

**Advancing Renewable Energy Decarbonization: Policy Insights for Brazil**

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**Executive Summary**

This report explores the critical pathways for advancing renewable energy and decarbonization efforts in Brazil, a country with a diverse electric system facing significant challenges due to climate change. The analysis focuses on three scenarios: maintaining the current electricity consumption patterns (Business as Usual), expanding Distributed Generation Photovoltaic (DGPV) systems, and increasing the adoption of electric vehicles (EVs).

Key findings indicate that financial incentives are vital for enhancing DGPV adoption, substantially improving the electricity system's capacity while easing congestion resulting from high renewable penetration. Although a 35% cost reduction in solar technology could significantly boost DGPV, the effects may not be realized until 2042, highlighting the necessity for long-term policy planning. Furthermore, a projected 20% increase in EVs by 2050 would minimally impact the electricity system while contributing to a 20% reduction in emissions, underscoring the importance of integrating renewable energy and sustainable transportation policies.

The report recommends that policymakers consider the long-term implications of renewable energy strategies, focus on designing effective financial incentives for DGPV, and create integrated policies that connect renewable energy growth with transportation sustainability. Future research should investigate more aggressive EV adoption scenarios and further refine models to address potential implementation challenges and interventions for a successful energy transition in Brazil.

**1. Introduction**

Climate change threatens global stability, affecting ecosystems, economies, and human well-being. To meet growing energy demands, countries must integrate renewable sources like solar and wind power to reduce greenhouse gas emissions and promote sustainability. Expanding renewables enhances energy security, diversifies the energy matrix, and decreases dependence on fossil fuels. A well-planned transition to clean energy is essential for a resilient, low-carbon future [1-3].

The expansion of distributed generation, particularly from photovoltaic systems, plays a vital role in enhancing the resilience and efficiency of Brazil's electricity system. However, the widespread adoption of this technology depends on well-structured incentives and public policies that encourage investment and integration. Financial support and regulatory measures can accelerate the penetration of distributed generation, reducing reliance on centralized power plants and alleviating grid congestion caused by high renewable penetration. By promoting decentralized energy production, these policies contribute to a more balanced and flexible electricity system, ensuring long-term sustainability and reliability [4-6].

The increasing adoption of EVs is crucial in reducing CO₂ emissions and promoting a more sustainable transportation system. As EVs replace internal combustion engine vehicles, they help decrease the burning of fossil fuels, one of the main contributors to greenhouse gas emissions. This transition is particularly beneficial when combined with a clean electricity matrix, ensuring that energy for charging EVs comes from renewable sources [7-10].

**2. Methodology**

The study will be conducted through simulations using an energy system modeling tool called the Open-Source energy Modelling SYStem (OSeMOSYS). This tool is specifically designed to assist in developing energy strategies at local, national, and multi-regional levels while supporting capacity-building initiatives.

In this study, the OSeMOSYS software will analyze the Brazilian energy sector, focusing on electricity generation and consumption [11]. The dataset for the simulations is obtained from reports issued by Brazilian institutions responsible for energy planning, such as the National System Operator (ONS), as well as other relevant organizations. Additionally, data from international agencies that provide energy-related information will be incorporated to ensure a comprehensive assessment. By leveraging these sources, the study aims to develop a robust model that accurately represents Brazil’s electricity system and evaluates different scenarios for renewable energy integration and policy impacts. A simplified flowchart can be seen in Figure 1.

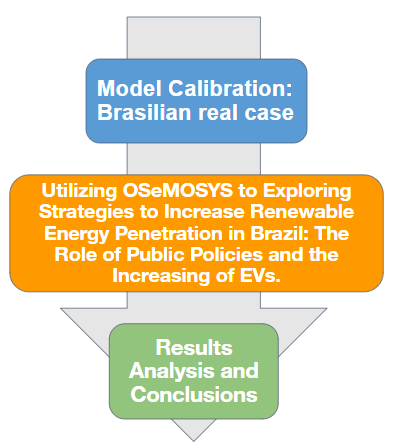


Fig. 1 - Simplified Flowchart of the used methodology

Brazil is a vast country with an electric system that is divided into multiple regions. For a more comprehensive analysis, it would be ideal to consider each region individually. However, Brazil was modeled as a single region in this analysis to simplify the study.

The three considered scenarios are listed below:

1. **Business as usual (BAU)**: In this scenario, the electric energy data from Brazil will be used. This scenario is essential to evaluate if the simulation results are following the current situation in Brazil, validating the model.
2. **Distributed Generation Photovoltaic (DGPV35)**: This scenario examines how the expansion of distributed photovoltaic generation, driven by financial incentive policies, can benefit Brazil's electricity system. The assumption adopted considers a decrease of 35% in the costs of distributed solar technology, starting in 2025.
3. **Electric vehicle (EV20):** This scenario projects a gradual increase in Brazil’s EV fleet, reaching 20% by 2050. Driven by battery advancements, cost reductions, and policy support, the transition from internal combustion vehicles to EVs is analyzed for its impact on electricity demand and broader energy and transportation challenges.

**3. Results**

This section presents the results, including each scenario's installed capacity, annual electricity generation, emissions, and costs. The business-as-usual case is a reference for comparing the behaviour of the other two cases.

In the BAU scenario, the total installed capacity reaches 606 GW by 2050, with wind and hydroelectric power accounting for most of the generation mix. In the second scenario, in which the cost of distributed photovoltaic generation (DGPV35) experiences a reduction of 35%, a notable increase in DGPV capacity is anticipated to commence in 2042. By the year 2050, DGPV is projected to contribute in excess of 30% to Brazil's total installed capacity, which is expected to attain 692 GW the total installed capacity increases, due to the lower capacity factor of solar energy. In the third scenario, with a 20% increase in the EV fleet (EV20), wind and hydroelectric power dominate the generation mix as in the BAU case. However, the total installed capacity will rise to 623 GW by 2050 due the electricity demand caused by the EVs. Figure 2 shows the total installed capacity for all three cases through 2050.

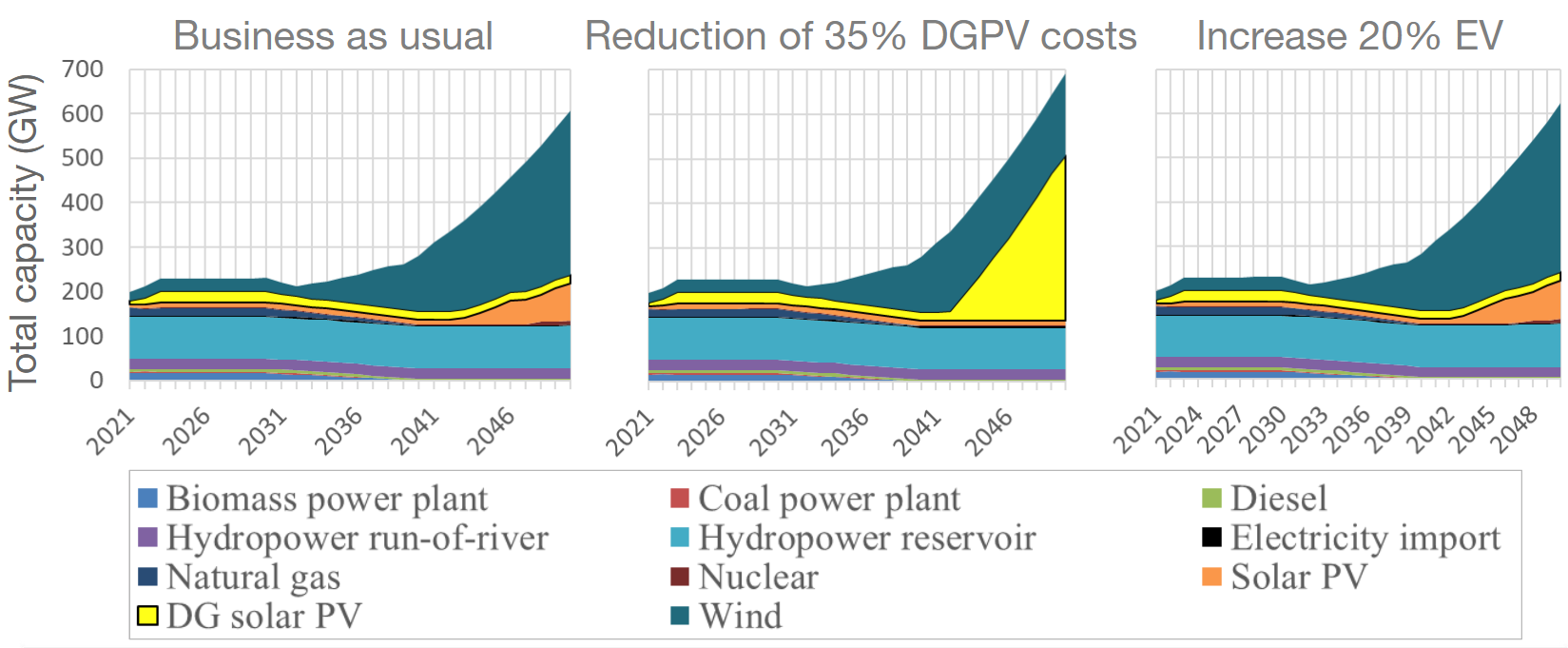


Fig. 2 Total installed capacity for all three cases through 2050

The annual electricity generation in each scenario follows a trend similar to the installed capacity. Wind and hydroelectric power remain dominant in the BAU case and the third scenario. By 2050, total electricity generation will reach 7896 PJ in the BAU case and 8057 PJ in the third scenario, representing a 2% increase due to the higher electricity demand from electric vehicles. In the second scenario, DGPV35, the total generation is 7600 PJ in 2050, corresponding to around a 4% decrease compared to the BAU case. Figure 3 illustrates the comparison of electricity generation across the three scenarios.

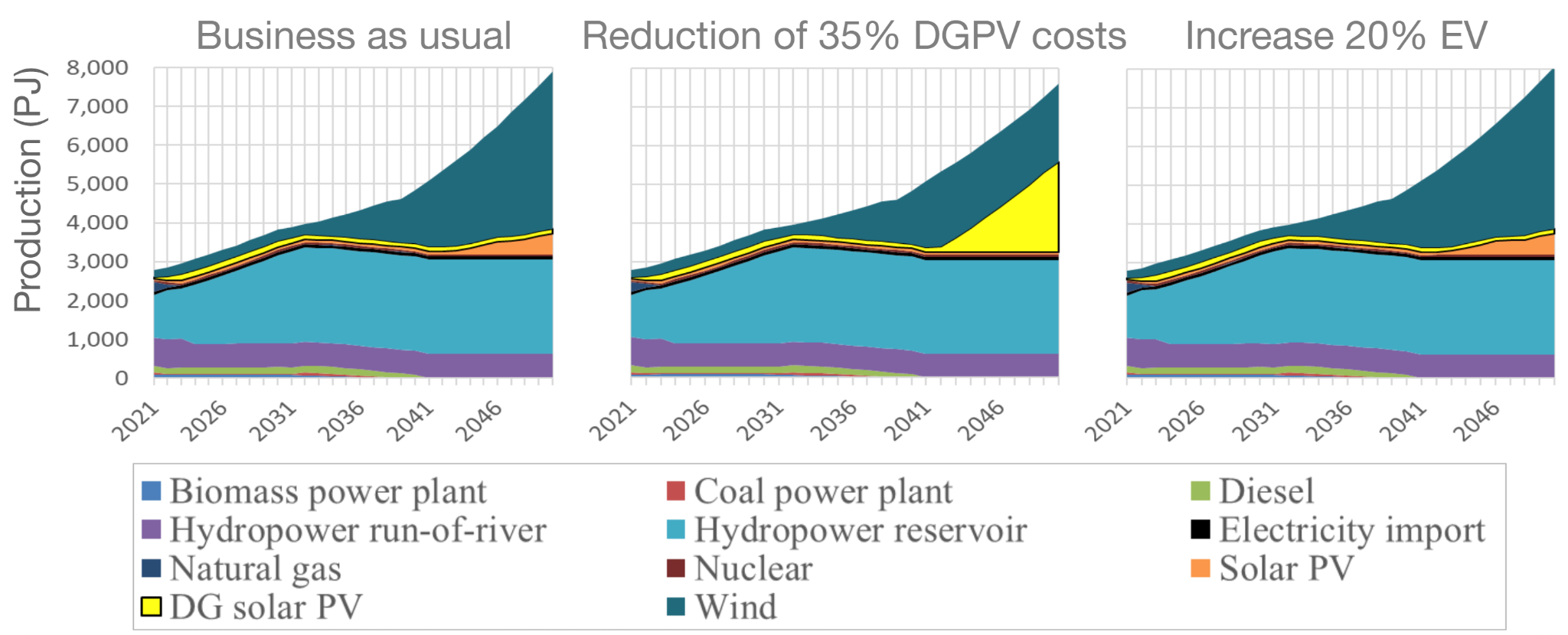


Fig. 3 Comparison of electricity generation across the three scenarios.

The comparative analysis of CO₂ emissions among the three scenarios demonstrates negligible disparities between the BAU and DGPV35 scenarios. In the EV20 scenario, where the fleet of electric vehicles experiences an increase of 20%, carbon dioxide emissions are anticipated to be 20% lower by the year 2050 compared to the Business As Usual (BAU) scenario. This reduction is ascribed to the displacement of fossil fuel consumption within the transportation sector. The trends in comparative emissions are depicted in Figure 4.

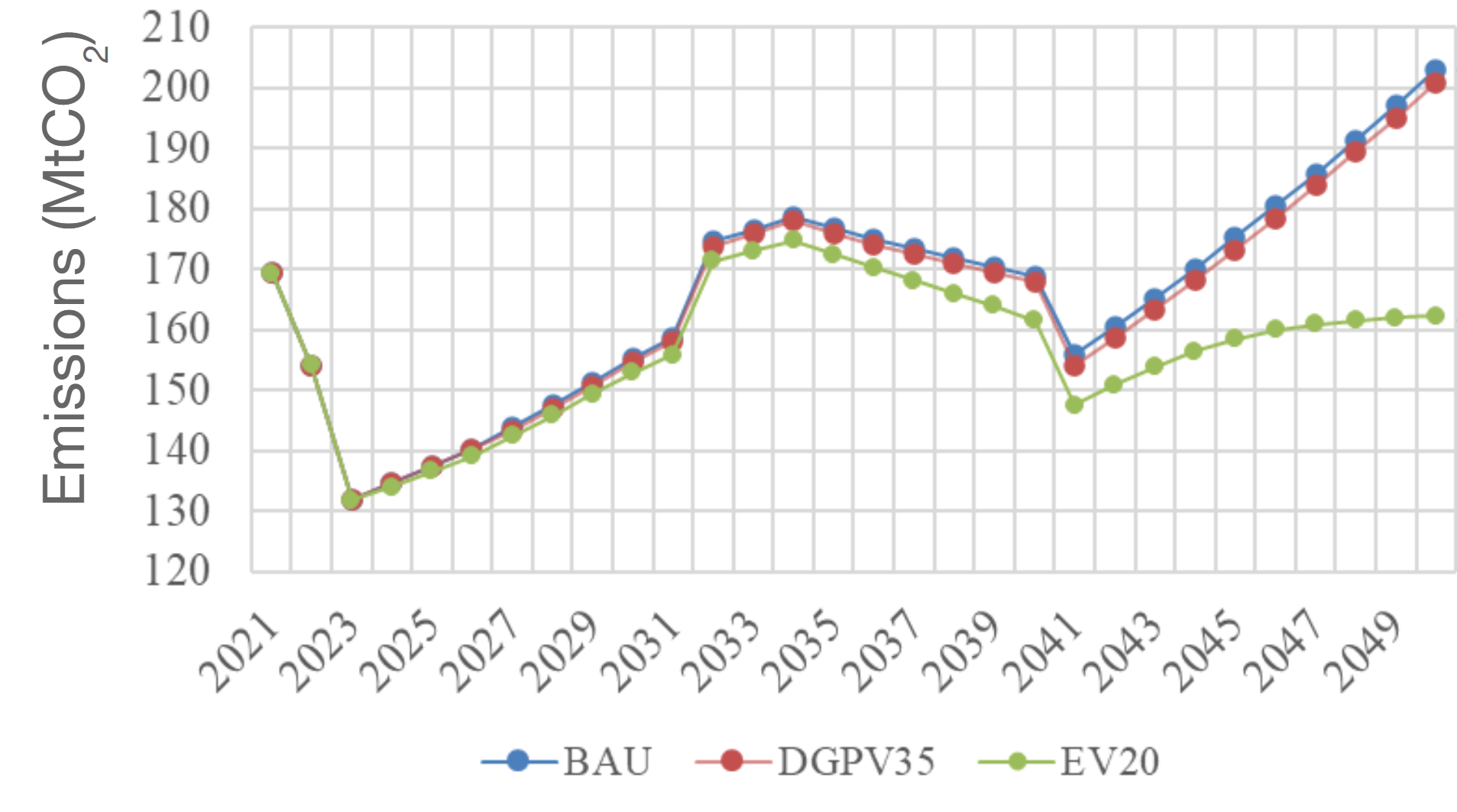


Fig. 4 Annual emissions of CO2

Figure 5 illustrates the total costs from 2021 to 2050 associated with the BAU, DGPV35, and EV20 scenarios. Notably, both DGPV35 and EV20 scenarios show a 3% cost increase compared to the BAU. This increase can be attributed to the initial investments required for solar infrastructure in the DGPV scenario and the necessary charging infrastructure and grid upgrades for EVs. While these upfront costs are significant, they are expected to yield long-term benefits regarding reduced emissions and energy sustainability.

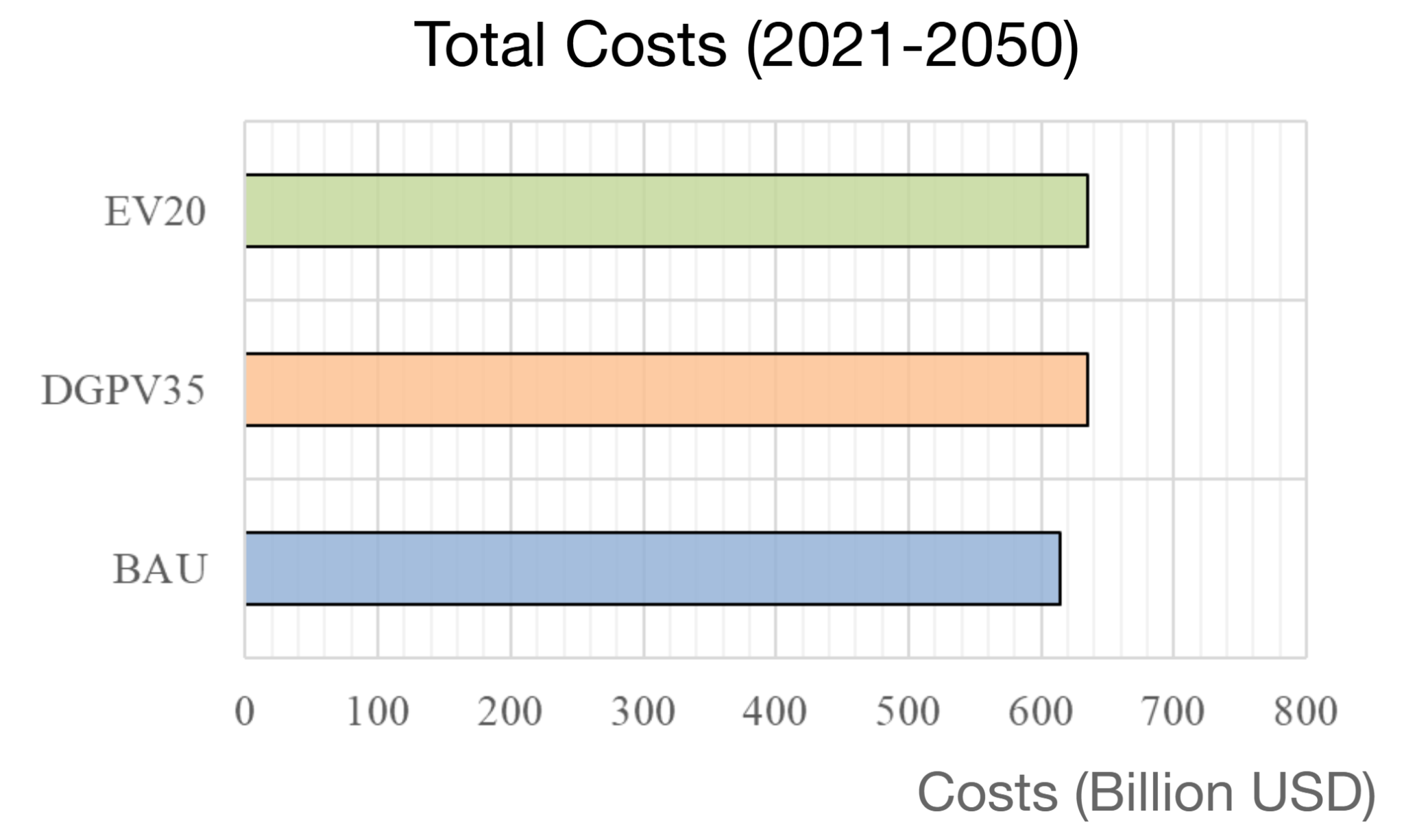


Fig. 5 Total Costs from 2021 to 2050

**5. Discussion**

The analysis presented in this report highlights the significant potential for renewable energy expansion in Brazil, primarily through DGPV systems and the adoption of EVs. Figures 2 and 3, which depict total installed capacity and annual electricity production, provide a comprehensive overview of the current landscape and underscore the necessary transitions to enhance Brazil's energy resilience and sustainability.

**Insights from Installed Capacity and Production Data**

The results show the total installed capacity and reveal a firm reliance on hydropower, which forms the backbone of Brazil's electricity generation. However, as climate change exacerbates weather patterns, such as prolonged droughts, this dependence on hydropower raises concerns about energy security. Expanding solar and wind contributions is essential for diversifying the electricity matrix and minimizing vulnerability to hydrological fluctuations. The results show that while Brazil's current energy system is predominantly renewable, a more balanced mix incorporating variable renewable energy sources is crucial for addressing future challenges.

As financial incentives are introduced, an optimistic outlook for DGPV expansion is presented by anticipating a 35% reduction in deployment costs for solar technologies. Although the immediate impact may not be fully realized until 2042, the gradual integration indicated in the model suggests a transformative shift for the electricity system. These advancements alleviate demand pressures during peak times and contribute to localized energy solutions, making communities less reliant on centralized hydropower resources.

**Impact of Electric Vehicle Adoption**

The projection regarding the EV fleet's growth reflects a significant trend that supports emission reduction goals. The analysis predicts a 20% penetration of EVs by 2050, corresponding to advancements in battery technology and supportive policies. While the immediate impact on electricity demand may seem minimal, the anticipated 20% reduction in emissions highlights the environmental benefits of transitioning to electric mobility. This finding emphasizes the interconnectedness of energy systems and transportation and calls for policies that synergistically promote both sectors.

Integrating EV infrastructure with renewable energy generation can lead to innovative solutions, such as vehicle-to-grid (V2G) technologies, where EVs serve as distributed energy resources. This approach addresses electricity demand spikes and enhances the energy system's resilience. The data supporting EV adoption underscores the importance of comprehensive planning and investment in both infrastructure and renewable energy generation to enable this transformation.

**Policy Recommendations and Future Directions**

Several policy recommendations emerge, given the insights derived from the models and simulations. First, to stimulate growth and encourage private investment, dedicated financial incentives for DGPV should be prioritized. Policymakers must recognize the long-term benefits of these initiatives, even if the short-term impacts seem delayed.

Furthermore, policies integrating DGPV expansion with EV infrastructures, such as incentivizing home charging stations powered by solar panels, could maximize the utility of both technologies. These integrated strategies should also consider the socio-economic aspects of energy transition, aiming to promote inclusivity and accessibility of renewable technologies across varied demographics.

However, certain limitations of the study must be acknowledged. The modeling approach primarily considers Brazil as a single region, which may overlook the unique energy dynamics within its diverse geographical areas. Future research could benefit from a more granular analysis, examining regional disparities to facilitate tailored solutions that meet local needs.

Additionally, exploring more aggressive scenarios for DGPV and EV adoption could provide a deeper understanding of potential impacts on electricity systems. As data on technological advancements and cost reductions evolve, continuously refining the models to reflect new realities will be crucial for maintaining relevance and applicability.

**7. Conclusion**

Financial incentives for DGPV are key to increasing its adoption and improving Brazil's electricity system by easing congestion caused by high renewable penetration. However, their long-term effectiveness depends on well-designed policies.

Although a 35% cost reduction significantly boosts DGPV capacity, its impact will only be felt from 2042 onwards. This delay highlights the need for long-term planning to ensure a smooth transition to a sustainable energy mix. Policymakers must consider this lag when implementing renewable energy policies.

Up to 20% of Brazil's electricity system and costs will be minimally affected by an increase in the EV fleet by 2050. Still, this will lead to a 20% reduction in emissions, reinforcing EVs' role in environmental sustainability. Integrated policies that link renewable energy expansion with sustainable transportation are essential.

Future work will improve the model by refining time slices, subregions, and sector disaggregation. Additionally, further studies will explore more aggressive EV adoption and assess how financial incentives for DGPV can support this transition.

**References**

[1] IRENA (2020). Innovation Landscape for a Renewable-Powered Future: Solutions to Integrate Variable Renewables. International Renewable Energy Agency. Available at: https://www.irena.org/

[2] ANEEL (2022). Geração Distribuída no Brasil: Panorama e Perspectivas. Agência Nacional de Energia Elétrica. Available at: https://www.aneel.gov.br

[3] Lund, H., Østergaard, P. A., Connolly, D., and Mathiesen, B. V. (2017). Smart energy and smart energy systems. Energy, 137, 556-565.

[4] REN21 (2021). *Renewables 2021 Global Status Report*. Renewable Energy Policy Network for the 21st Century. Available at:<https://www.ren21.net/>

[5] Barbose, G., Darghouth, N., O’Shaughnessy, E., and Forrester, S. (2021). *Residential Solar-Adopter Income and Demographic Trends: September 2021 Update*. Lawrence Berkeley National Laboratory.

[6] De Jong, P., Sánchez, A. S., Esquerre, K., Kalid, R. A., and Torres, E. A. (2016). *Solar and wind energy production in relation to the electricity load curve and hydroelectricity in the northeast region of Brazil*. Renewable Energy, 88, 192-203.

[7] International Energy Agency (IEA) (2022). *Global EV Outlook 2022: Securing Supplies for an Electric Future*. Available at:<https://www.iea.org/>

[8] Cozzi, L., and Gould, T. (2021). *World Energy Outlook 2021*. International Energy Agency (IEA).

[9] Khalid, F., Javaid, N., and Ahmad, A. (2020). *Electric vehicles and smart grid integration: A comprehensive review on challenges and solutions*. Energy Reports, 6, 1012-1034.

[10] Xu, B., Hodge, B.-M., and Florita, A. (2018). *On the role of electric vehicles in renewable energy integration: A review*. Renewable and Sustainable Energy Reviews, 81, 1450-1463.

[11] Bitencourt, L., Abud, T., Santos, R. and Borba, B. (2021). Bass Diffusion Model Adaptation Considering Public Policies to Improve Electric Vehicle Sales—A Brazilian Case Study.

**Appendices**

Before selecting the percentage reduction in DGPV installation costs, sensitivity analyses were conducted, employing 30%, 35%, and 40% discount values to ascertain the most suitable option. Figure A.1 delineates the results, illustrating the contribution of DGPV installed capacity across each discount scenario. Based on these findings, a 35% reduction was deemed appropriate, as it offers a balanced outcome between cost-benefit considerations and the penetration rate.

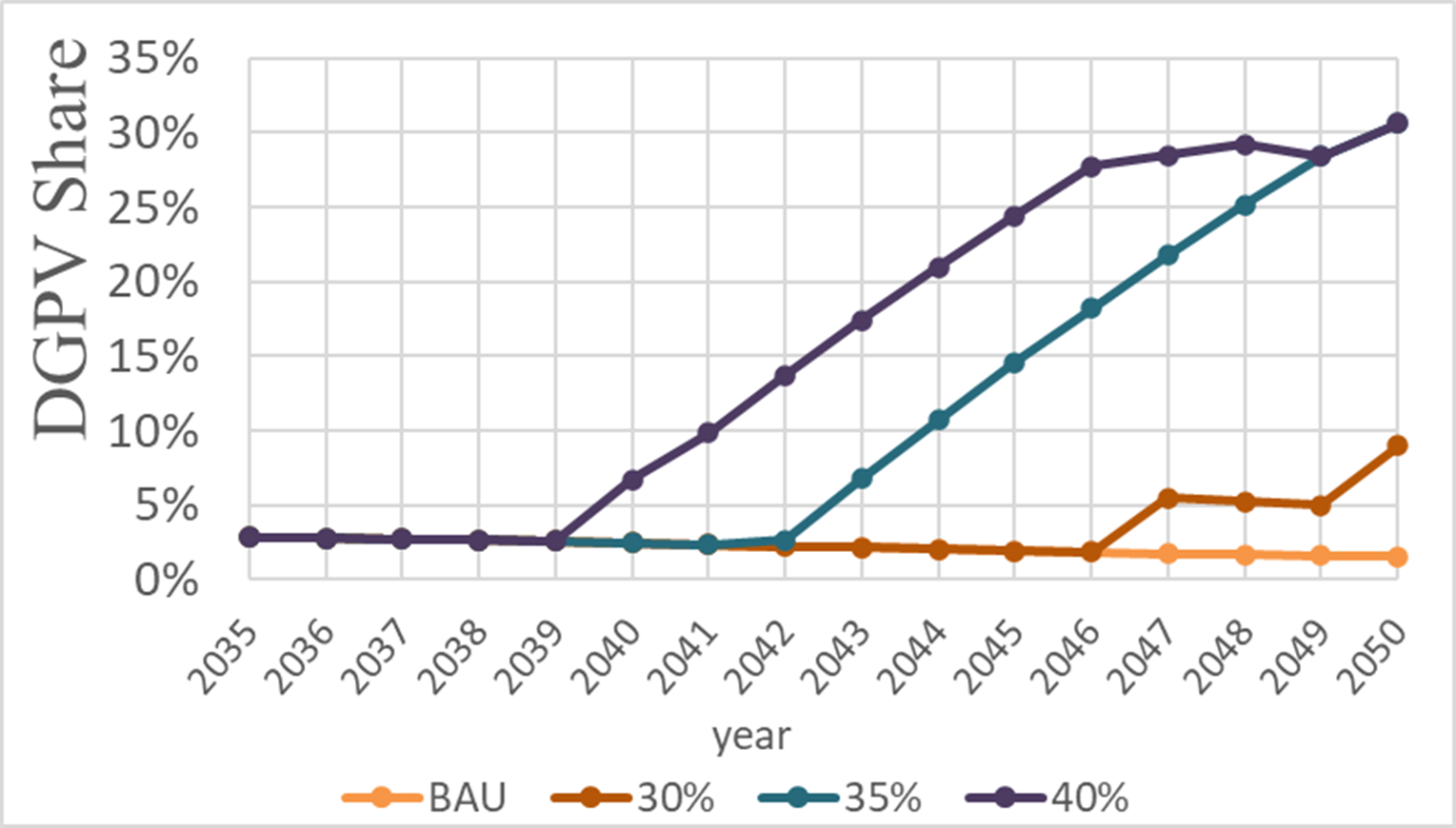


Fig. A.1 The contribution of DGPV with varying discount levels on trends in installed pricing.

