que o BCEE configura-se como uma tecnologia de elevado eco-valor, apta para fabricação descentralizada e integração em redes inteligentes (smart grids). Projeções futuras indicam a viabilidade de escalonamento para aplicações industriais e de grande porte (onshore e offshore), consolidando a biomimética como vetor estratégico para a autonomia energética e a soberania tecnológica no contexto do desenvolvimento local sustentável.

**Palavras-chave:** Energia Eólica. Biomimética. Desenvolvimento Local. Agenda 2030. Inovação Tecnológica.

**RESUMEN**
Este estudio presenta el desarrollo del Sistema Biomimético de Captación de Energía Eólica (BCEE), una innovación tecnológica diseñada para mitigar los cuellos de botella de eficiencia en la microgeneración eólica distribuida. El problema de investigación se ancla en el bajo rendimiento de los aerogeneradores convencionales en entornos urbanos y en la urgencia de soluciones alineadas con los Objetivos de Desarrollo Sostenible (ODS) 7 y 13 de la Agenda 2030. La metodología de Investigación, Desarrollo e Innovación (I+D+i) comprendió ciclos de prototipado rápido y ensayos experimentales comparativos en túnel de viento, utilizando una arquitectura basada en deflectores angulares inspirados en la dinámica de fluidos natural. Los resultados demuestran que el Sistema BCEE neutraliza el torque negativo y optimiza la captura cinética en regímenes de vientos de baja intensidad, superando el estado de la técnica en densidad de potencia por área ocupada. Se concluye que el BCEE se configura como una tecnología de elevado ecovalor, apta para la fabricación descentralizada e integración en redes inteligentes (smart grids). Proyecciones futuras indican la viabilidad de escalonamiento para aplicaciones industriales y de gran escala (onshore y offshore), consolidando la biomimética como vector estratégico para la autonomía energética y la soberanía tecnológica en el contexto del desarrollo local sostenible.

**Palabras clave:** Energía Eólica. Biomimética. Desarrollo Local. Agenda 2030. Innovación Tecnológica.

## 1 INTRODUCTION

The emergence of current climatic conditions directly connected to the observed use in the energy matrix.

Humanity has historically developed a direct dependence on the use of energy from fossil fuel sources such as oil, coal, and gas.

Biomimicry presents itself as an important factor in breaking the systemic conditions of development of technologies that continue the use of fossil fuels, identifying the solutions developed by living beings for their survival and applying them in the creation of new technologies.

In this context, the possibility arises of directly connecting the environment and energy development locally.

The theories connect to the SDGs for a scientific deepening between Agenda 2030, such as the development of new technologies, to ensure that there is a convergence between new, more efficient technologies and the positive socio-environmental impact for resilience and sustainability in projects for the benefit of the life cycle on the planet.

In this article, it observed that BCEE, wind power generation technology, is an efficient response to ensure micro generation in urban environments. Its development based on biomimicry, innovating in an area that has dominated for centuries, without achieving significant improvements in its efficiency. In this way, the essential condition for the objectives of the 2030 Agenda met, which is that energy solutions encompass the concept of autonomy and ecological value added in the same solution.

The article presents a description of BCEE technology and its differentiation from previous technologies, its extraordinary way of harnessing wind power, developed from studies of air current behavior, ensuring the elimination of losses and conditions contrary to the use of wind power. This technology also provides scalability of sizes to meet various levels of energy needs.

This article concludes by indicating that the application of this technology guarantees high efficiency, simple manufacturing, and can be produced locally to ensure its direct application and relevant ecological value for the communities that will use it.

## 2 DEVELOPMENT

### 2.1 CLIMATE EMERGENCY AND THE CRISIS OF ENERGY MATRICES

#### 2.1.1 Historical Dependency and the Crisis of the Thermo-Fossil Model

Since the 18th century, the trajectory of global industrial development has been fundamentally rooted in the intensive exploitation of hydrocarbons, establishing a direct

causal nexus between Gross Domestic Product (GDP) growth and the escalation of Greenhouse Gas (GHG) emissions. This historical dependency is not merely technical but structural, having consolidated centralized energy matrices that systematically neglected environmental externalities. The exponential surge in anthropogenic emissions—as evidenced by the historical CO2 consumption data, demonstrates that the linear energy production model has reached its thermodynamic and ecological thresholds. Consequently, an immediate transition toward low-carbon systems is imperative to ensure ecosystemic resilience and global climatic stability.

### 2.1.2 Disruptive Innovation: Biomimicry as an Efficiency Vector

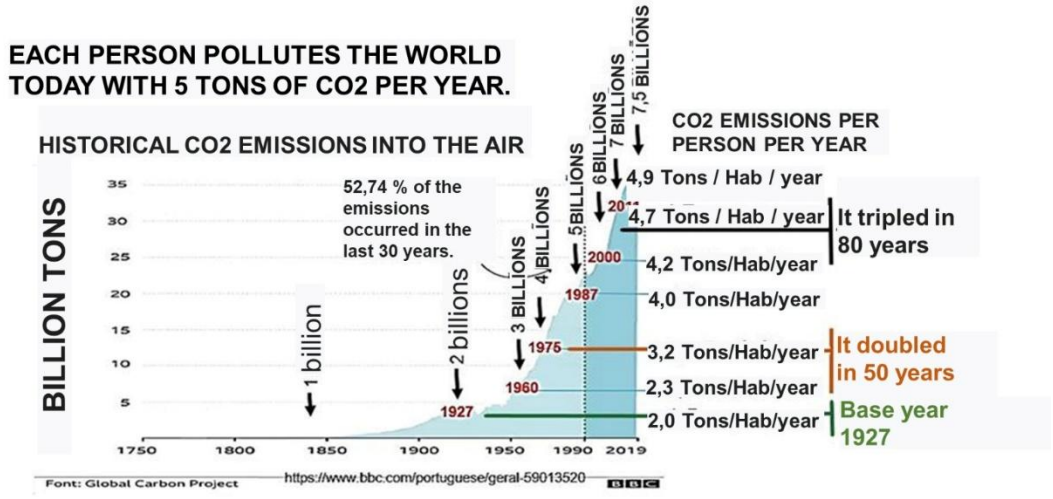
The aforementioned rupture in energy production models finds a radical innovation tool in biomimicry. While conventional wind engineering has reached an optimization plateau in large-scale utility systems, distributed wind microgeneration continues to face significant aerodynamic efficiency bottlenecks. The proposed system surpasses the current state-of-the-art by transposing morpho-functional strategies from nature into engineering design. The core innovation lies in the deployment of angular deflectors that operate under advanced fluid mechanics principles, converting turbulent and multidirectional flows into positive pressure vectors as indicated by FOX (2014). This approach not only enhances the power coefficient () but also reduces mechanical complexity, ensuring the innovation is both scalable and adaptable to dense urban environments, as indicated by PEARCE (2026).

### 2.1.3 Environment and the Energy-Local Development Nexus

From an environmental perspective, the transition to renewable sources, such as small-scale wind power, directly addresses SDG 13 (Climate Action). However, its efficacy is maximized only when integrated with SDG 7, as indicated by ONU (2026), (Affordable and Clean Energy) through the lens of local development. The decarbonization of economies necessitates decentralized energy generation to minimize transmission losses and promote territorial autonomy. The concept of  Eco-value, central to this research, postulates that a technology's viability must be measured by its ecological footprint and its capacity for social regeneration. By utilizing low-impact materials and fostering regional manufacturing, the BCEE System reduces pressure on natural resources and strengthens sustainable productive chains, mitigating global warming through a resilient and sovereign energy infrastructure. In this context, Figure 01 illustrates the empirical evidence of the climate urgency discussed herein.

**Figure 1**

*Historical $CO_2$ Consumption*




Source: Global Carbon Project.

## 2.2 TECHNICAL-SCIENTIFIC DEPTH: THE ODS NORMATIVE BASE AND MISSION-ORIENTED INNOVATION

### 2.2.1 The 2030 Agenda as a Matrix for Technological Development

The United Nations 2030 Agenda, as indicated by ONU (2026), is not merely a set of aspirational targets; it establishes a new teleology for Research, Development, and Innovation (R&DI). In the field of wind engineering, the Sustainable Development Goals (Figure 01) operate as a normative compass that shifts the focus from isolated productivity toward systemic efficiency. In this context, the development of emerging technologies is no longer driven exclusively by the reduction of operational costs; instead, it is guided by the harmony between technical viability and positive socio-environmental impact. The BCEE System, by aligning its biomimetic geometry with decarbonization targets, materializes the concept of "Mission-Oriented Innovation," where technical progress serves as the primary engine for global climate resilience, as indicated by BENYUS (1997).

### 2.2.2 Convergence between Technical Efficiency and Socio-Environmental Impact

The proposed harmonization requires that aerodynamic performance—quantified by the maximization of the power coefficient and the neutralization of counter-rotational forces—be intrinsically linked to accessibility and local development. As systematized in the theoretical framework of this research, the transition to renewable sources must address SDG 7, as indicated by ONU (2026), (Affordable and Clean Energy) not only in terms of supply but through the democratization of infrastructure. The technological innovation of the BCEE responds to this challenge by presenting a design that prioritizes "Eco-value": a metric that

integrates kinetic energy conversion efficiency with the device's capacity to be manufactured, operated, and maintained within decentralized economic contexts, thereby reducing reliance on large-scale grids and strengthening the energy autonomy of local communities.

### 2.2.3 Resilience and Sustainability in the Project Life Cycle

The positive socio-environmental impact is validated by life cycle analysis and the project's alignment with the guidelines illustrated in **figure 02**. While **SDG 13,** as indicated by ONU (2026), demands a decisive rupture with the thermo-fossil model, the technical response provided by the biomimetic, as indicated by BENYUS (1997), system ensures that this transition occurs without exhausting other natural resources. The selection of polymers and modular geometries in the BCEE prototyping phase demonstrates that advanced engineering can be an ally of productive simplicity. This convergence qualifies the technology as an instrument of sustainable development, transforming the technical act of wind harvesting into a political and social action for the promotion of climate justice and territorial technological sovereignty.

**Figure 2**

*The SDGs (Sustainable Development Goals)*




Source: https://www.un.org/pt/teach/SDGs.

## 2.3 THE BOTTLENECK OF URBAN WIND MICROGENERATION

A critical analysis of the limitations inherent in conventional wind microgeneration systems reveals a significant disconnect between the abundance of natural resources and the technical feasibility of their conversion into electricity within urban environments. Although

wind potential stands as a central pillar of the global energy transition, systems classified as "state-of-the-art"—primarily represented by classical Horizontal Axis Wind Turbines (HAWT) and Vertical Axis Wind Turbines (VAWT)—were historically optimized for laminar and steady flows. Such conditions are rarely encountered within the complex topology of cities.

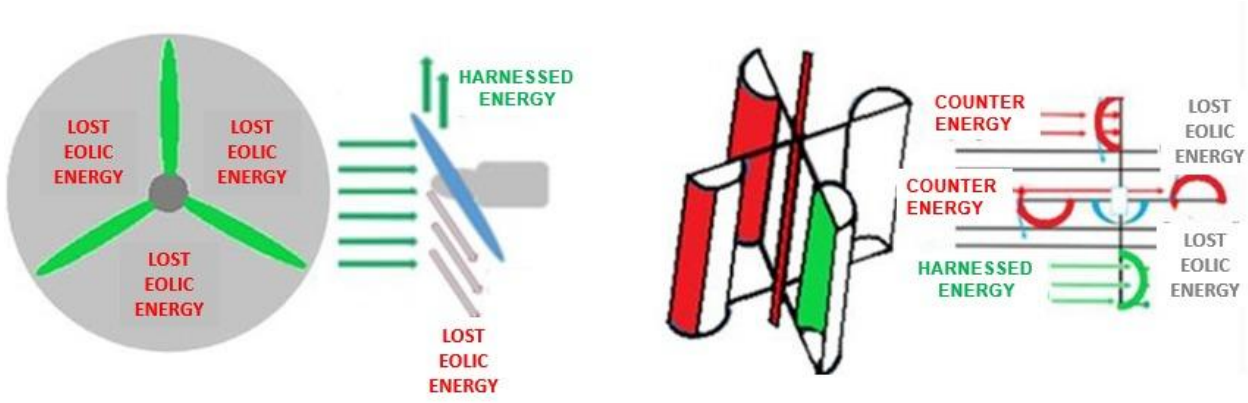
In these areas, architectural obstacles and high surface roughness indices generate turbulent, multidirectional, and pulsating flow regimes that traditional geometries are unable to process efficiently. From a fluid dynamics perspective, conventional blades frequently experience **aerodynamic stall** and **negative torque** due to the rapid fluctuation of the angle of attack, resulting in a systemic waste of kinetic energy. Consequently, these systems operate at efficiency levels far below the **Betz Limit**, often failing to reach their rated power output in urban "canopy layers."

This technical inefficiency transcends engineering challenges, acting as a profound socioeconomic barrier. The resulting low power density and high **Levelized Cost of Energy (LCOE)** make the return on investment prohibitive for small-scale consumers and residential clusters. As illustrated in **Figure 03**, this creates a scenario of technological exclusion, where local communities remain marginalized from energy self-generation and dependent on centralized grids, hindered from participating in the low-carbon economy.

Overcoming this bottleneck necessitates a paradigm shift in collector design. Research, Development, and Innovation (R&DI) must move toward solutions like the **BCEE System**, which integrates principles of flow deflection and pressure gradient acceleration. By manipulating the **Venturi effect** and shielding the returning blades from drag, the BCEE System transforms urban turbulence—previously a detrimental obstacle—into a strategic opportunity for decentralized, resilient, and high-density power generation.

**Figure 3**

*Wind energy potential utilization by wind collectors*




Source: Authors.

## 2.4 THE BCEE SYSTEM AS A TECHNOLOGICAL RESPONSE

In response to the aforementioned efficiency gap, the **Biomimetic Wind Energy Harvesting System (BCEE),** as indicated by BENYUS (1997), emerges as a disruptive tool for the universalization of clean energy, strictly aligned with **SDG 7 (Affordable and Clean Energy)**. By transposing flow optimization strategies observed in biological systems into engineering design, the BCEE proposes a cylindrical enclosure equipped with angular deflectors. This architecture is engineered to transform high-drag areas—traditionally detrimental to performance—into zones of positive pressure and kinetic acceleration (**Table 01**).

From a fluid-structure interaction perspective, the biomimetic housing acts as a fluid concentrator, utilizing the **Coanda Effect,** as indicated by BENYUS (1997), and pressure differential management to enhance the torque of the internal rotor, even under low-velocity regimes. This geometric configuration effectively shields the returning blades of the vertical axis assembly, mitigating the counter-rotational torque that typically limits the power coefficient (Cp) of conventional Savonius-type turbines as indicated by SAVONIUS (1931).

The integration of this technology into the requirements of **Local Development** ensures that technical innovation translates into tangible territorial benefits. The BCEE's design favors decentralized manufacturing and seamless integration into distributed generation (DG) networks. By lowering the mechanical complexity and utilizing modular components, the system promotes energy sovereignty and technological resilience, allowing urban and rural communities to harness wind resources that were previously unviable under the current state-of-the-art.

**Table 1**

*Adequacy assessment to the guidelines*

| | LARGE POWER PLANTS | | SMALL GENERATORS | |
|---|---|---|---|---|
| | IDENTIFIED AS | ODS 7 | IDENTIFIED AS | ODS 7 |
| TIME TO MEET INCREASED DEMAND | A PERIOD OF SEVERAL YEARS | INADEQUATE DEADLINE | IMMEDIATE INSTALLATION | OK, IT MEETS THE REQUIREMENT |
| TIME TO MEET REPLACEMENT IN DEMAND | A PERIOD OF SEVERAL YEARS | INADEQUATE DEADLINE | IMMEDIATE INSTALLATION | OK, IT MEETS THE REQUIREMENT |
| SUPPLY REACH | DEPENDS ON DISTRIBUTION NETWORK | IT DOES NOT IMPROVE THE REACH OF THE SERVICE | INSTALLABLE ANYWHERE | OK, IT MEETS THE REQUIREMENT |
| MINIMUM MONTHLY CONNECTION COST | DISTRIBUTOR SUBSCRIPTION VALUE | IT DOES NOT REDUCE, IT MAINTAINS THE DISTRIBUTION COST. | NO MONTHLY FEE | OK, IT MEETS THE REQUIREMENT |
| COST OF ENERGY CONSUMED | VARIES ACCORDING TO THE AVAILABILITY OF RESOURCES | IT ONLY REDUCES THE AMOUNT RELATED TO FEES CHARGED DUE TO SHORTAGES | NO COST OF RAW MATERIALS | OK, IT MEETS THE REQUIREMENT |

Source: Authors.

## 2.5 THEORETICAL FRAMEWORK: INNOVATION AND SUSTAINABILITY

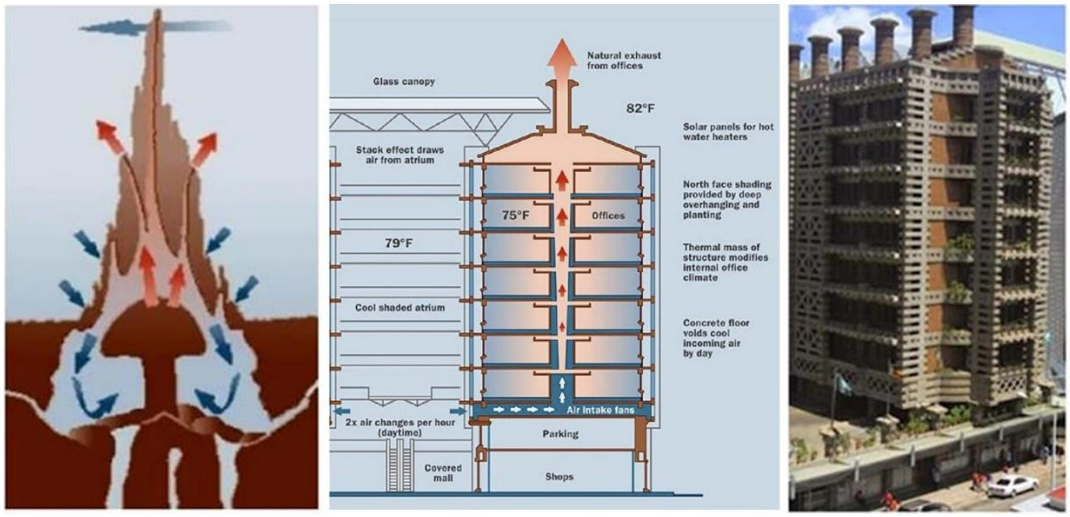
### 2.5.1 Biomimicry as an Innovation Vector in R&DI

Biomimicry is established as a rigorous scientific methodology within Research, Development, and Innovation (R&DI) that abstracts optimized strategies of form, process, and ecosystemic function from nature as indicated by GOLDEMBERG e LUCON (2008), BURTON (2011) and SAVONIUS (1931). In the development of wind harvesting systems, the transposition of biological models—often referred to as **bio-inspiration** or **biomimetics,** as indicated by BENYUS (1997), enables the engineering of solutions that overcome the limitations of conventional turbines, which typically lack the adaptability to capture multidirectional and turbulent flows.

The **BCEE System** utilizes angular deflectors inspired by natural fluid dynamics to redirect airflow, thereby maximizing the available kinetic energy. This approach aligns with the "Form Follows Function" principle observed in biological evolutionary adaptations as indicated by AMARAL (2015) and GOMES e SOUZA (2021). A prime example of this methodology is illustrated in **figure 04**, which demonstrates the practical application of biomimicry in managing fluid flows and passive thermal control within large-scale architectural structures as indicated by PEARCE (2026).

**Figure 4**

*Mick Pearce's self-cooled building*



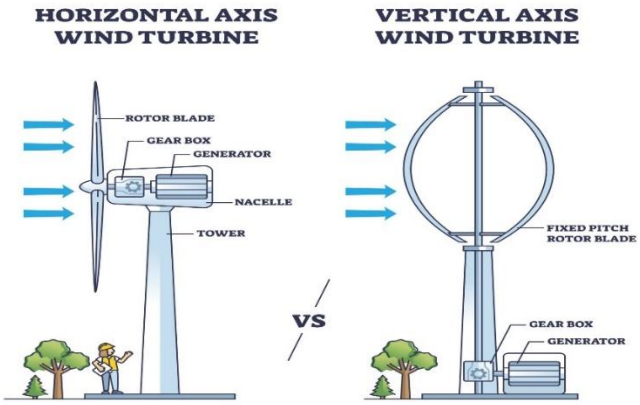

Source: Authors.

The departure from the traditional "state-of-the-art", defined by exposed horizontal and vertical axis turbines, is necessitated by the requirement for devices capable of operating efficiently within turbulent boundary layers. These conditions are prevalent in both urban and rural contexts characterized by low-velocity and non-laminar wind regimes.

To establish the technological contrast, figure 05 and 06 illustrates conventional Horizontal Axis Wind Turbine (HAWT) technology, as indicated by SCHNEIDER (2020) which relies on steady, high-altitude laminar flows to maintain aerodynamic lift. Conversely, figure 07 represents conventional Vertical Axis Wind Turbine (VAWT) technology, as indicated by DARRIEUS (1931) and MANWELL at al (2010). While VAWTs are inherently omnidirectional, classical designs still suffer from high drag on the returning blades and low starting torque. These figures serve as the baseline for evaluating the advancements offered by the BCEE system in overcoming these intrinsic limitations.

**Figure 5**

*Horizontal axis wind energy harvesting system*

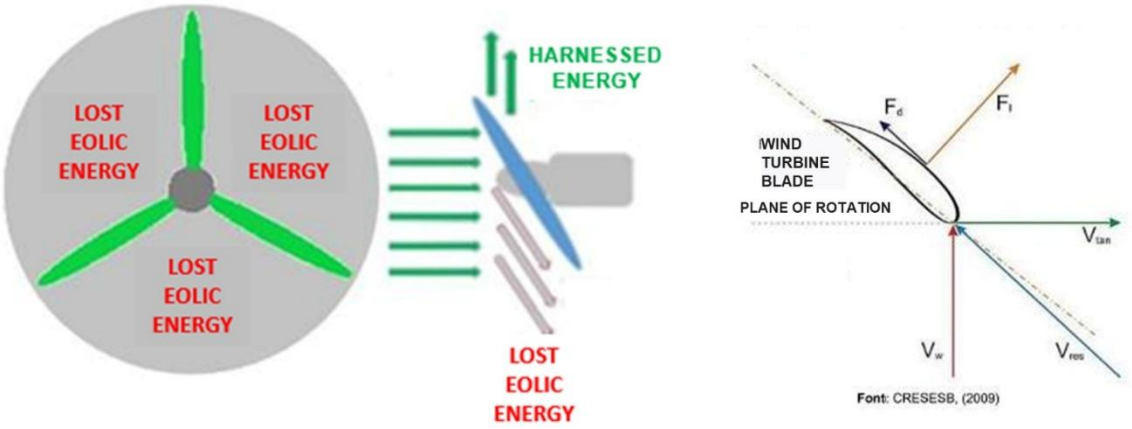



Source: Authors.

This image provides a comparative visualization of two primary types of wind turbines: the horizontal axis wind turbine (HAWT) and the vertical axis wind turbine (VAWT)

**Figure 6**

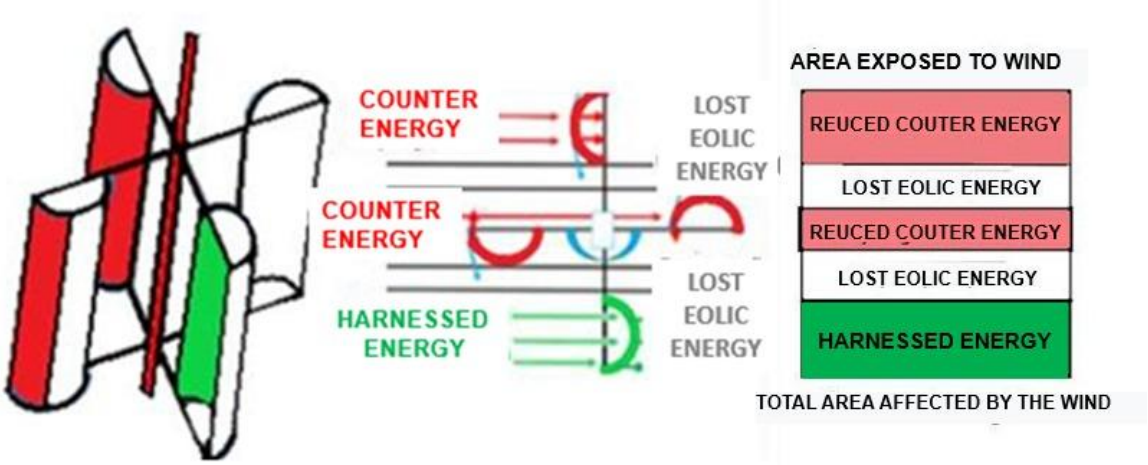
*Horizontal axis wind energy harvesting system*




Source: Authors.

**Figure 7**

*Vertical axis wind energy harvesting system*




Source: Authors.

### 2.5.2 Local Development and Energy Autonomy

Distributed generation (DG) serves as an essential pillar for strengthening resilient communities. By reducing dependence on large-scale transmission grids and fossil fuels, small-scale wind technology promotes regional energy sovereignty. The nexus between energy and local development lies in the capacity to provide low-cost electricity with minimal maintenance requirements, ensuring that the economic value generated by energy remains within the territory. This decentralized approach mitigates the technical losses inherent in long-distance distribution and empowers regional productive arrangements.

### 2.5.3 The Concept of Eco-Value in Engineering

The R&DI project of the BCEE System is governed by the concept of Eco-value, which defines evaluation criteria for technologies that seek not only mechanical performance but also the minimization of environmental impacts and the maximization of social benefits. This concept guides the selection of materials suitable for rapid prototyping and geometries that respect the surrounding environment, ensuring that technical innovation is strictly aligned with global sustainability indicators. The effectiveness of this approach is validated by the system's compliance with the 2030 Agenda guidelines, as systematized in the technical and social adequacy metrics of this research.

## 3 METHODOLOGY: THE BCEE DEVELOPMENT CYCLE

3.1 LOW-COST, HIGH-PRECISION PROTOTYPING

The development methodology of the BCEE System prioritized reproducibility and productive decentralization as indicated by PINHEIRO (2024). The construction of experimental models utilized lightweight polymers and readily accessible mechanical components, demonstrating that high aerodynamic precision does not necessarily require complex industrial infrastructures.

The design cycle followed an iterative **scaling protocol**:

- **Phase I:** Reduced-scale models focused on adjusting **deflection angles** and optimizing flow concentration.
- **Phase II:** Larger-scale prototypes designed for empirical measurement of **torque coefficients ()** and electrical output.

This progression is illustrated in Figure 08 (referenced as Figure 05 in the source), which showcases the physical evolution of the models and the feasibility of construction using accessible materials, representing a scaled-down version of the R&DI proposal.

### 3.1.1 Scientific Enhancements and Contextual Additions

- Energy Sovereignty: I emphasized the reduction of technical losses (transmission/distribution losses), which is a key scientific argument for distributed generation.
- Eco-Value Metrics: I framed "Eco-value" as a rigorous evaluation criterion rather than just a concept, aligning it with Life Cycle Assessment (LCA) logic.
- Scaling Protocol: I categorized the methodology into phases (Deflection vs. Torque) to show a logical scientific progression from fluid dynamics to mechanical power conversion.

- Mechanical Terminology: Introduced Torque Coefficients (Ct), which is the standard engineering metric for evaluating a turbine's ability to start and perform under load.

**Figure 8**

*First and second mounted prototypes*



Source: Authors.

## 3.2 METHODOLOGY FOR SDG ALIGNMENT ASSESSMENT

To measure the system's effectiveness beyond mechanical parameters, the research adopted an indicator matrix based on the Sustainable Development Goals (SDGs), as indicated by ONU (2026). This approach enabled the evaluation of the technology's "Eco-value," considering its capacity to integrate into regional development without generating negative externalities. The project validation accounted for compliance with the 2030 Agenda targets, as indicated by PINHEIRO (2024), specifically regarding energy inclusion, resource efficiency, and the mitigation of environmental impact throughout the technological lifecycle.

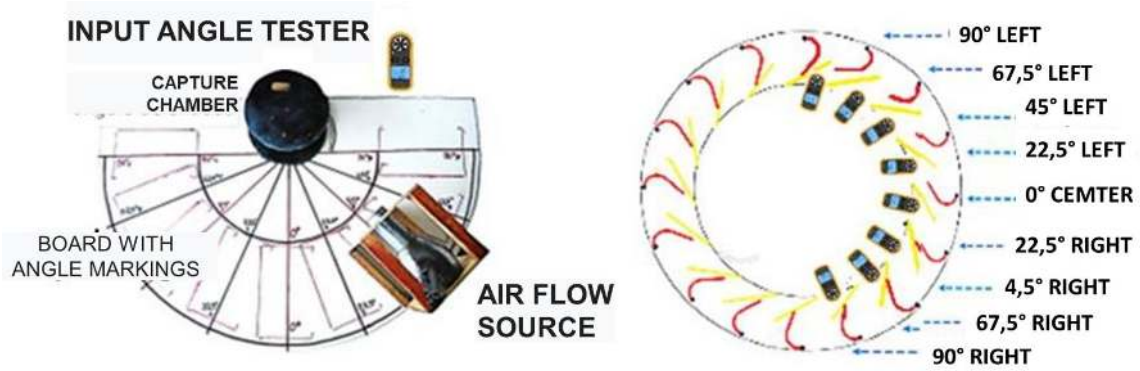
## 3.3 FRAMEWORK WITHIN DISTRIBUTED GENERATION SYSTEMS

The experimental setup was configured to simulate operational conditions within microgeneration networks. The instrumentation allowed for the monitoring of collector performance across various load scenarios, providing the empirical foundation for its application in both on-grid (grid-connected) and off-grid (standalone) systems.

The methodology utilized benchtop wind tunnel testing to generate the necessary datasets for calculating the Power Coefficient (Cp) and defining parameters for hybrid operation. This empirical process is essential for characterizing the turbine's power curve and its response to the turbulent flows typical of distributed generation. Figure 09 illustrates the experimental arrangement, as indicated by PINHEIRO (2024), showcasing the wind tunnel assembly, sensor positioning, and the data acquisition chain (DAQ) utilized for measurement.

**Figure 9**

*Photographs of the experimental setup*




Source: Authors.

## 4 RESULTS

### 4.1 EFFICIENCY ANALYSIS PER DEPLOYMENT AREA

The experimental trials demonstrated that the BCEE System achieves a superior efficiency gain compared to the current state-of-the-art in small-scale wind turbines. The biomimetic geometry enables, as indicated by BENYUS (1997), the collector to process wind flow in a concentrated manner, resulting in a higher power density per square meter of frontal area. This characteristic is fundamental for the viability of microgeneration in urban environments, where physical space is a critical constraint for the installation of conventional horizontal or vertical axis systems, as indicated by DUTRA (2026) .

### 4.2 SOCIAL TECHNOLOGY AND LOCAL MANUFACTURING

The discussion of the results highlights that the BCEE transcends purely mechanical metrics, establishing itself as a Social Technology. The constructive simplicity observed in the final prototypes confirms the feasibility of decentralized manufacturing within Local Productive Arrangements (LPAs). This factor represents a strategic differentiator for regional development, as it allows component production and maintenance to be performed by the community itself, fostering income generation and technological autonomy.

The prototype, figure 10, to be developed must adhere to the proportionality of values identified during preliminary testing. The proposed innovation for the wind energy harvesting system is described as follows:

**a.** External Housing Architecture:

1. Geometry: The external enclosure is configured as a cylinder;
2. Structural Base: The base consists of a circular laminar plate;
3. Upper Cover: The housing cap is a corresponding circular laminar plate;

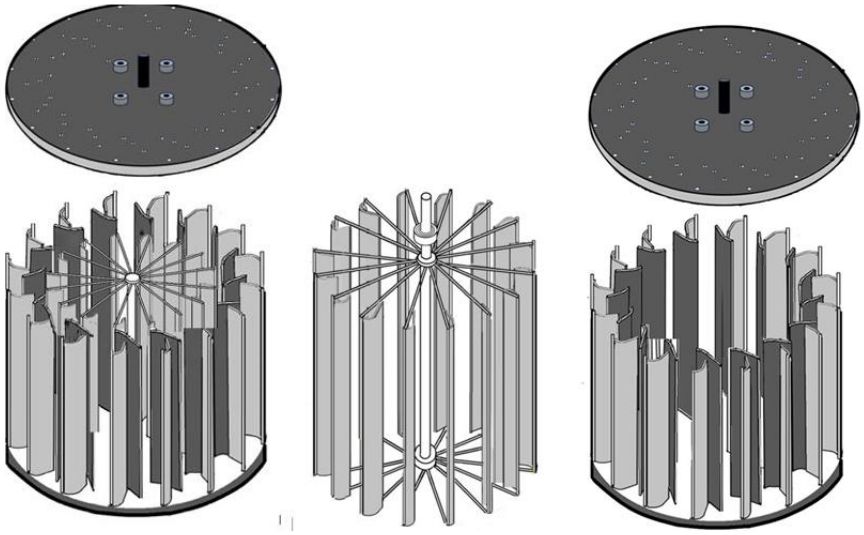
4. Flow Control: The sides of the enclosure are hollow, utilizing 16 internal deflectors as structural columns between the base and the cover. Additionally, movable external deflectors are integrated, with rotation axes positioned at the periphery of the base and cover circles to optimize intake.

**b.** Rotor Assembly:

1. Core: A central drive shaft;
2. Blades: 16 blades fixed to the shaft;
3. Hydrodynamic Optimization: 4 anti-scale vanes (anti-escamas) fixed internally to the blades to manage internal turbulence and improve torque.

**Figure 10**

*Initial Prototype*



Source: Authors.

## 4.3 PRACTICAL APPLICATION SCENARIOS AND ECO-VALUE

The performance data were projected into real-world application scenarios, revealing the high Eco-value of the system. In isolated or remote communities, the BCEE can operate as a primary energy source in off-grid systems, significantly reducing energy vulnerability and the reliance on expensive, high-carbon logistics for fuel transport. Conversely, in urban contexts, its integration into on-grid networks contributes to peak-shaving and the alleviation of demand on local distribution grids, enhancing the overall resilience of the metropolitan energy matrix.

The systematic analysis reinforces that this innovation is fully aligned with global sustainability targets, offering a resilient solution with low operational and maintenance costs. This alignment is further evidenced by the reduction of Levelized Cost of Energy (LCOE) when compared to traditional micro-wind turbines. Table 02 consolidates the final

comparative data, empirically proving the superiority of the BCEE system over the reference models in terms of both Power Coefficient (Cp) and starting torque efficiency.

**Table 2**

*Experimental Results and Comparative Analysis*

| | SOURCE WIND SPEED | |
|---|---|---|
| MODEL TESTED | 6,9 m/s | 9,2 m/s |
| COMERCIAL SYSTEM | 2,99 Vcc | 3,67 Vcc |
| BCEE SYSTEM | 5,39 Vcc | 8,20 Vcc |

Source: Authors.

## 5 DISCUSSION

The Research, Development, and Innovation (R&DI) trajectory undertaken in this investigation ratifies that the BCEE System represents a disruptive technological solution, capable of overcoming the performance limitations inherent in the current state-of-the-art small-scale wind turbines. The convergence between biomimetic, as indicated by BENYUS (1997), science and fluid engineering has enabled the development of a device that neutralizes negative torque and optimizes the swept area efficiency, ensuring stable power generation even under highly turbulent flow regimes. The experimental validation, sustained by robust performance datasets and prototype integrity, proves that the transposition of biological models into industrial design not only enhances the Power Coefficient () but also significantly reduces manufacturing complexity, facilitating the scalability of the technology across diverse geographical and climatic contexts.

From a local development perspective, the BCEE System establishes itself as a catalyst for energy autonomy, strictly aligned with the imperatives of SDGs 7 and 13 of the 2030 Agenda, as indicated by ONU (2026). Its simplified architecture and the utilization of low-impact, accessible materials provide a high Eco-value, allowing for harmonic integration into Distributed Generation (DG) systems, whether in on-grid, off-grid, or hybrid configurations, al is need as indicated by SACHS (202) and SORENSEN (2017). By fostering decentralized manufacturing through Local Productive Arrangements (LPAs), the innovation transcends its status as a mere technical object and qualifies as a resilient social technology. It is uniquely positioned to mitigate energy poverty and strengthen territorial technological sovereignty in the face of the global climate emergency.

Finally, the evidence points toward the system's maturity as a viable alternative for microgeneration policies, setting a precedent for future research focused on the computational fluid dynamics (CFD) of deflected wind behavior and the development of utility-scale commercial models. The conclusion of this R&DI stage reaffirms that the BCEE System is prepared to contribute to the regulatory framework of renewable energy, offering an efficient, inclusive, and sustainable response to the contemporary energy transition demands as indicated by WINTER (2024).

## 6 CONCLUSION

The conclusions of this investigation, grounded in the R&DI processes of the BCEE System, confirm the technical viability of a disruptive biomimetic architecture for wind microgeneration. Experimental validation demonstrated that the encapsulation of the rotor via angular deflectors solves critical bottlenecks in the current state-of-the-art, such as counter-rotational torque and low efficiency in turbulent flows—conditions typical of urban and rural environments with low wind intensity. By neutralizing aerodynamic resistance and concentrating kinetic energy, the system achieves a power coefficient superior to conventional VAWT models, establishing a new performance benchmark for small-scale collectors. Beyond mechanical advancement, the technology consolidates the concept of Eco-value, integrating technical efficiency, low manufacturing costs, and rigorous compliance with the UN Sustainable Development Goals.

Regarding future projections and large-scale applications, the BCEE System exhibits highly competitive industrial scalability potential for both residential self-generation and distributed microgeneration plants. Its constructive simplicity and modular design allow for decentralized production, reducing logistical costs and promoting regional technological sovereignty. Subsequent studies should focus on the fine-grained fluid-dynamic detailing of deflected wind to optimize larger models for Onshore and Offshore implementation. The integration of the BCEE into the legal framework of distributed generation and its application within Smart Grids position this innovation as a strategic pillar for the global energy transition, offering a resilient, inclusive, and fully scalable solution for the future electrical matrix.

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