

Challenges and Opportunities for the Integration of Distributed Generation into Brazil's Power Dispatch Framework

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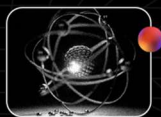
The ongoing transformation of power systems demands a reassessment of traditional centralized operation and planning models, driven by the growing participation of intermittent renewable sources and distributed energy resources (DERs). This study critically examines the regulatory and technical barriers that hinder the full integration of distributed generation (DG), with an emphasis on photovoltaic microgeneration (PV-MG), into dispatch structures and energy markets within the Brazilian context. Despite a predominantly clean energy mix and the rapid expansion of DG—fueled by public policies such as the Net Metering Scheme (*Sistema de Compensação de Energia Elétrica*) and Law No. 14,300/2022—the role of these agents remains limited to local consumption, with no effective participation in the system's operational and market mechanisms. Based on a systematic review of national regulation and consolidated international experiences, such as those observed in Germany, the United States, Australia, the United Kingdom, Spain, Japan, and China, the study identifies regulatory gaps, the absence of real-time coordination, technological constraints in digital infrastructure, and deficiencies in economic signaling. To overcome these challenges, a three-phase strategy is proposed: in the short term, enhancements to time- and location-based pricing inspired by regulatory sandboxes; in the medium term, the creation of local flexibility markets and institutional recognition of aggregators; and in the long term, the full integration of DG through digital DER management platforms, smart metering, and virtual power plants. Aligning regulation, technology, and governance is essential for DG to move beyond a compensatory mechanism and consolidate its role as a strategic agent in Brazil's decentralized energy transition.

Keywords: photovoltaic microgeneration, dispatch framework, energy regulation, electricity market flexibility.

The ongoing transformation of power systems requires a reassessment of traditional centralized operation and planning models, due to the growing participation of intermittent renewable sources and distributed energy resources (DERs). This shift is primarily driven by the increasing share of intermittent renewable sources and distributed energy resources, which challenge the conventional logic of centralized control and demand greater operational flexibility [10,11,5]. At the international level, this energy transition process has been driven by two major forces: the accelerated electrification of energy-intensive

sectors and the expansion of variable renewable energy sources [10,5,11].

According to the International Energy Agency [9], the world is entering a new “Electricity Era,” characterized by an average annual expansion of global demand of around 3,500 TWh through 2027, driven primarily by emerging economies such as China and India. In this context, power systems face the challenge of integrating growing volumes of solar and wind generation, whose variability demands new mechanisms for control, real-time response, energy storage, and decentralized coordination [10,11,5].



The Paris Agreement, signed during the 21st Conference of the Parties (COP 21) to the United Nations Framework Convention on Climate Change in 2015, represents a milestone in this process by establishing global commitments to emission reductions and fostering policies aimed at the decarbonization of energy systems [14]. This agenda is closely aligned with the Sustainable Development Goals (SDGs), particularly Goal 7, which seeks to ensure universal, reliable, and sustainable access to modern energy by 2030.

In this context, several countries have been reformulating their operational and market models, replacing centralized structures with more open and decentralized architectures in which small-scale agents—such as distributed solar plants, batteries, and controllable loads—assume active roles in power system operations [10]. More dynamic dispatch models, based on time-based pricing, distributed control, and digital platforms, have been successfully tested.

However, this transition is unfolding unevenly. Developing countries face specific challenges, such as institutional gaps, lack of digital infrastructure, and the absence of regulatory frameworks for aggregators, as noted in [12]. These factors limit the systemic integration of distributed energy resources, even when there is significant growth in installed capacity.

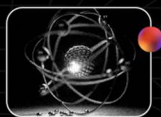
In this global context, Brazil stands out as a relevant case by combining one of the cleanest electricity mixes in the world—with more than 80% from renewable sources—and one of the

most significant growth rates in photovoltaic distributed generation (DG) in recent years [19]. Brazil ranks among the five countries with the largest cumulative installed capacity in photovoltaic distributed generation (PV-DG), according to the specialized literature, as a result of incentives such as the Net Metering Scheme and the enactment of Law No. 14,300/2022 [4]. Despite this progress, the effective incorporation of distributed generation into the operational and planning processes of the national power system remains limited [5,9].

Studies show that, in centralized systems such as Brazil's, decentralized energy production still plays a marginal role in dispatch models [8], creating a gap between the growth of installed capacity and its functional integration.

Furthermore, the country faces structural barriers that limit the role of distributed generation infrastructure as an active resource [7,10]. The absence of adequate digital infrastructure—such as smart metering, grid automation, and real-time control—undermines the dynamic participation of these agents in the system [5,9,6].

Official planning instruments, such as the Ten-Year Energy Expansion Plan, while acknowledging the growth of DG over the next decade, continue to treat it as exogenous to operational and tariff models. Therefore, this article conducts a critical review of the technical-regulatory literature to analyze the barriers to integrating decentralized energy sources into the Brazilian dispatch model.



The choice of this topic is justified by the growing relevance of photovoltaics in Brazil and the need to align technological advances with operational and regulatory models. The focus is on comparing the national scenario with consolidated international experiences.

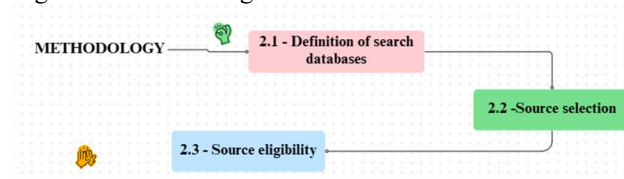
The central proposal seeks to identify regulatory, technical, and institutional pathways that will allow microgeneration to move beyond being merely an individual compensation mechanism and become a strategic agent for the stability, efficiency, and innovation of the power system. To this end, the research was conducted using normative, institutional, and technical sources, selected based on criteria of authority, timeliness, and thematic relevance. This approach aims to ensure methodological rigor and analytical consistency in assessing the opportunities and barriers to the active integration of DG into Brazil's electricity sector.

2. Methodology

This research adopted a systematic approach to technical-regulatory document review, focusing on the critical analysis of institutional sources, grey literature, and technical-scientific publications related to distributed generation (DG), photovoltaic microgeneration (PV-MG), and flexibility in the electricity sector, both in national and international contexts. The methodology employed in this study was structured based on systematic review guidelines that emphasize the clear definition of criteria, traceability of analytical decisions, and reproducibility of results [13]. The

methodological protocol comprised three main stages, as described below.

Figure 1- Process Stages

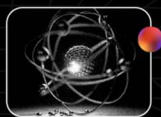


2.1. Search strategy design:

The first stage consisted of defining the objectives and thematic criteria for the search, focusing on the integration of DG in different regulatory, operational, and institutional contexts. Keywords were extracted from regulations, sectoral plans, and technical literature, such as “distributed generation,” “photovoltaic microgeneration,” “dispatch model,” “energy regulation,” “power system flexibility,” “smart grid,” “energy aggregators,” “DERs,” and “energy transition.” These terms were combined using Boolean operators to broaden the scope and precision of the search, in accordance with technical guidelines [13].

2.2. Data sources

The search covered public databases, institutional repositories, and technical-regulatory platforms—both national and international—considering as eligible the documents published between 2015 and 2024, with identifiable institutional authorship, public access, and methodological, regulatory, or technical content. The adopted time frame begins with the Paris Agreement signed during COP 21 in 2015, which established international decarbonization commitments and, globally, spurred policies aimed at the valorization of distributed energy



resources, smart grids, and local flexibility markets.

The selection of materials followed predefined inclusion and exclusion criteria. Documents with explicit authorship, validated technical or regulatory character, and thematic relevance to the study's objectives were included. The systematization of identified sources was organized according to their direct contribution to the central analysis or as a comparative basis for the regulatory framework. This approach seeks to ensure technical consistency and the reliability of the data used in the subsequent discussion.

2.3 Source eligibility

Three main criteria will guide this process:

1 - Institutional authority, with an emphasis on publications issued by official bodies and recognized institutions in the electricity sector;

2 - Timeliness, considering exclusively documents published from 2015 onward, a time frame justified by the signing of the Paris Agreement, which has globally driven policies for decarbonization and the integration of distributed energy resources;

3 - Thematic relevance, prioritizing materials that directly address the central axes of this work, such as distributed generation, photovoltaic microgeneration, operational flexibility, and decentralized dispatch models. In addition to these core criteria, inclusion and exclusion filters were applied. Documents with explicit

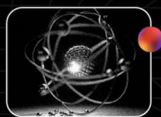
institutional authorship, validated technical, regulatory, or strategic content, and direct applicability to the study's objectives were included. Opinion-based sources, outdated materials, methodologically weak studies, or those thematically disconnected from the research scope were excluded.

To reinforce the robustness of the analysis, a thematic triangulation technique will be adopted, consisting of cross-comparison between national and international documents, seeking to validate interpretations, enhance argumentative consistency, and identify regulatory convergences and gaps. This methodological approach is in line with the best practices of documentary synthesis recommended in the specialized literature [13].

3. Results and Discussion

The advancement of PV-MG in Brazil demonstrates its strategic potential for modernizing the electricity sector. However, this modality still operates under a model that frames it as a passive agent, detached from short-term dispatch, planning, and pricing processes [4]. Despite the progress brought by Law N°. 14,300/2022 and ANEEL Resolutions No. 1000/2021 and N°. 1059/2023—such as the consolidation of the Net Metering Scheme (*Sistema de Compensação de Energia Elétrica*, SCEE) and the introduction of time-of-use tariffs—barriers persist that restrict its active participation in flexibility markets [2,3].

Although these regulations represent important advances, such as the consolidation of the SCEE,



the provision for time-based pricing, and the opening for new billing modalities, their regulatory framework keeps DG restricted to the role of energy compensation, without operational integration or explicit recognition as a flexibility resource [2,4]. This finding aligns with the central objective of this research, which seeks to understand the extent to which current regulation enables or limits the active participation of DG in more dynamic and digitalized market arrangements.

In contrast, countries such as Germany, the USA, Australia, the United Kingdom, Spain, Japan, and China demonstrate models in which distributed generation is integrated into decentralized systems through the use of aggregators, virtual power plants (VPPs), and digital platforms [7,12,17,15,16].

In these jurisdictions, PV-MG operates in a coordinated manner, contributing to flexibility, security, and operational efficiency, with dispatch based on price signals, automated algorithms, or grid conditions.

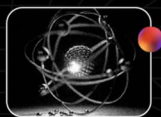
In Brazil, however, regulatory and digital infrastructure shortcomings persist. The absence of a legal framework for aggregators, the lack of interoperable platforms, and the absence of appropriate economic signals—such as time-based tariffs with locational granularity and the valuation of flexibility services—prevent the systemic utilization of distributed generation. As a result, PV-MG remains restricted to volumetric compensation, without reflecting the dynamic value its energy represents to the grid [2,7,8,9,12].

3.1 International Comparison: Country Overview

Although there have been technological advances and the global dissemination of distributed generation, there is no uniformity among countries regarding its regulatory classification and participation in dispatch processes. The document review shows that different jurisdictions adopt distinct strategies, both in terms of operational integration and the structuring of flexibility markets. Germany, the United States, Australia, the United Kingdom, Spain, Japan, and China already operate advanced models that actively integrate distributed resources through digital platforms, aggregators, virtual power plants (VPPs), distributed energy resource management systems (DERMS), and local markets [7,11,12].

In these experiences, distributed generation is treated as an active resource, with real-time response capability and participation in dynamic pricing mechanisms [11]. However, there is a lack of regulatory and institutional convergence among countries, revealing the complexity of the ongoing transformation. In many cases, including Brazil, DG remains tied to compensatory logics and exempt from operational obligations, hindering its effective contribution to system stability and flexibility [8].

Given this international heterogeneity and the fragility identified in the Brazilian context, it is pertinent to deepen the normative and comparative analysis. Accordingly, this research adopts a technical-regulatory document review approach to examine the main frameworks and



practices that can guide the evolution of DG's role in modern power systems.

In these jurisdictions, PV-MG operates in a coordinated manner, contributing to flexibility, security, and operational efficiency, with dispatch based on price signals, automated algorithms, or grid conditions.

Based on this, the international comparative framework developed in this study was structured using a systematic analytical approach, anchored in recognized technical-regulatory literature and in the experiences of countries that have advanced in the integration of distributed generation, such as Germany, Australia, the United Kingdom, and the United States [7,9,11,12].

The selection of the eight criteria adopted aims to reflect key dimensions that influence the degree of regulatory, economic, and technological maturity of the countries analyzed, avoiding arbitrary choices. Among these criteria, four core elements stand out: Regulatory Status, Market Type, Incentive Model, and Digital Infrastructure, as they represent structural pillars for the transition of DG from a passive resource to an active agent in contemporary energy systems [11,13].

This foundation is aligned with guidelines from institutions such as the IEA, IRENA, ENTSO-E, and ANEEL [5,9,10,11], and was constructed on a robust methodological protocol that combined a systematic documentary review, explicit inclusion and exclusion criteria, and the application of thematic triangulation across

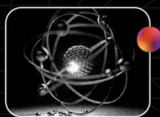
national and international sources. This approach provided solidity to the comparative results and support for the discussion, ensuring analytical coherence and alignment with good practices in regulatory analysis [14].

Regulatory status plays a central role in conferring legitimacy and stability to the actions of distributed agents [4,3,11]. Notwithstanding the advances brought by Law No. 14,300/2022, Brazil still lacks sub-regulatory instruments that enable the commercialization of flexibility services, resource aggregation, or coordinated participation in local markets [4,3]. The market type, in turn, determines the possibilities for DG's economic insertion. In countries with more open and decentralized markets, decentralized energy sources participate actively in price formation and dispatch.

In Brazil, the maintenance of a centralized model prevents such participation, limiting distributed energy resources to indirect compensations outside the system's economic signals [5]. The incentive model adopted also directly influences the evolution of DG. Leading countries offer mechanisms compatible with the services provided to the grid, such as time-based tariffs, payments for flexibility, and capacity auctions.

3.2 Specific Challenges of the Brazilian Model

Brazil, on the other hand, still relies primarily on net metering, which generates tariff distortions and prevents the efficient allocation of resources [1,3,12]. Finally, digital infrastructure is the element that enables real-time control,



automation, and dynamic pricing [5,10]. Its absence in the Brazilian context constitutes one of the greatest barriers to the transition to a decentralized model, as already acknowledged in official planning documents [5].

The other criteria assessed—Technological Focus, Real-Time Integration, Implementation Scale, and Funding Source—also play an important role, but their progress depends directly on strengthening the four main dimensions already highlighted [11,10,8]. Together, these dimensions form the foundation for transforming the role of DG: from a passive, compensatory resource to an active, intelligent, and integrated agent within new energy paradigms [10,9,7].

In this context, Table 1 presents a comparative overview that incorporates, in addition to regulatory aspects, complementary technical criteria such as technological focus, real-time integration, and implementation scale. These elements provide a broader view of the maturity level of international models and highlight the gaps that still need to be addressed in Brazil to enable the effective participation of aggregators and the active insertion of distributed generation in local flexibility markets [21,22].



Table 1 - Key Differences Between Countries Regarding Energy Aggregators (2025)

Country / Region	Regulatory Status	Market Type	Incentive Model	Digital Infrastructure	Technological Focus	Real-Time Integration	Implementation Scale
Brazil	Nonexistent	Does not exist	None	Very Low	Passive PV DG	None	Very Initial
Germany	Mature	Ancillary + VPPs	Services + Capacity	High	VPPs, Batteries	Full	Broad
United Kingdom	Advanced	Local Flexibility + Balancing	Flexibility + Balancing	High	DR + Local Flex	Full	Broad
Australia	Consolidated	Grid + DR	DR + Local Auctions	High	Residential DR + Batteries	Full	Broad
USA (California)	Consolidated	EIM + Capacity	Capacity + DR	Very High	Commercial DR + Storage	Full	Broad
France	Consolidated	Capacity + DR	Capacity + DR	Medium	Industrial DR	Partial	Medium
Italy	Emerging	Locational Flexibility + Balancing	Flexibility + Ancillary	Medium	DR + Flexibility	Partial	Emerging
Japan	Recent	VPPs + DR	Public Subsidies	High	VPP + IoT	Full	Medium-High
Spain	Initial / Pilot	Local Flexibility (pilot)	Pilot Programs	Medium-Low	Local Flex Pilot	Partial / Pilot	Initial

Source: Author's elaboration, 2025

To illustrate the differences between international models and the Brazilian one, the following comparative overview is presented:

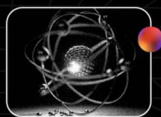
Germany operates a decentralized, digital dispatch model in which VPPs aggregate PV-MG, batteries, and flexible loads [6]. These resources are dispatched automatically according to market signals, generating revenue for prosumers. The contrast with Brazil lies in the structure: here, PV-MG injects energy passively, without forecasting or control.

The United States (California) uses DERMS systems that allow distributed energy resources (DERs), including PV-MG, to participate in the Energy Imbalance Market [9], receiving financial compensation. In Brazil, microgenerators still

lack the technical and legal means to participate in operational markets.

Australia has strong PV-MG integration into regional VPPs, notably the Tesla VPP [10], enabling predictive dispatch with residential batteries and real-time digital control. The contrast with Brazil lies in the fact that, there, it contributes to system reliability; here, it is simply deducted from the bill.

The United Kingdom adopts local flexibility markets organized by aggregators [11], allowing small generators to participate in negotiations with distribution system operators (DSOs). Plans such as the Smart Systems and Flexibility Plan have created regulatory frameworks for the entry of these new players and promoted data



interoperability, essential for the operation of local flexibility markets.

Spain allows scheduled exports and conducts tests with experimental regulations (sandboxes), including the use of technologies such as blockchain [9]. Although Law N°. 14,300/2022 provides for the possibility of selling surpluses in Brazil, the country still lacks the technical and contractual structure to enable the active scheduling of PV-MG in sync with market mechanisms.

Japan applies a regionalized and digital model, integrating PV-MG and DERs into smart grids [8], especially in smart cities. In contrast, Brazil still faces structural challenges, such as the absence of adequate infrastructure for large-scale adoption of smart metering—an essential element for system digitalization and decentralized control.

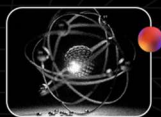
The United Kingdom stands out as a robust reference from both an operational and regulatory perspective. The government's Smart Systems and Flexibility Plan presents a set of coordinated measures that enable the active participation of DERs, such as PV, in flexibility markets and ancillary services—defined as complementary functions to power generation that enable the safe, stable, and efficient operation of the power system [18,19].

The implementation of recognized aggregators, the standardization of interoperability between digital platforms, dynamic pricing by location and time, and the mandatory deployment of smart

meters form a regulatory framework consistent with the digital energy transition [16]. This model contrasts sharply with the Brazilian reality, where interoperable platforms, local operational mechanisms, and regulatory structures for the coordinated and efficient operation of distributed agents are still absent [15].

China applies a hybrid regional dispatch model, combining central dispatch with DER control in provinces such as Guangdong [9]. Although the structure remains predominantly centralized, the country already surpasses Brazil by testing preventive control mechanisms and regional coordination of DG. In addition, there are initiatives aimed at active management through local platforms similar to the concept of distribution system operators (DSOs). In Brazil, by contrast, there are no formally recognized aggregators or structured platforms for participation in local flexibility markets.

Other European countries, such as France, Italy, and Denmark, also offer relevant experiences with aggregators and local flexibility markets. In France, initiatives such as the Projet FlexGrid focus on grid digitalization and active consumer participation. Italy is developing regional flexibility platforms based on smart meter use and zonal pricing. Denmark is a benchmark in integrating distributed wind generation with automated dispatch and demand response systems. Although these models were not examined in depth in this study, their contributions were incorporated into the comparative analysis of Table 1 [21].



4. Conclusion

The regulatory and technical analysis conducted in this study shows that DG in Brazil remains embedded in a restrictive model, based on net metering, without integration into dispatch, short-term price formation, or the provision of flexibility services. Even with institutional advances such as Law N°. 14,300/2022, ANEEL Resolution No. 1000/2021, and ANEEL Resolution N°. 1059/2023, regulatory bottlenecks persist that prevent the full valorization of DG as an active system resource [3]. The main challenges include:

1. The absence of a legal framework for aggregators, which undermines the coordinated operation of small distributed energy resources.
2. Limitations of the Net Metering Scheme (SCEE), which disregard the locational, temporal, and flexibility value of the generated energy.
3. The lack of sub-regulatory provisions for local flexibility markets, hindering DG's participation in price and dispatch dynamics.
4. The absence of adequate digital infrastructure, which prevents smart metering, predictive control, and real-time response.

When comparing the Brazilian model with consolidated experiences in Germany (VPPs and aggregators), the United Kingdom (Smart Systems Plan), California (EIM and DERMS), and Australia (local auctions and demand response), a systemic lag is observed in Brazil—

not only regulatory but also digital and operational. In light of this scenario, a gradual evolution roadmap is proposed, inspired by international benchmarks:

Short term: strengthen time-based pricing with locational signals and create regulatory sandboxes inspired by Spain's experience.

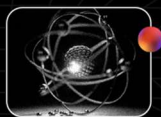
Medium term: establish local flexibility markets and regulate aggregator participation.

Long term: fully integrate DG into dispatch through DERMS platforms, widespread smart metering, and the consolidation of VPPs. This path requires institutional coordination among ANEEL, MME, ONS, distribution companies, and market agents, as well as investments in digital infrastructure and interoperable platforms, in addition to reformulating the DG incentive model [3].

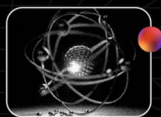
Given this scenario, DG in Brazil is at a decisive turning point: either it remains a marginal compensatory instrument or evolves into a strategic pillar of a fair, intelligent, and decentralized energy transition. For this, aligning regulation, technology, and governance is essential, as successfully demonstrated by several international jurisdictions.

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