# PERCEPTION OF DRIVERS AND BARRIERS TO THE ADOPTION OF DECENTRALIZED RENEWABLE TECHNOLOGIES. AN ANP-BASED APPROACH IN COLOMBIA

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## Highlights

- Fiscal incentives and market mechanisms drive RET adoption in Colombia.
- Lack of financing and high CAPEX are key barriers to RET deployment.
- Technical uncertainties and adopter motivation are vital for overcoming challenges.
- Aligning expert views enhances renewable energy policy and transition strategies.

**ABSTRACT**

The adoption of Renewable Energy Technologies (RETs) is critical for advancing Colombia's energy transition and achieving its sustainability goals. This study provides a comparative analysis of the drivers and barriers influencing the adoption of two decentralized RETs: batteries and photovoltaic (PV) solar systems. Using the Analytic Network Process (ANP), input from experts in industry, government, and academia was analyzed to prioritize the most significant factors. Economic and institutional drivers, such as fiscal incentives, stabilization of energy prices, and market participation mechanisms, emerged as key enablers for both technologies. Social and technical drivers, while less influential, highlighted the importance of adopter motivation and addressing service

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failures. Economic barriers, particularly the lack of financing and high CAPEX, were identified as the most significant challenges, emphasizing the need for innovative financing mechanisms. Technical and institutional barriers, including techno-economic uncertainty and lack of standardization, also impede adoption. The study underscores the importance of aligning expert perspectives to create cohesive strategies and strengthen renewable energy policies. While the findings are specific to Colombia, they provide valuable insights into addressing economic and technical barriers in similar contexts.

**Keywords (3-6):** renewable energy, decentralized, solar PV, electric batteries, ANP, Colombia

## 1. Introduction

The adoption of Renewable Energy Sources (RES) represents a promising approach to mitigating climate change and achieving sustainable development goals. Renewable Energy Technologies (RET), particularly decentralized or distributed systems, are transforming the traditional energy paradigm. In Colombia, decentralized energy systems offer unique benefits, including enhanced energy autonomy, resilience to natural disasters, and improved energy access. However, their implementation is shaped by diverse drivers and barriers, which vary significantly among sectors, adding complexity to their deployment (Jacksohn et al., 2019).

This study employs the Analytic Network Process (ANP) to evaluate the significance of drivers and barriers in the adoption of decentralized RET in Colombia. This country presents a unique case, facing challenges such as limited energy access, fragmented grid infrastructure, and evolving regulatory frameworks. This research focuses on rooftop solar photovoltaic (solar PV) systems and decentralized Battery Energy Storage Systems (batteries), analyzing the perspectives of experts from academia, industry, and government.

The findings provide a deeper understanding of the context-specific dynamics influencing decentralized RET adoption and offer valuable insights for evidence-based policymaking aimed at promoting renewable energy adoption and advancing the energy transition.

## 2. Literature Review

Colombia's electrical system is largely based on a hydrothermal energy matrix that heavily depends on water resources, leaving it highly vulnerable to climate variability and the uncertainties of climate change. To mitigate these risks and diversify its energy mix, the country has been promoting distributed renewable energy sources. The introduction of Law 1715 in 2014 marked a significant step toward fostering renewable energy deployment. However, these technologies still face substantial barriers, including regulatory challenges and infrastructure limitations (Gómez-Navarro & Ribó-Pérez, 2018).

Despite achieving 96% to 98% electricity coverage in interconnected areas, Colombia faces strong disparities in Non-Interconnected Zones (ZNI), which cover more than half of the national territory. In these regions, only 38% of users have continuous electricity access. Moreover, rising tariffs and deficient service quality intensify inequalities in the energy sector in the country. Addressing these challenges requires robust state intervention

and a shift from a market dominated by private entities. To support a fair energy transition, Colombia must expand renewable generation capacity, reduce energy poverty through small-scale self-generation programs, and enhance its regulatory framework to enable the efficient integration of renewables into the national energy system (Ministerio de Minas y Energía de Colombia, 2023; Campillo, 2024).

## 3. Objective

The objective of this study is to identify and analyze the drivers and barriers influencing the adoption of Renewable Energy Technologies (RET) in Colombia. Using the Analytic Network Process (ANP), this research aims to evaluate the relative importance of these drivers and barriers and compare those associated with two different decentralized RETs—Batteries and Solar PV—to provide insights into the specific challenges and opportunities shaping their adoption in the Colombian context.

## 4. Research Design/Methodology

The process begins with the preparation of the ANP models, following the methodology outlined by Aparisi-Cerdá et al. (2024). A preliminary list of drivers and barriers was presented to a group of energy experts in Colombia, who adapted the list to reflect the specific context of the country.

The second stage focused on constructing the ANP models for the two decentralized RETs—Batteries and Solar PV. The third stage involved solving these models with input from 10 experts in industry, government, and academia to obtain prioritizations. Finally, the fourth stage analyzed the compatibility among experts using the Spearman Rank Correlation Index (SRCI), providing insights into the level of consensus or variability in their perspectives.

## 5. Results/Model Analysis

The drivers and barriers influencing the adoption of RET in Colombia are summarized in the next table:

**Table 1.** Drivers and barriers to the adoption of Renewable Energy Technologies (RET) in Colombia

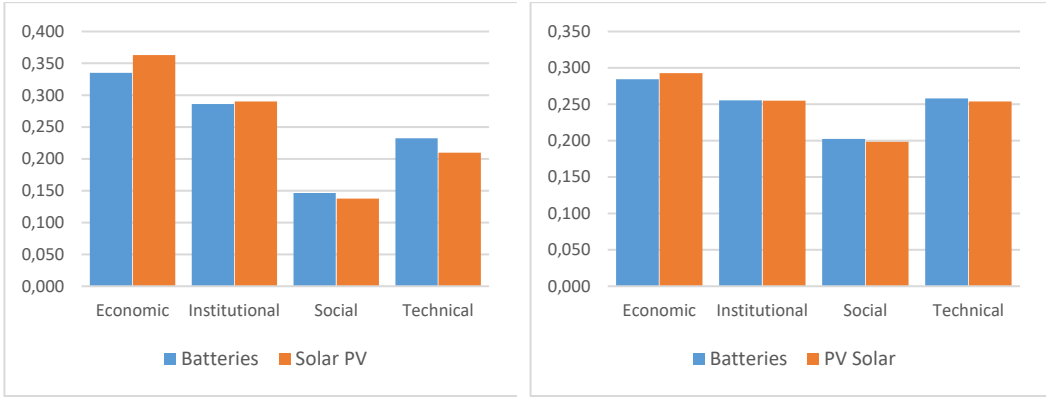
| **Drivers** | | **Barriers** | |
|---|---|---|---|
| **Id** | **Economic drivers** | **Id** | **Economic barriers** |
| DE1 | Fiscal and economic incentives. | BE1 | Investment cost (CAPEX) |
| DE2 | Environmental charges. | BE2 | Economic profitability. |
| DE3 | Stabilisation of low energy prices. | BE3 | Lack of funding |
| **Id** | **Institutional drivers** | **Id** | **Institutional barriers** |
| DI1 | Political will. | BI1 | Lack of technical definition and standardisation. |

| Drivers | | Barriers | |
|---|---|---|---|
| DI2 | Market participation mechanisms. | BI2 | Institutional inertia. |
| DI3 | Regulatory developments | BI3 | Licensing. |
| **Id** | **Social drivers** | **Id** | **Social barriers** |
| DS1 | Clear, reliable and accessible information. | BS1 | Risk aversion. |
| DS2 | Awareness, education and training programmes. | BS2 | Lack of energy awareness |
| DS3 | Adopter's motivation. | BS3 | Lack of know-how |
| **Id** | **Technical drivers** | **Id** | **Technical barriers** |
| DT1 | Technological maturity. | BT1 | Space issues |
| DT2 | Development of infrastructures and uses. | BT2 | Techno-economic uncertainty |
| DT3 | Service supply failures | BT3 | Technological complexity |
| | | BT4 | Environmental conditions |

In terms of drivers, for batteries, economic drivers hold the highest priority with a weight of 0.335, followed by institutional drivers (0.286), technical drivers (0.232), and social drivers (0.147). For PV Solar, economic drivers are also the most relevant, with a weight of 0.363, followed by institutional drivers (0.290), technical drivers (0.210), and social drivers (0.138).

Regarding barriers, for batteries, economic barriers hold the highest priority with a weight of 0.284, followed closely by technical barriers (0.258) and institutional barriers (0.255). Social barriers have a lower weight of 0.202, indicating relatively less influence compared to the other categories. For PV Solar, economic barriers are also the most significant, with a weight of 0.293, followed by institutional (0.255), technical (0.254), and social barriers (0.199).

For both RETs, economic factors play a crucial role in Colombia's context, serving as both the primary drivers and the main barriers.




**a.** Drivers **b.** Barriers

**Fig 1.** Cluster prioritization

In terms of specific drivers, for both RETs, DI2 (market participation mechanisms) is the most significant, followed by the economic drivers DE3 (stabilization of low energy prices) and DE1 (fiscal and economic incentives). Although social and technical drivers are rated lower, they still highlight the importance of DS3 (adopter motivation) and DT3 (addressing service failures) in encouraging RET adoption.

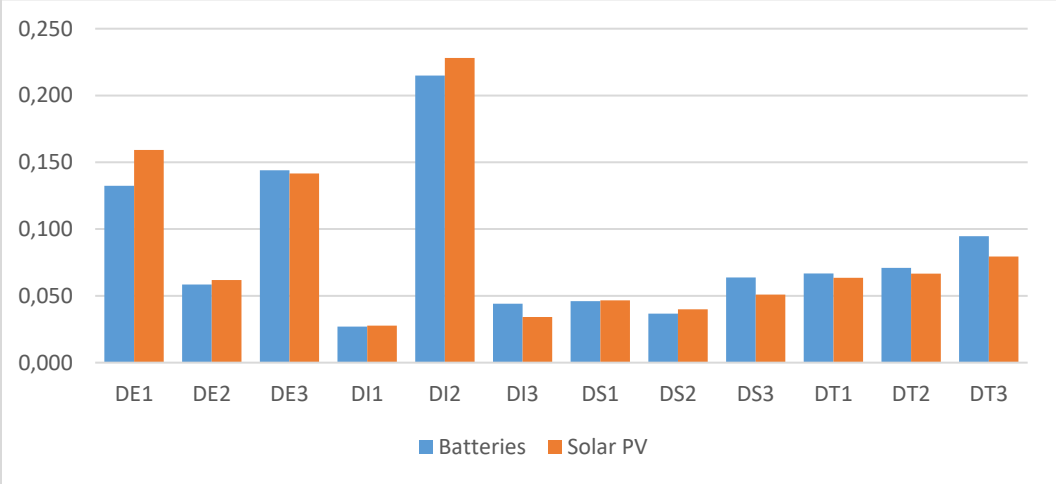



**Fig. 2** Drivers' prioritization by technology type

For batteries, economic barriers are the most significant, primarily driven by the lack of funding **(**BE3**)** and high investment costs (CAPEX, BE1**)**. The second most important group comprises technical barriers, with techno-economic uncertainty (BT2) and technological complexity **(**BT3**)** being the key challenges. Institutional barriers closely follow, with the lack of technical definition and standardization (BI1) standing out. Among social barriers, the lack of know-how (BS3) emerges as a notable constraint.

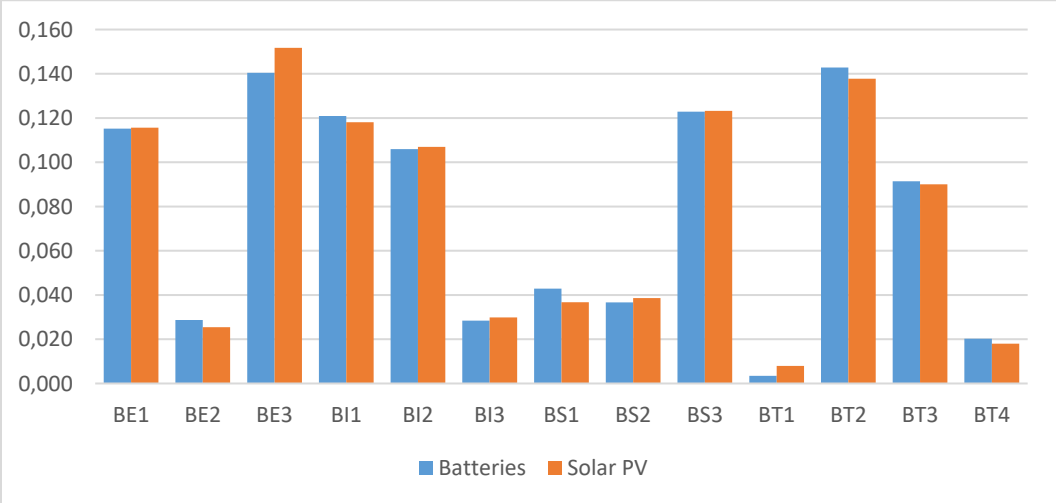



**Fig. 1** Barrierss' prioritisation by technology type

The following tables show the compatibility of experts' perspectives on drivers and barriers. An SRCI closer to 1, that is a high correlation, implies that experts agree on which drivers/barriers are most impactful or challenging.

**Table 2.** Spearman correlation drivers

| | IND1 | IND2 | IND3 | IND4 | IND5 | GOB1 | GOB2 | GOB3 | ACD1 | ACD2 |
|---|---|---|---|---|---|---|---|---|---|---|
| **IND1** | 1.000 | 0.671 | 0.476 | 0.203 | 0.629 | -0.007 | 0.923 | 0.657 | -0.021 | 0.650 |
| **IND2** | | 1.000 | 0.741 | -0.126 | 0.734 | -0.175 | 0.594 | 0.622 | 0.357 | 0.762 |
| **IND3** | | | 1.000 | -0.147 | 0.895 | -0.189 | 0.483 | 0.301 | 0.406 | 0.860 |
| **IND4** | | | | 1.000 | 0.161 | 0.252 | 0.371 | 0.245 | 0.042 | 0.014 |
| **IND5** | | | | | 1.000 | -0.021 | 0.601 | 0.406 | 0.266 | 0.776 |
| **GOB1** | | | | | | 1.000 | 0.105 | 0.140 | 0.161 | -0.385 |
| **GOB2** | | | | | | | 1.000 | 0.636 | 0.126 | 0.629 |
| **GOB3** | | | | | | | | 1.000 | -0.056 | 0.448 |
| **ACD1** | | | | | | | | | 1.000 | 0.343 |
| **ACD2** | | | | | | | | | | 1.000 |

**Table 3.** Spearman correlation barriers

| | IND1 | IND2 | IND3 | IND4 | IND5 | GOB1 | GOB2 | GOB3 | ACD1 | ACD2 |
|---|---|---|---|---|---|---|---|---|---|---|
| **IND1** | 1.000 | 0.758 | 0.808 | 0.819 | 0.830 | 0.879 | 0.846 | 0.685 | 0.770 | 0.692 |
| **IND2** | | 1.000 | 0.824 | 0.824 | 0.786 | 0.896 | 0.912 | 0.737 | 0.801 | 0.791 |
| **IND3** | | | 1.000 | 0.934 | 0.912 | 0.874 | 0.901 | 0.713 | 0.856 | 0.912 |
| **IND4** | | | | 1.000 | 0.934 | 0.885 | 0.835 | 0.586 | 0.949 | 0.907 |
| **IND5** | | | | | 1.000 | 0.797 | 0.841 | 0.696 | 0.883 | 0.846 |
| **GOB1** | | | | | | 1.000 | 0.863 | 0.713 | 0.856 | 0.819 |
| **GOB2** | | | | | | | 1.000 | 0.746 | 0.754 | 0.808 |
| **GOB3** | | | | | | | | 1.000 | 0.529 | 0.594 |
| **ACD1** | | | | | | | | | 1.000 | 0.919 |
| **ACD2** | | | | | | | | | | 1.000 |

## 6. Conclusions

This study offers a comprehensive comparative analysis of the drivers and barriers influencing the adoption of decentralized RETs in Colombia. The results indicate that economic and institutional factors are the most critical enablers for both batteries and PV Solar, while social factors play a comparatively minor role.

Economic and institutional drivers, such as fiscal incentives, stabilization of energy prices, and market participation mechanisms, are identified as the primary facilitators of RET adoption. Social and technical drivers, while less influential, remain relevant in specific contexts. On the other hand, economic barriers, particularly the lack of financing, emerge as the most significant challenge, emphasizing the urgent need for innovative financing

mechanisms and improved access to capital. Addressing these economic and technical barriers is crucial for advancing the adoption of both technologies in Colombia.

The analysis of expert compatibility emphasizes the necessity for more cohesive strategies and inter-sectoral dialogue. The disparities observed among expert perspectives highlight the importance of aligning viewpoints to strengthen renewable energy policies. Enhancing collaboration and consensus, particularly in areas where accessibility and variability impede a unified national approach, could significantly accelerate the energy transition in Colombia.

This study has some limitations that should be considered. It focuses exclusively on batteries and PV Solar, limiting its generalizability to other RETs. The findings are specific to Colombia's unique context and may not fully apply to other regions. Lastly, the emphasis on quantitative prioritization limits the exploration of systemic or sociocultural factors, which could provide deeper insights into the adoption challenges. Future research addressing these limitations could enhance the applicability and depth of the findings.

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