Assessment of the policy framework's impact on the renewable energy generation expansion in the Brazilian power grid

ICAT
Initiative for Climate Action Transparency

Initiative for Climate Action Transparency – ICAT

ICAT Brazil Project phase 3

Assessment of the policy framework impact on the renewable energy generation expansion in the Brazilian power grid

Output 8 - Results of the sustainable development impacts assessment and initial steps for the Just Transition monitoring

July 2024

Initiative for Climate Action Transparency - ICAT

Results of the sustainable development impacts assessment and initial steps for the Just Transition monitoring

Deliverable #8

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List of abbreviations

ANEEL	Brazilian Electricity Regulatory Agency
BNDES	Brazil's National Development Bank
CAPEX	Capital Expenditure
CBC	Brazil Climate Centre
CO2e	Carbon Dioxide Equivalent
CPS	Current Policies Scenario
CVU	Variable Unit Cost
DDS	Deep Decarbonization Scenario
DG	Distributed Generation
DGRV	German Cooperative and Raiffeisen Confederation
EPE	Energy Research Office
FC	Capacity Factor
FINAME	Special Industrial Financing Agency
GHG	Greenhouse Gas
HHI	Herfindahl-Hirschman Index
HPP	Hydroelectric Power Plant
IBAMA	Brazilian Institute of Environment and Renewable Natural Resources
ICAT	Initiative for Climate Action Transparency
IRENA	International Renewable Energy Agency
LCOE	Levelized Cost of Electricity
MRV	Measurement, Reporting, and Verification
MWh	Megawatt-hour
NDC	Nationally Determined Contribution
O&M	Operation and Maintenance
PERS	Social Renewable Energy Program
PNRS	National Solid Waste Policy
PV	Solar Photovoltaic
PVDG	Solar Photovoltaic Distributed Generation
R$	Real (Brazilian Currency)
SCEE	Electric Energy Compensation System
SD	Sustainable Development
SDG	Sustainable Development Goals
SO2	Sulfur Dioxide
STEM	Science, technology, engineering and mathematics
TPP	Thermal Power Plants
UNEP CCC	United Nations Environment Programme Copenhagen Climate Centre

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Forewords

This report is part of the ICAT Brazil Project phase 3, hereafter referred to as ICAT project, which is implemented by Centro Brasil no Clima (Brazil Climate Centre – CBC) in partnership with Centro Clima (PPE/COPPE/UFRJ) with support from the Initiative for Climate Action Transparency (ICAT) and technical support from the UNEP Copenhagen Climate Centre (UNEP CCC).

The previous phases of the ICAT project aimed at the enhancement of the transparency framework in Brazil by developing MRV indicators to assess climate policies and actions at the national (1st phase) and subnational (2nd phase) level. These phases developed mitigation scenarios that provided critical insight for policy development at the national and sub-national levels and proposed MRV indicators to track the implementation of the Brazilian NDC.

The third phase of the ICAT Brazil project, which started in March 2023, builds off insight gained from the first two phases by providing a detailed analysis of the energy sector in Brazil. The project assesses the potential expansion of the power sector in the country through variable renewable energies (wind and solar photovoltaic) and biomass, the sustainable development impacts of sectoral policies by applying the ICAT's Sustainable Development Methodology and contributes for the Just Energy Transition planning in Brazil.

This report, constituting Output 8 of the ICAT project, was prepared by Centro Brasil no Clima (CBC) and presents the results of the Sustainable Development Assessment of the expansion of distributed photovoltaic generation, allowed by the regulatory framework of distributed generation in Brazil. Additionally, this report also discusses the initial steps taken to monitor just energy transitions in Brazil.

1 Introduction

In the contemporary landscape of climate challenges, the imperative for sustainable development is fundamental due to the pivotal role of renewable energy sources in shaping energy transitions, which are expected for the achievement of Brazilian Nationally Determined Contribution (NDC). This report examines the Sustainable Development (SD) impact of specific Brazilian energy policies, emphasizing their social, economic, and environmental impacts.

In this report, the focal point of the SD Assessment is the SD transformative impact potential of solar photovoltaic distributed generation (PVDG), specifically within the dynamic of the Brazilian power sector expected for 2050 from a conservative Current Policies Scenario (CPS), which follows the trend of ongoing mitigation actions; and a Deep Decarbonization Scenario (DDS), which follows a greenhouse gas (GHG) emissions trajectory compatible with the global objective of 1.5ºC, achieving net-zero emissions in 2050. These scenarios have been evaluated by Centro Clima and presented in Output 2 and Output 3, respectively.

As outlined by projections from Centro Clima, PVGD is expected to play a pivotal role in Brazilian electricity matrix by 2050. Considering the scenarios without interference in protected areas, in the CPS scenario, PVDG installed capacity is expected to expand around 1200%; while in the DDS scenario, around 1300% - representing around 18% and 20% of the total installed capacity in the period respectively. This trajectory underscores the escalating prominence and potential transformative impact of distributed photovoltaic generation in shaping Brazil's energy landscape in the coming decades.

Amidst the necessity of meeting escalating energy demands, mitigating environmental degradation while also seeking to eradicate the inequalities operated within the Brazilian energy system, the integration of solar power into the energy matrix assumes a great significance, given that it drastically changes the vertical energy planning rationale, it incorporates final consumers as decisive agents in the dynamic of the sector and it incorporates new arrangements, opportunities and challenges for the sector and for the climate agenda.

The SD assessment results of the present report builds on the previous outputs of the ICAT project, namely, Output 2, Output 3 and Output 6. The scenarios developed by Centro Clima presented in Output 2 and Output 3 were used as baseline projections for the ex-ante SD assessment in the horizon of 2050. Output 6 presents the objectives, the policy framework, the impact categories, and indicators used the sustainable development assessment.

While Output 6 also anticipated the possibility of assessing policies related to bioelectricity and wind energy generation, the final SD assessment only used PVGD as a case study for two main reasons. First, because of the importance of the PVDG turned out to have both in the CPS and DDS scenario developed throughout the course of the project; second, because of the observed political timing, availability and opportunities to discuss just energy transitions, which led to a re-evaluation of the project's course and the proposal for an extension, which is explained in Output 9.

In the next sections, this report delves into the impacts on sustainable development that have been quantitatively and qualitatively examined through a comprehensive literature review. It is crucial to emphasize that further consultations with stakeholders are planned to validate the assessment. Part 1 of this report presents the sustainable development assessment of photovoltaic distributed power generation regulatory framework in Brazil. Furthermore, as part of this project's efforts to contribute to the planning of an evaluation and monitoring of the just transition in Brazil, part 2 presents initial steps for the just transition monitoring.

PART 1: SUSTAINABLE DEVELOPMENT ASSESSMENT OF PHOTOVOLTAIC DISTRIBUTED POWER GENERATION (PVDG) EXPANSION

This section presents the main results of the Sustainable Development Assessment of PVDG expansion, enabled by the regulatory framework of DG generation in Brazil. The premises used to for the construction of the impact scenarios were presented in Output 2 and Output 3 and the definition of the objectives, police framework, impact categories and indicators for the assessment were presented in Output 6. The section is divided in four subsections. Subsection 2 presents the regulatory framework of DG; Subsection 3, the summary of the SD impact assessment; Subsection 4, the methodology used in the assessment and Subsection 5, its results, and discussions.

1 Regulatory Framework of Distributed Power (DG) Generation in Brazil (PV generation)

As presented in more detail in Output 6, Distributed Generation (DG) in Brazil, governed by Normative Resolution n. 482/2012, enables end consumers to generate renewable energy while connected to the national grid – promoting them to become *prosumers*. Subsequent amendments via Normative Resolutions n. 687/2015 and n. 786/2017 contributed to expanding DG, particularly in solar photovoltaic (PV) installations, which grew exponentially from 7 MW in 2012 to 4.6 GW in 2020.

The regulatory response to this surge proposed changes to tariff rules, seeking to end tariff parity and provide only partial compensation for energy credits. Anticipating adverse impacts on solar investments, the sector initiated Bill n. 5,829/2019, leading to the enactment of Law n. 14,300/2022. This law not only establishes guidelines for solar energy installation and self-consumption but also modifies the Electric Energy Compensation System (SCEE) and introduces the Social Renewable Energy Program (PERS).

The SCEE involves a "loan" of surplus energy to the distributor, returned as credits. The Law introduces a gradual taxation system on these credits, commencing at 15% in 2023 and incrementally reaching 90% by 2028. However, the taxations apply exclusively to installations post-January 2023, whereas existing installations will face taxation only after 2045. The modalities of participation in SCEE encompass local and remote self-consumption, distributed generation in multiple consumer unit developments, and shared generation.

Post-law enactment, over 780,000 DG connections have been established, aggregating 7.6 GW of installed capacity. The Brazilian Electricity Regulatory Agency's (ANEEL) February 2023 data for DG indicate a 60% increase in the number of connections and a 54% increase in installed capacity compared to the preceding 13 months.

While the regulatory framework is not exclusively tailored for PV systems, since its publication 99% of the accumulated installed capacity has originated from PV generation (EPE, 2024). Therefore, this SD assessment will exclusively evaluate PV generation as the main favoured source of the Regulatory Framework of Distributed Power Generation in Brazil.

As for the projections utilised to evaluate the impacts on Sustainable Development resulting from the expansion of decentralised PV power generation, we employed scenarios CPS 2 and DDS 2 developed by Centro Clima (Outputs 2 and 3 of the ICAT project, respectively). CPS 1 and DDS 1 scenarios were omitted from the quantitative scenarios in the SD assessment due to their inclusion of interference in protected areas. Thus, CPS 2 and DDS 2 will be referenced as CPS and DDS in this report.

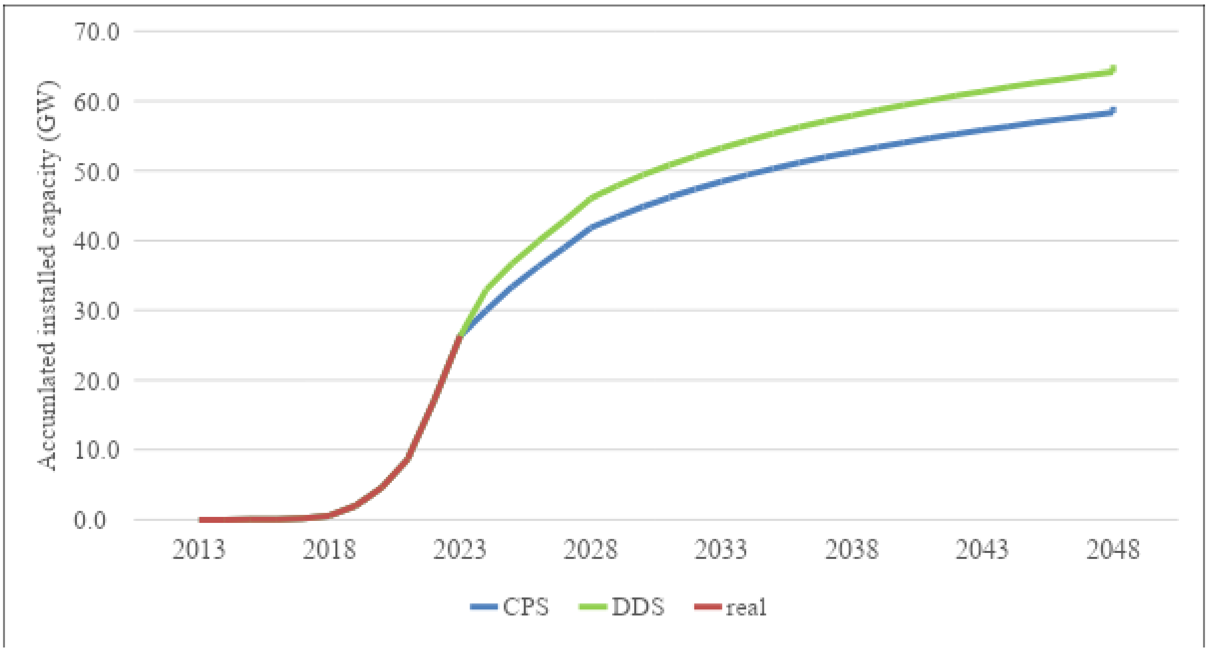


Figure 1 – Current Policies and Deep Decarbonization Scenarios (without interference in protected areas)

Source: Prepared by the authors.

Note: The accumulated capacity also includes decommissioned panels, set in Matrix to have an average lifetime of 30 years.

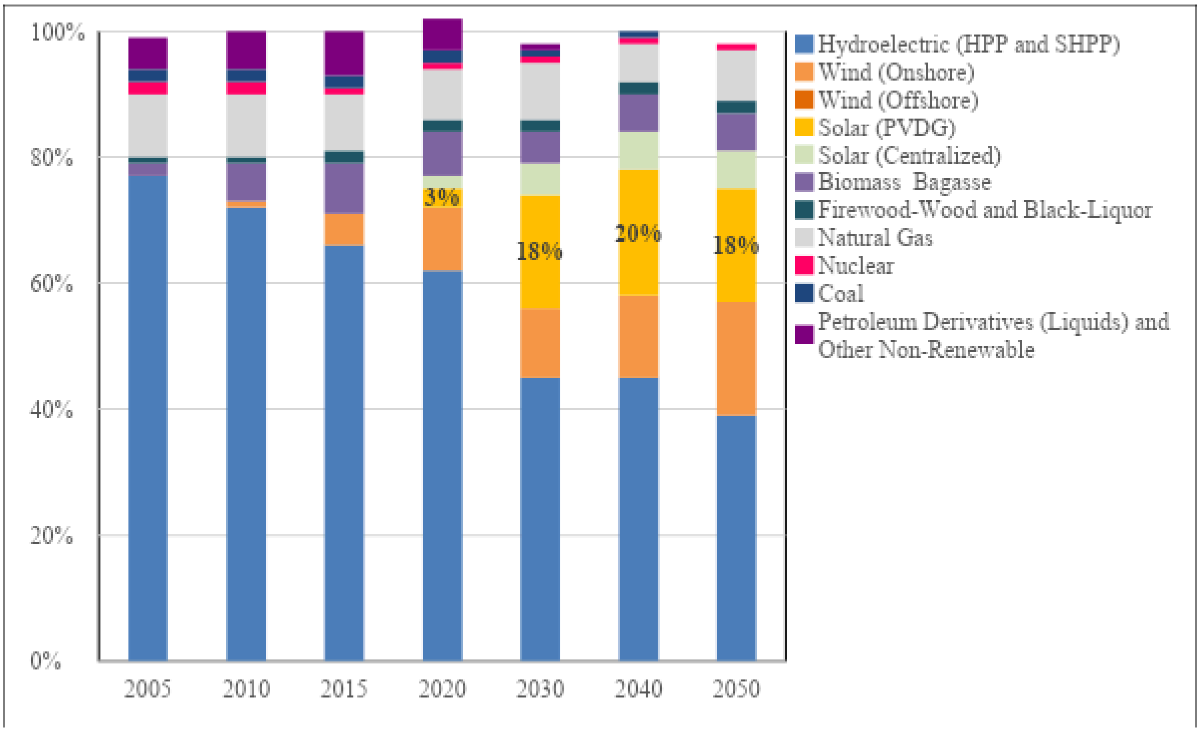


Figure 2 – Brazilian electricity mix evolution (2005-2050) for CPS

Source: Prepared by the authors based on Centro Clima's report.

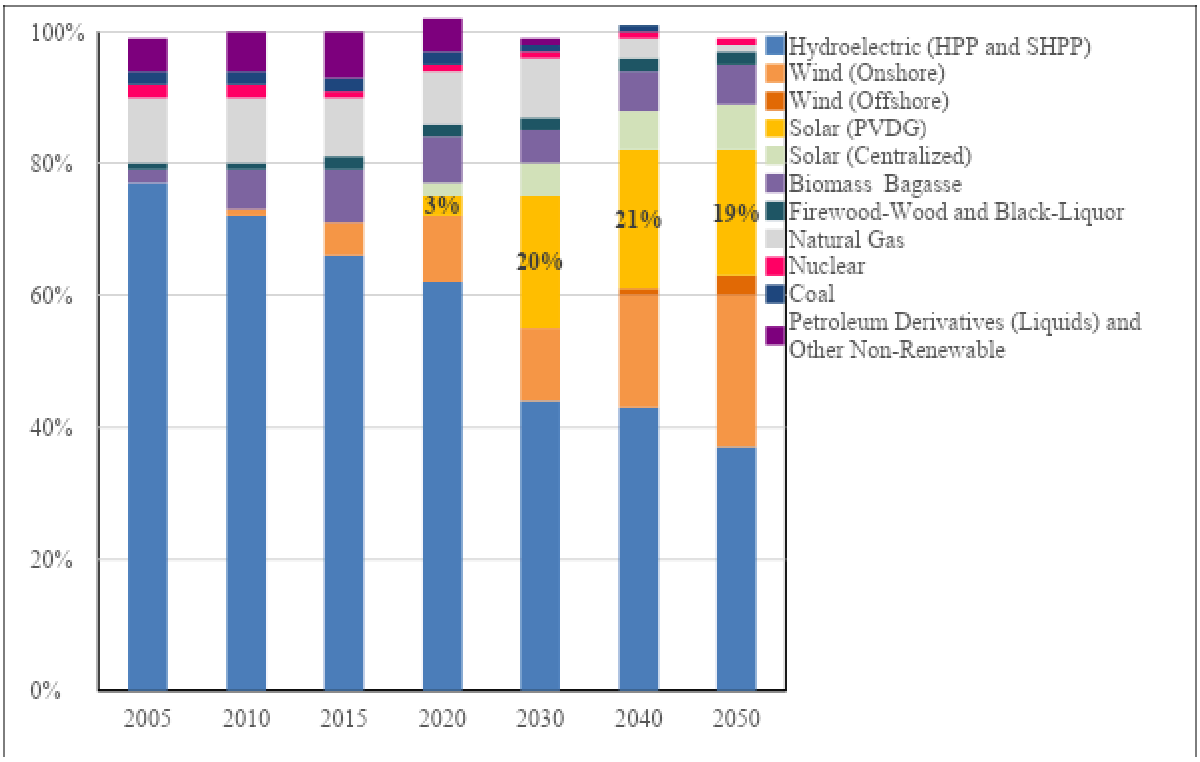


Figure 3 – Brazilian electricity mix evolution (2005-2050) for DSS

Source: Prepared by the authors based on Centro Clima's report.

Summary of the SD impact assessment of PVDG Regulatory Framework

Table 1 – Summary of the SD impact assessment for the Regulatory Framework of Distributed Power Generation

Dimension	Impact categories included in the assessment	Specific impacts identified	Positive or negative impact	Significant?	Summary of qualitative assessment results for each impact category	Methods / sources used	Feasible to quantify?	Included in the quantitative assessment boundary?	Justification for exclusions or other comments
Environment	GHG mitigation	Promoting distributed generation (GD) implies lower emissions from the energy sector	Positive	Yes	PVDG expansion avoids a considerable amount of GHG emission in 2050 and highlights the importance final energy consumers will have in climate mitigation in Brazil.	Ex ante quantitative assessment based on three alternatives scenarios in case PVDG expansion was not to occur.	Yes	Yes	
	Cities' air quality	Promoting distributed generation (GD) implies a reduced need for the use of coal thermal power	Positive	Yes	The expansion of distributed PV generation contributes to the elimination of coal energy supply by 2050 and entails the eradication of polluting practices in the southern	Literature Review	No	No	Is not feasible to quantify due to the lack of data on municipal emissions of air pollutants related to power generation

					cities of Brazil.				
	Electronic waste	The policy will lead to a higher quantity of e-waste (electronic waste)	Negative	Yes	It is anticipated that between 2040 and 2050, the production of photovoltaic waste will skyrocket, posing numerous challenges related to collection, recycling, and disposal of these residues and materials.	Ex-ante assessment based on the assumption of a methodology to determine the probability of PV panel loss in two scenarios: early-loss and regular-loss	Yes	Yes	
	Land use	Favouring PVDG in residential buildings implies a reduced need for land use in centralised power generation	Positive	Yes	By 2050 the land area conserved is expected to be 414 km² in the CPS and approximately 456 km² in the DDS.	Ex-ante assessment based on the assumptions: an average power of 4kW per solar energy system; an average minimum area of 28m² per system.	Yes	Yes	-
	Reduced costs	PVDG works as an investment for those who can afford it	Positive	Yes	Investing in PVDG significantly reduces energy costs, with the maximum expenditure reduction in 2050	An estimate of the financial return until 2050 relative to the year of system installation was elaborated.	Yes	Yes	

					expected for those who invested between 2016 and 2021, reaching around 160,000 BRL.				
	Energy literacy	The policy enhances knowledge on the relationship between energy production/ consumption and its environmental impacts for those interested in generating their own energy	Positive	Yes	While one of the PVDG expansion's consequences is the higher engagement of final consumers in the energy system; environmental consciousness is one of its determinants.	Literature review	No	No	Is not feasible to quantify due to the qualitative nature of the indicator.
	Creation of jobs	The policy increases job offers	Positive	Yes	It is expected a considerable expansion of job opportunities in the sector throughout the period assessed, despite a decrease in the employability rate from 2030 onwards.	Ex-ante quantitative assessment using a learning curve to model the expansion	Yes	Yes	

	Integration of women on the workforce	The new jobs will require higher qualification in STEM and thus will implicate lower employment access for traditionally marginalized segments of the society, including women	Negative	Yes	Even though an ex-ante assessment was not feasible, literature has demonstrated that female employability in the sector has decreased from 2012 to 2019.	Literature Review	No	No	Is not feasible to quantify due to the fact that, currently, there is no mechanism drawn to include female workforce in PVDG policy framework.
	New sociotechnical arrangement	The policy foments new levels of leadership, associations, and provides the energy sector with multiple new stakeholders	Positive	Yes	Since DG regulatory framework was published, new sociotechnical arrangements were created within the energy system, such as sharing of PV credits within condominiums, cooperatives and consortiums. Considering the fact that these new arrangements are continuously growing, it is expected that a high volume of these new arrangement	Literature review	Yes	No	Even though data on new arrangements is available, the construction of scenarios for 2050 relies on very weak premises, given that linearity is not expected for this indicator.

					penetrates the energy system.				
Econom y	National industry	The policy energises the sector and promotes the national industry	Positive	No	The PV industry in Brazil is still incipient, with a predominant focus on the assembly of PV modules rather than the production of PV cells. Indirectly, this dynamic contributes to the advantageous position of the domestic metallurgical and polymeric industry.	Quali/Quanti assessment: Literature Review+quantitative assessment of indirect industrial production (raw materials)	Yes	Yes	

	Imports	Considering the fact that the PV industry is still in early stages in the country, PVDG have favoured the energy sources which require technology importation	Positive	Yes	PVDG has favoured technology importation and will continue to in the next years, even though greater domestic production of cells and photovoltaic modules would be more advantageous for the country.	Quali/Quanti Assessment: Literature review+quantitative assessmet of expected imports (business as usual scenario)	Yes	Yes	
	Cheaper technology	As the policy fosters the sector, technological costs are expected to become lower	Positive	Yes	The expansion of distributed PV generation stimulates technological gain and contributes to the reduction of the prices of photovoltaic kits and module integration services.	Literature Review	No	No	It is not feasible to project due to its dependence on other variables, such as inflation, market dynamics, exchange rates, input prices, and other factors that directly influence the Brazilian and global economy.

	New business related to PV DG	The policy energises a chain of economic sectors	Positive	Yes	The expansion of distributed PV generation energizes the sector and contributes to the emerging of new business in the PV decentralized generation chain.	Literature Review	No	No	It is not ideal to project due to its dependence on other variables that influence market dynamics.
	Energy diversity	The policy enhances complementary PV energy which provides more reliance to the energy system through periods of draughts	Positive	Yes	An important evolution in diversity terms that is intrinsically related to PVDG expansion, which leads to higher energy security	Literature Review	No	No	Given that the horizon is 2050, the assessment would have to estimate scenarios of draughts, which is not ideal to the deemed method defined.
	Lower necessity for new investments	The expansion of PVDG leads to lower need to invest in centralized installed capacity	Positive	Yes	As individuals, the impact of the penetration of PVDG units in Brazilian energy system may not seem to have a high impact, but combined and with the proper energy planning, the total avoided cost until	PVDG expected installed capacity in CPS and DDS scenarios were compared to infrastructure costs needed to construct and maintain centralized power production	Yes	Yes	

					2050 would be around 269 billion and 311 billion reais.				
	Higher energy efficiency	PVDG expansion is associated with lower levels of energy loss, given that the energy consumption occurs nearer to the energy production	Positive	Yes	Distributed generation has the potential to mitigate losses within the energy system by reducing the demand for energy flowing through transmission and distribution lines	Literature Review	No	No	It would require primary technical data collection

Source: Prepared by the authors.

Methodology

The definition of the objectives, policy framework, impact categories, and indicators for the sustainable development assessment and planning of a just transition assessment, as well as the required engagement with stakeholders to refine the scope of the project, was detailed in Output 6. Stakeholder engagement was crucial in selecting the impact categories employed in the SD Assessment presented in this report. This engagement was conducted through bilateral meetings and questionnaires. A detailed explanation of the procedure is provided in Output 6. The results of the current report will still be validated by the stakeholders.

The SD Assessment was elaborated to allow for an ex-ante assessment of the impacts PVDG expansion might have on Brazilian sustainable development until 2050, enabled by the set of rules and incentives of the PVDG Regulatory Framework. Ideally, the methodology was expected to assess indicators quantitatively and qualitatively. However, as indicated in Table 1, not all indicators allowed for a quantitative assessment, given their qualitative nature or lack of data. Thus, some of them were assessed qualitatively, through a literature review.

The next subsection presents the quantitative approaches used in the assessment.

1.1 Qualitative approach

1.1.1 Energy literacy

Assessing the qualitative aspects of the energy literacy indicator presents a significant challenge due to its inherently complex and multifaceted nature, specially because literacy encompasses pollical, economical, environmental, and social aspects of "energy". To address this, several qualitative methodologies were employed, integrating insights from diverse sources to form a comprehensive discussion:

(1) Theoretical Framework: Goulden et al. (2014) and Carvalhais and Pinto (2023) provided a foundation for understanding the role of individuals as energy prosumers and their potential to influence and spread changes in energy practices. This theoretical framework highlighted the active participation of prosumers in energy distribution networks and the likelihood of practice changes being adopted by others;

(2) Public Audience Data Collection and Comparative Analysis: data from a public audience held by ANEEL in 2019 were analyzed, focusing on contributions related to energy tariffs and distributed generation (DG). The significantly higher number of contributions from final consumers compared to other stakeholders indicated a strong engagement and increased political capital among prosumers, which may be interpreted as an increase in energy literacy,

a higher understanding of energy tariff effects and prosumers rights This analysis was supported by examining other public audiences, providing context for the level of engagement specific to energy-related topics;

(3) Policy Report Examination: Further qualitative insights were derived from examining policy reports, particularly the report by the Energy Research Office (EPE) used for the Brazilian National Energy Plan (PNE 2050). This report emphasized higher environmental consciousness as a critical behavior indicator among prosumers, aligning with the motivations identified in other sources;

(4) Survey and Interview Content Analysis: A content analysis of a survey by ANEEL (2015) among early adopters of MMGD systems revealed that 45% of respondents cited "Sustainable development" as their primary motivation for installing DG. Additionally, qualitative interviews with prosumers in Holambra city, São Paulo, conducted by Soares and Lazaro (2023), confirmed that environmental concerns and personal values/beliefs were significant motivators for investing in solar PVDG systems.

Overall, this integrated approach ensured a comprehensive understanding of the qualitative aspects of energy literacy among prosumers, emphasizing their active role, environmental motivations, and political engagement.

Integration of women on the workforce

Limited market research exists on this topic in Brazil, but the available GIZ study was used for the assessment. The approach involved a detailed analysis of job market data to understand gender distribution, complemented by a trend analysis to track changes in gender representation over time (Profissionais do Futuro, Sistemas de Energia do Futuro and GIZ, 2023).

1.1.1.1.1 New Socio-technical Arrangements

To evaluate the indicator "New Socio-technical Arrangements," the methodological approach focused on analyzing the PVDG regulatory framework and its effects on introducing new stakeholders and arrangements in the energy sector. The analysis utilized secondary data from the 2022 report “Cooperatives of Distributed Generation in Brazil” by The German Cooperative and Raiffeisen Confederation (DGRV) and Ideal Institute, alongside information from the Energy Research Office (EPE) on "Installed PVDG Capacity under Sharing Credits Mechanisms".

The approach examined two key aspects as new socio-technical arrangements: the introduction of cooperatives into the electricity distribution sector and the implementation of credit-sharing mechanisms. The inclusion of cooperatives represents a significant shift, as these entities enable collective ownership and management of distributed generation resources, thus altering traditional energy distribution dynamics. Simultaneously, credit-sharing mechanisms allow for the virtual transfer of energy credits between consumers, further redefining how energy resources are utilized and shared.

1.1.1.2 Cheaper Technology

The methodology for assessing the indicator "Cheaper Technology" involved a qualitative analysis of the impact of technological advancements on the costs of photovoltaic systems. Given the limited market research specific to Brazil, the approach used available data from sources such as Greener (2023) and IRENA (2023). This involved examining historical trends in photovoltaic system prices, including reductions in installation costs over recent years, and identifying key factors influencing these trends, such as inflation, market dynamics, and input prices.

The methodology also included a comparative analysis of cost reductions in Brazil relative to other countries to understand the broader context. The approach recognized the challenges of projecting future costs due to the non-linear nature of price reductions and the influence of various factors. Instead of making precise future projections, the focus was on understanding current trends and how technological advancements and regulatory frameworks affect photovoltaic technology costs.

1.1.1.3 New Businesses

The qualitative approach to assessing the indicator "New Businesses" involved analyzing the growth and dynamics of integrating companies in the photovoltaic energy sector in Brazil. The methodology began with a review of data from Greener on the number of integrating companies in the sector from 2017 to 2023. This analysis focused on how the increase in decentralized generation influenced the proliferation of companies supplying photovoltaic kits, as well as those providing installation and maintenance services.

1.1.1.4 Cities’ air quality

To conduct the qualitative analysis of the city's air quality, the study employed a review of existing literature and environmental studies. This approach provided insights into the emissions from power generation and transportation activities and their impact on air quality.

Additionally, the analysis included the examination of specific case studies and historical data on coal reserves and thermal power plants in Brazil. This involved reviewing studies by Caldeira (2013), Fritz and Waquil (2003), and environmental impact assessments from the Brazilian Institute of

Environment and Renewable Natural Resources (IBAMA), offering a focused understanding of the local air quality issues and their broader implications.

1.1.1.5 Higher Energy Efficiency

To assess the indicator "Higher Energy Efficiency," the qualitative approach involved examining the relationship between the expansion of photovoltaic distributed generation (PVDG) and energy loss within the grid. The methodology began with a review of existing studies and literature that highlight the potential benefits of PVDG in reducing energy losses. Key studies by Sharma and Koppal (2010), PAATERO and LUND (2007), PURVINS and L'ABBATE (2017), RAZAVI et al. (2019), and SINGH, MUKHERJEE, and TIWARI (2016) were analyzed to understand how distributed generation can lower electrical line losses, particularly during periods of high demand.

1.2 Quantitative approaches

The quantitative approaches were grounded on Centro Clima's projections on PVDG expansion, named in Output 2 and Output 3 as "Solar – Distributed (small scale)." These projections are illustrated in Figure 1, and refer to the scenarios CPS and DDS.

While CPS follows the trend of ongoing mitigation actions, DDS follows a GHG emissions trajectory compatible with the global objective of 1.5ºC, achieving net-zero emissions in 2050. In this report, CPS and DDS refer to the CPS 2 and DDS 2 scenarios of Output 2 and Output 3, which are projections that consider only Hydroelectric Power Plants (HPPs) that do not interfere with protected areas. This is because Output 8 sets as a ground Just Transitions' perspectives. Thus, hereinafter, CPS2 and DDS2 scenarios constructed by Centro Clima will be called CPS and DDS scenarios.

The next subsections present the premises and approaches used to quantitatively assess the impacts of PVDG expansion, enabled by its regulatory framework.

1.2.1.1 GHG emissions

To analyse avoided GHG emissions associated with PVDG expansion, three scenarios were developed:

(1) avoided emission if the expected PVDG installed capacity were to be substituted by Brazilian thermal energy mix (2020);
(2) avoided emission if the expected PVDG installed capacity were to be substituted by 2020 electricity matrix composition;

(3) avoided emission if the expected PVDG installed capacity were to be substituted entirely by natural gas thermal power plants.

Scenarios Premises:

(1) To calculate the avoided emissions, it was considered the average emission factor of 0.608 tCO_{2eq}/MWh of Brazilian thermal power plants in 2020 (IEMA, 2022);
(2) To calculate avoided emissions, it was considered the emission factor of 0.0979 tCO_{2eq}/MWh of Brazilian electricity matrix in 2020 (MCTI, 2024);
(3) To estimate the emission factor of natural gas in thermal power plants (TPP) in Brazil in 2020, it was considered the participation of natural gas in Brazilian electricity matrix to be 11% (EPE, 2021), the total energy production to be 460,901.666 GWh (MCTI, 2024) and the estimated emissions to be 18525337 tCO_{2eq} (2020) (SEEG, 2021). This led a final emission factor of 0.36 $tCO_{2eq.}$

1.2.1.2 PV Waste

The electronic waste indicator refers to the projection of the number of PV panels that will be discarded by 2050. It was developed based on the assumption of the International Renewable Energy Agency's (IRENA) methodology to determine the probability of PV panel loss in two scenarios: the early-loss and the regular-loss scenarios (IRENA and IEA-PVPS, 2016). The probability of losses during the PV panel life cycle is determined by the shape factor α, which differs for the regular-loss and early-loss scenarios. Both scenarios assume a 30-year average panel lifetime and a 99.99% probability of loss after 40 years. The probability equation is presented below and illustrated in Figure 4.

$$F(t) = 1 - e^{-\left(\frac{t}{T}\right)^{\alpha}}$$

Where:

t = time in years

T = average lifetime

α = shape factor, which controls the typical S shape of the Weibull curve

Figure 4 – Probability of panel loss over the years
Source: Prepared by the authors.

In parallel, taking into account the CPS and DDS projections by Centro Clima (Output 3) for the annual decentralized PV installed capacity, it was assumed an average power per panel installed in Brazil of 510 W (0.00051 MW/panel) to estimate the number of discarded panels throughout the years.

1.2.1.3 Land Use

The hypothesis assumed to assess this impact category is that the expansion of PVDG implies a reduced need for land use in centralised power generation. To measure the saved land use indicator (m^2/year), it was necessary to find information on the average area occupied by solar energy systems for certain capacity ranges (m^2 of PV panel/GW installed), this being the baseline indicator.

Therefore, the main indicator was developed based on the assumptions:

- An average power of 7.2 kW per system (EPE, 2024); and
- An average minimum area of 28 m^2 per system (Portal Solar, 2024).

The total area was calculated using the following equation:

$$Total\ area = \frac{Total\ installed\ capacity \times Occupied\ area\ per\ system}{Capacity\ per\ system}$$

1.2.1.4 National Industry

The domestic production of photovoltaic modules and other equipment is still in its early stages, making it difficult to project how the national industry would develop by 2050. Current data is insufficient for such a projection, as other factors and variables will influence market dynamics and the consequent promotion of the industry.

Therefore, considering that the domestic photovoltaic industry has been evolving in the assembly of modules and kits rather than in the development of photovoltaic cells, to test the hypothesis that the policy energizes the sector and promotes the national industry, indirect production was considered, meaning the inputs necessary for the production of wiring and metal structures for the installation of solar modules and systems. Table 2 below presents the parameters of the quantity of supplies per installed capacity used.

Table 2 – Supplies per installed capacity

Material	Quantity per MW (t/MW)
Aluminium	15.78
Steel	1.48
Copper	0.56
Polymer	0.05

Source: Profissionais do Futuro, Sistemas de Energia do Futuro and GIZ (2023).

1.2.1.5 Imports

Considering that the national industry is still very incipient and that, throughout the years after the publication of the DG regulatory framework, the national industry did not impress in terms of technological development because Brazil still lacks incentives to foster national PV technology production (see results in Section 4.1.4), the current import rate was used to estimate import volumes. The current importation rate is 97%. Additionally, an average photovoltaic module capacity of 510 W was considered to estimate the quantities of imported modules per period until 2050.

1.2.1.6 Energy Diversity

To assess the level of energy production diversity in Brazilian regions, the Herfindahl-Hirschman (HHI) method (Gozgor et al., 2022) was used. This method allows for an examination of the distribution of energy sources in the Brazilian electricity mix, treating it as a reference portfolio.HHI equation goes as follows:

$$HHI = \sum_{i=1}^{n} S_i^2$$

Where:

n is the number of options;

S_i is the proportion of option I expressed as percentage.

1.2.1.7 Lower necessity for new investments

To assess the avoided costs with centralized energy generation, PVDG expected installed capacity in CPS and DDS scenarios were compared to costs associated with the centralized expansion of the system, as indicated in Table 3[1,2]. To estimate the costs required to expand Brazilian energy infrastructure, PVDG expansion was substituted by the electricity mix projected by CPS and DDS scenarios, respecting the share of each source in these projections.

Table 3 – CAPEX, O&M, CVU, FC, and lifespan values for different technologies considered for Levelized Cost of Electricity (LCOE) calculation

Energy source	CAPEX (R$/kW)		O&M (R$/kW)	CVU (R$/MWh)		Capacity Factor (FC)	End Life
	Min	Max		Min	Max		
Biogas	7,500	23,000	500	-	-	80%	20
Biomass	3,000	8,000	90	120	300	80%	20
Coal	8,000	13,500	160	120	300	80%	25
Wind (Onshore)	3,800	5,500	90	-	-	50%	20
Wind (Offshore)	9,800	18,600	190	-	-	60%	20
Solar (centralized)	2,800	4,500	50	-	-	30%	25
Natural gas (simple cycle)	2,900	4,700	80	250	500	30%	25
Natural gas (combined cycle)	3,600	6,100	80	120	300	70%	25
Nuclear	22,000	29,400	490	30	50	80%	30
Hydro (SHPP)	6,000	11,000	90	-	-	50%	30

Source: EPE (2021).

4.2.8 Reduced costs

This indicator was in order to analyse the effects PVDG may have for families who invested in PVDG technology. The assumptions used to estimate it were based on current data of PVDG expansion (EPE, 2024):

- 100% of PVDG in CPS and DDS scenarios are residential;
- Average installed capacity per system 7.2 kW;
- Average lifetime pf PV pannel: 30 years (Irena, 2016);
- Average tariff in Brazil: 0,65 BRL/kWh (Aneel, 2024);
- Average efficiency of solar pannel: 80%;
- Peak hours of solar irradiation: 4.5 hours;

[1] Considering that all sources installed units have an endlife older than 20 years, endlife was not considered in the analysis.
[2] Average costs were used as a reference (between min and max).

- Real payback illustrated in Figure 5. The assumption considered as a premise is that the payback would stabilize around 4 years[3].

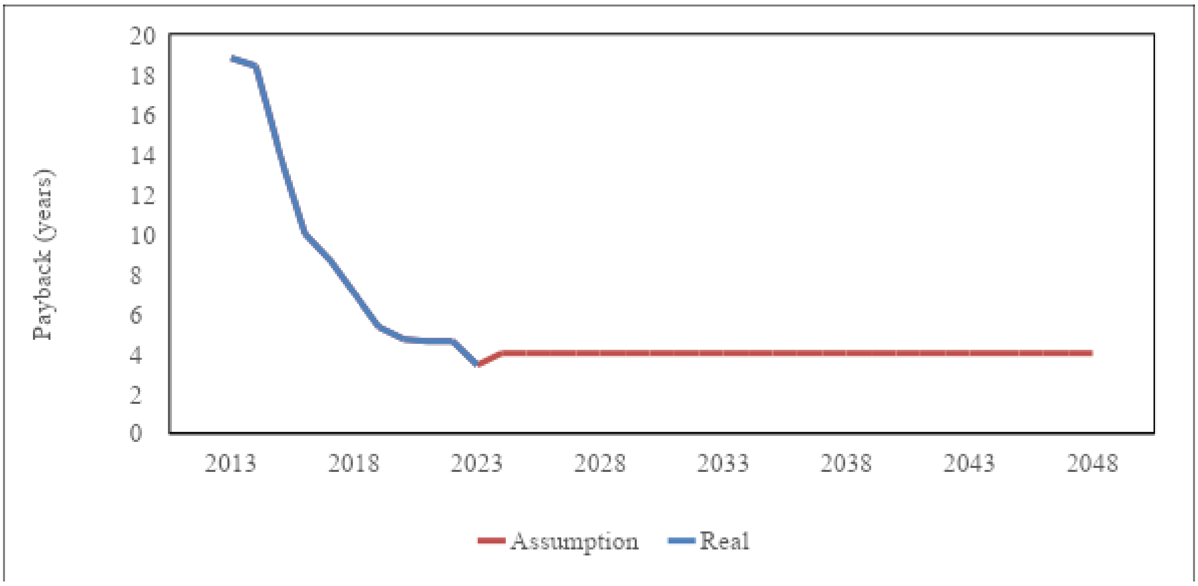


Figure 5 – Payback of PVDG investment
Source: Prepared by the authors based on EPE, 2024.

1.2.1.8 Social Inequality

This indicator was developed to measure the proportion of the minimum wage needed to purchase a solar system.

To quantify the indicator, data about the adjustment rate of the minimum wage in the country were collected from the Ministry of Labor and Employment (MTE, 2022). As shown in the 'Cheaper Technology' indicator, projecting the costs of solar energy by 2050 is not feasible. Therefore, two scenarios were created: one with the equipment price in 2023 and another with 10% cost reduction every 10 years, which is the reduction in the costs observed throughout the ten years after the DG regulatory framework was launched.

Table 4 – Indicator scenarios

Scenario	Year	Price (BRL)
Scenario 1: Equipment price	2023	14,720
Scenario 2: 40% cost reduction (10% every 10 years)	2030	13,248
	2040	11,776
	2050	10,304

Source: Prepared by the authors.

[3] The real payback of 2013 of 3,6 years was not considered as a reference given the extraordinary expansion observed in this year.

4.2.9 Job creation

The employment index was calculated based on the Profissionais do Futuro, Sistemas de Energia do Futuro and GIZ (2023) report, following the equation below. It is important to note that the learning curve is considered, which means that the study doesn't assume the same growth of job offer by 2060. In other words, in a scenario where PVDG was incipient, it is evident that there will be an explosion in job opportunities.

$$EF_t = EF_{base} \times \left(\frac{accumulated_t}{accumulated_{base}}\right)^{-a}$$

Where:

EF_t = Employment index for year t, expressed in jobs/MW;

EF_{base} = Employment index in the reference case, expressed in jobs/MW;

a = Learning coefficient = 0,1779;

$accumulated_t$ = Centro Clima projections of installed capacity (MW);

$accumulated_{base}$ = installed capacity (MW) (2019).

2 Results and discussions

2.1 Environmental dimension

2.1.1.1 GHG emissions

As presented in Table 1 above, the hypothesis for this impact category is that promoting PVDG implies lower GHG emissions from the energy sector, given that this expansion in DG will substitute part of the fossil fuel energy provided for the power sector. In fact, it is important to note that the power sector in Brazil has already a large share of renewables (mostly hydropower), and therefore presents low GHG emissions when compared to the world average. The carbon intensity of electricity generation in the country was 118.5 $kgCO_2e/MWh$ in 2021, which is very low if compared to countries of the European Union, the USA, and China (ICAT Output 3). Nevertheless, reducing even more this sector emissions is crucial to achieve the net zero target in 2050.

As presented in Output 3, the results of the Current Policies Scenario (CPS) and the Deep Decarbonization Scenario (DDS) show that, whereas the installed capacity of coal power plants was 3.2 GW in 2020, this will reduce gradually until it is null in 2050, in both scenarios. For petroleum derivates and other non-renewables, in both scenarios the installed capacity is expected to reduce from 8 GW in 2020 to 1 GW in 2050. On the other hand, natural gas will likely expand in the CPS from 14.9 GW in 2020 to 27 GW in 2050, while in the DDS this installed capacity is expected to reduce from 14.9 GW in 2020 to 4 GW in 2050. This expectation of a shift from expansion in the CPS to decline in the DDS in relation to the installed capacity of natural gas is due to hydro expansion restrictions. From 2040 onwards, there is a need to incorporate energy storage options such as reversible hydroelectric plants (pumped storage hydropower) or batteries in the DDS scenario. While natural gas provides the flexibility required to meet demand in the CPS, the DDS, with the introduction of a carbon tax, foresees the inclusion of storage despite its high cost. In DDS, due to the domestic carbon tax, the competitiveness of natural gas-based power generation reduces, while new technology improvements can enable the competitiveness of renewables.

It is not possible to ensure that the reduction in installed capacity of coal and oil power plants will be necessarily compensated by PVGD, given that other sources of energy are also expanding in this scenario, such as hydro, wind, biomass and even natural gas and that the Brazilian power network not only is dynamic but also interconnected. However, in order to understand the magnitude of the effect of PVDG expansion in global emissions, three scenarios were developed: the first one analyses the avoided emission if the expected PVDG installed capacity were to be substituted by Brazilian TPP mix (2020 as a reference); the second, by 2020 Brazilian electricity mix; the third, entirely by natural gas TPP. Figure 6 and Figure 7 illustrate the results of this exercise (CPS and DDS scenarios, respectively).

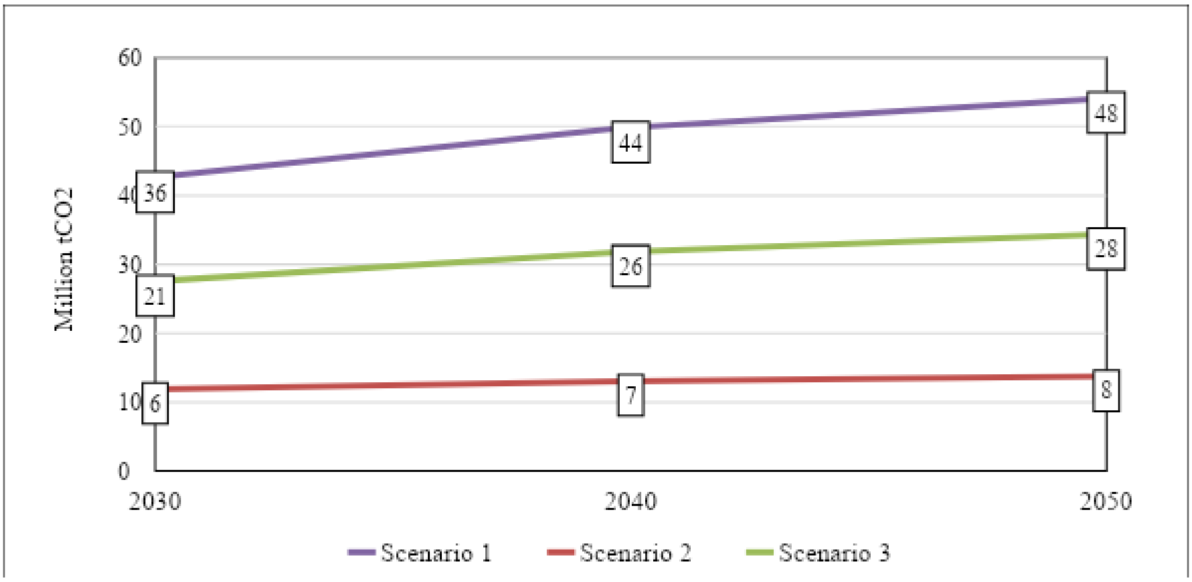


Figure 6 – Avoided emissions scenarios for CPS
Source: Prepared by the authors.

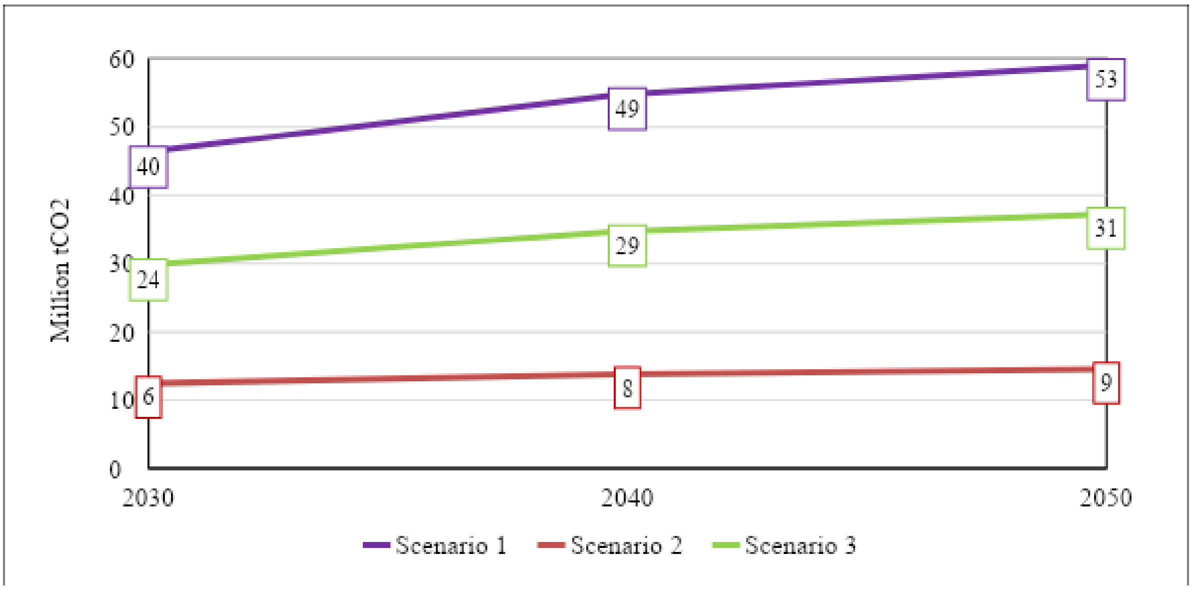


Figure 7 – Avoided emissions scenarios for DDS
Source: Prepared by the authors.

Even though these scenarios do not precisely reflect the effect of PVDG expansion in the sector's emissions, they provide us with an interesting reflection in terms of the expected energy transition. If PVDG expansion was not to occur and its expected installed capacity in 2050 (in both CPS and DDS) was to be offered by 2020 Brazilian TPP production mix, around 53 million tons of CO_2 would be emitted in 2050. If it was to be substituted by different sources, considering their participation in Brazilian current mix, around 9 million tons of CO_2 would be emitted in 2050. Finally, it if was to be substituted exclusively by natural gas, around 31 million tons of CO_2 would be emitted in 2050.

This exercise provides important reflections regarding the Brazilian energy transition: first, that it is already underway and that the current electricity mix enables a significant mitigation scenario in comparison with the scenario of a TPP (thermal power plant) mix; second, that the so-called "transition fuel" – natural gas – does not seem to enable a transition in Brazil. On the contrary, it represents a shift backward from a mitigation perspective. Finally, it demonstrated the impact solar energy expansion is expected to have in energy transition, highlighting the importance final consumers will have in Brazilian climate mitigation through energy inclusion.

2.1.1.2 Cities' air quality

Air quality in cities is influenced by several factors including topography and meteorological conditions, as well as the level of emission of pollutants. Activities such as power generation and transportation are among the main sources of pollutants and thus contribute to worsening air quality. The hypothesis for this indicator is that promoting GD contributes to the goal of eradicating coal power generation until 2050, therefore having a positive impact the cities' air quality.

To assess this indicator, it is important to note that air quality is rather a local level aspect (i.e., varies from city to city). The coal reserves in Brazil are located in the extreme south, particularly in the state of Rio Grande do Sul (aprox. 88%). Even though reserves are said to be 2.48 billion tonnes, they do not attract interest in the global market because of their subpar quality and low utility value (Caldeira, 2013). Thermal power plants were installed in Brazil in the 1960s, the most important plants being: Candiota, Seiva Sul and Charqueadas in Rio Grande do Sul, and Jorge Lacerda in Santa Catarina state.

Analyses conducted by the Brazilian Institute of Environment and Renewable Natural Resources (IBAMA) revealed that SO_2 emissions were eight times higher than the permissible limit during the initial construction stage of a power plant in Candiota. Additionally, particulate matter emissions exceeded the allowed volume by 26 times in the construction phase. These pollutants include not only particulate matter but also nitrogen oxides, which can lead to respiratory and skin diseases. More significantly, there are elevated levels of sulfur oxides, known precursors to acid rain. In the region, this has resulted in atmospheric and rain acidification (FIOCRUZ, 2024).

Even though the impact on air quality from the exploration, transport, and transformation of coal has been extensively explored in the literature, in their study, Fritz and Waquil (2003) interviewed 81 people in the city of Candiota to understand the local perspectives of residents in areas near coal mines. 25% of the interviewee have lived in the region prior to the mining activities. Approximately 40% of the respondents identified air and water pollution, as well as ashes and dust, as issues stemming from this activity.

2.1.1.3 PV Waste

The disposal of PV panels is complex and requires legal and technological considerations. Unlike other countries, there is still no specific legislation for solar panel recycling in Brazil. The panels contain a small amount of valuable metals, such as silver and copper, as well as more polluting substances like lead and polymers, which complicates their disposal. Given that glass and aluminium make up almost 90% of the modules, ensuring the recycling of PV modules has the potential to reduce the energy required for the extraction and production of the original materials, such as silver and silicon. Additionally, it can contribute to mitigating the environmental impacts associated with the mining of these metals (Jones, 2024).

Besides that, PV panels recycling is also important to guarantee that the reverse waste logistics can proceed. According to Brazilian National Solid Waste Policy (PNRS) (Brazil, 2010), manufacturers and importers of electrical and electronic products are obligated to establish reverse logistics systems for their items once consumers have utilized them. These systems must operate independently of public urban cleaning systems (De Sousa et al., 2023).

Figure 8 illustrates an estimate of PV waste expansion in both scenarios (CPS and DDS); the curves show the same growth pattern.

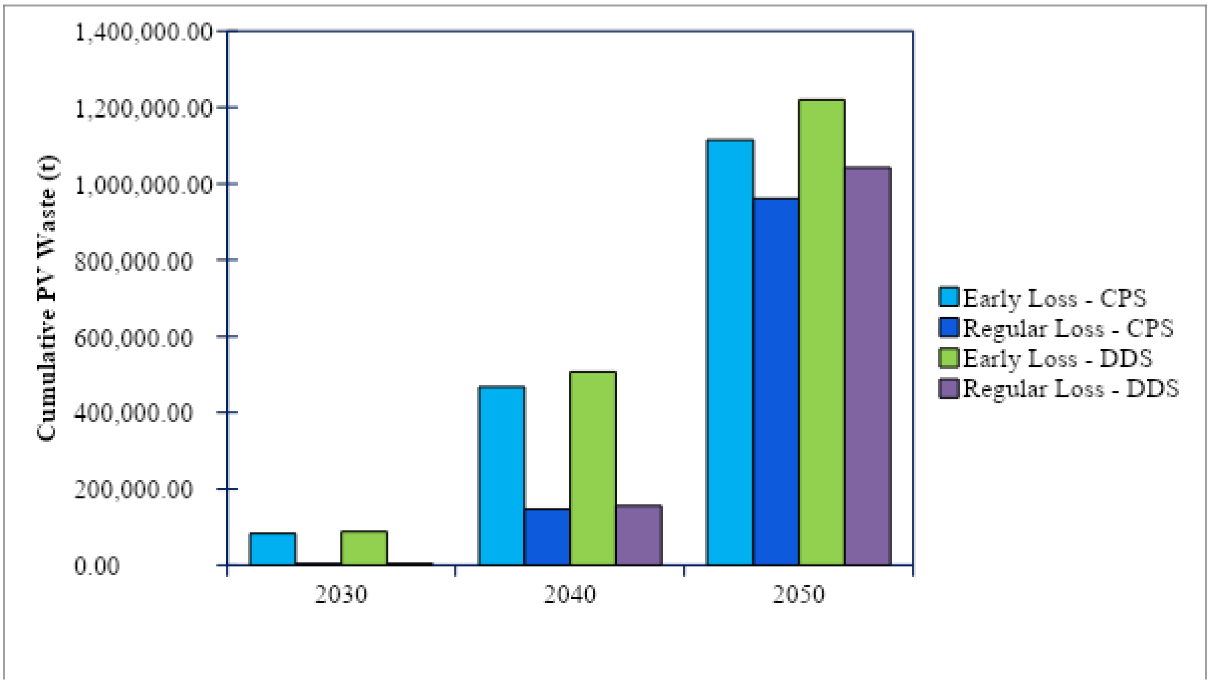


Figure 8 – Total accumulated loss of panels (number of units lost)
Source: Prepared by the authors.

Considering that up to 2050 it is expected that between 962 to 1116 thousand tonnes of PV waste to be discarded in the CPS and between 1042 to 1120 thousand in the DDS, it is important to establish mechanisms for managing photovoltaic waste while significant losses are not yet occurring. It is anticipated that between 2040 and 2050, the production of photovoltaic waste will skyrocket, posing numerous challenges related to collection, recycling, and disposal of these residues and materials.

2.1.1.4 Land Use

Considering the CPS and DDS projections outlined by Centro Clima (Output 3) for the cumulative decentralized PV installed capacity, Figure 9 illustrates the hypothesis that prioritizing energy generation in residential households and on consumers' premises (distributed generation) results in a noteworthy reduction in the requisite land for centralized power generation. In essence, there is an anticipated growth in the land area conserved for this purpose over the years, and by 2050 the land area conserved is expected to be 382 km² in the CPS and approximately 420 km² in the DDS.

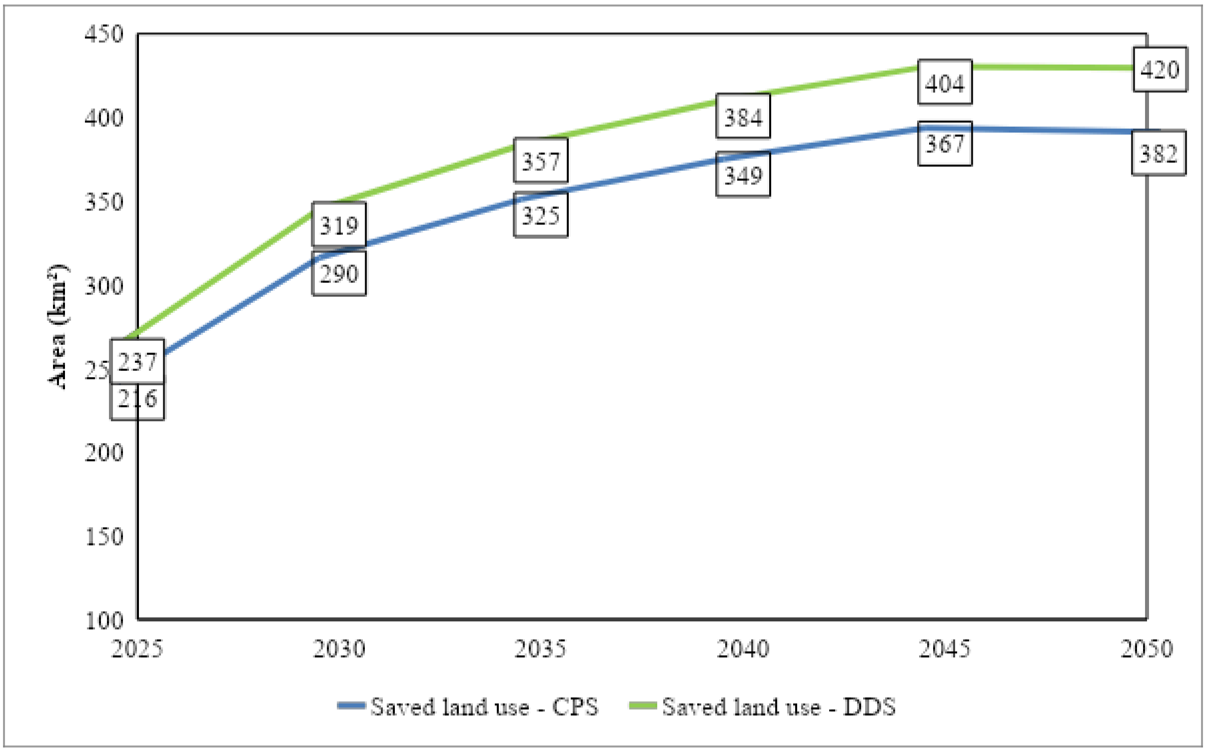


Figure 9 – Saved land use by decentralized generation for CPS and DDS
Source: Prepared by the authors.

The preserved land should be interpreted in contrast to centralized PV energy generation. Centralized PV energy generation, also known as solar farms, poses numerous sustainability challenges to the energy transition, including competition with productive lands, impacts on traditional communities' landscapes, and land use costs. For this reason, the expansion of territorially dispersed distributed photovoltaic systems on the rooftops of Brazilian residences carries significant environmental and social externalities related to land use.

2.2 Economic Dimension

2.2.1.1 National Industry

The national production of photovoltaic energy technology in Brazil is still very incipient, considering that decentralized generation has only been regulated in the country for eleven years. Table 5 below shows the number of national producers in the solar sector registered in the Special Industrial Financing Agency (FINAME), a financing program of Brazil's National Development Bank (BNDES). It is observed that in 2019 there was a high number of producers of photovoltaic solar kits, but this value decreased in the following years, and then experienced a significant increase in 2023. For other products associated with solar PV systems, the values did not vary as much over the past few years.

Table 5 – Number of manufacturers registered at the BNDES FINAME

National manufacturers	2019	2020	2021	2022	2023
Photovoltaic Solar System (Kit)	100	64	85	82	139
Photovoltaic Inverter	14	11	10	10	10
Solar Tracker	11	8	8	8	9
Photovoltaic Module	8	8	7	8	8
Battery	1	1	2	3	1
String Box	2	1	1	1	5

Sources: ABSOLAR (2019, 2020, 2021, 2022, 2023).

Considering that the domestic photovoltaic industry has been evolving in the assembly of modules and kits rather than in the development of photovoltaic cells, the required quantities of aluminium, steel, copper, and polymer were calculated, as shown in Figure 10.

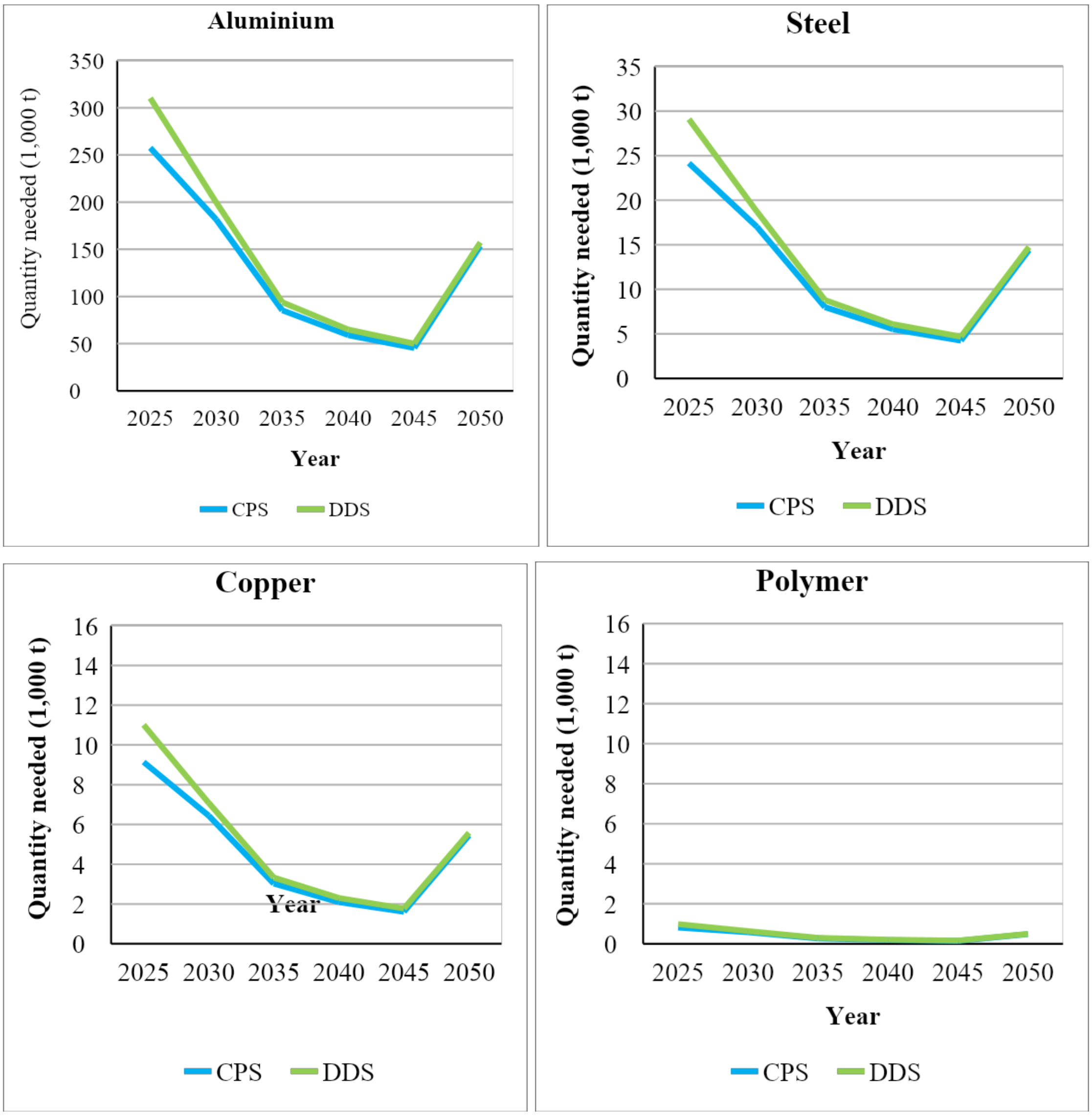


Figure 10 – Future projection of required quantities of supplies for both scenarios
Source: Prepared by the authors.

It is observed that the growing PVDG market has promoted the national industry, by demanding materials, especially aluminium, for the construction of wiring and metal structures necessary for the installation of photovoltaic systems for distributed generation. Figure 10 illustrates the peak demand that will occur in 2025, following the recent grow of the market, due to the establishment of PVDG regulatory framework. After this peak, the projections for both scenarios indicate lower installed capacity of PVDG in the next years. Thus, there is a decrease in the demand for materials. In 2045, it is projected the smallest installed capacity in the period for both scenarios: 2,879 and 3,165 MW for CPS and DDS, respectively, when the demand for materials will reach the lower projection. After 2045, however, the installed capacity and the demand for material will grow again.

Figure 10 also indicates the slightly difference between CPS and DDS, the last one being the scenario that most promotes the national industry. It is important to highlight that, even with a lower PVDG demand in the next years, a great quantity of supplies will be needed. For example, in 2050, when the market will heat up again, there will be a demand of over 153 and 157 kilo tons of aluminium in CPS and DDS, respectively. Thus, the projection of PVDG installed capacity in future years highlights the greater need for inputs, which will promote the national industry.

Still, even if the national industry may also benefit indirectly from PVDG expansion, it is important to highlight that PVDG policies still lack incentives to foster national production, particularly, of high value-added products, such as PV modules and cells. As demonstrated, PVDG boom starts to decline from 2030 onward. Thus, it would be important that new policies were to be developed under the PVDG policy framework, providing incentives mechanisms for national production to ensure that the advancement of PVDG in Brazil is aligned with income generation, wealth creation, scientific and technological progress.

2.2.1.2 Imports

Currently, almost all photovoltaic modules used in Brazil are imported. On average, between 2019 and 2021, 97% of the volume in MWp was imported into the country, while only 3% was produced domestically[4] (Greener, 2021). As discussed in the indicator 'National Industry', the Brazilian domestic industry is still very incipient, relying significantly on international production.

Considering the 97% importation rate, the projected installed capacities for the future, and an average photovoltaic module capacity of 510 W, the quantities of imported modules per period until 2050 were estimated. These projections are detailed in the table below.

[4] Considering both centralized and distributed generation.

Table 6 – Projected quantity of imported modules

Year	Imported modules by period (in millions) - CPS	Imported modules by period (in millions) - DDS
2025	31.05	37.41
2030	21.89	24.07
2035	10.28	11.31
2040	7.11	7.82
2045	5.48	6.02
2050	18.52	18.96

Source: Prepared by the authors.

National imports of modules are projected to decrease in the next few years, as the market has recently passed throw a peak of installed capacity. Even though, the market will still grow, but at a lower rate. After 2045, imports will rise again with the increase of the PVDG installed capacity. While the national industry does not grow as much as the demand for PVDG, national imports will continue to be an important strategy to meet the projected installed capacity. Both the CCS and DDS scenario present a similar trajectory, but the last one will require more imports to guarantee the higher demand for PVDG in a decarbonized scenario. Besides that, from 2045 onward, it is expected a new wave of imports given the fact that the average lifetime considered for the pannels is 30 years. Thus, consumers who had invested in PV Systems are likely to replace misfunctioning panels[5].

It is important to highlight that Brazil is one of the main global producers of silicon, a basic raw material for the production of photovoltaic cells. In 2013, the country produced around 170 million tons, equivalent to 8% of global production (Carvalho, 2014). However, the country exports the raw material and imports products with higher added value, such as the photovoltaic cell and the photovoltaic module.

In 2017, the imports of photovoltaic modules reached US$ 350 million, while the imports of photovoltaic cells summed US$ 150 million (MDIC, 2018). The main countries from which photovoltaic modules and cells were imported include China, Hong Kong, France, Germany, and Argentina, while photovoltaic modules are mainly imported from China, Taiwan, Cambodia, Hong Kong, and Germany (Logcomex, 2023).

The import of photovoltaic cells, differently from solar modules, is linked to the development of the domestic industry for assembling solar panels. This industry started in 2015 in Valinhos/SP

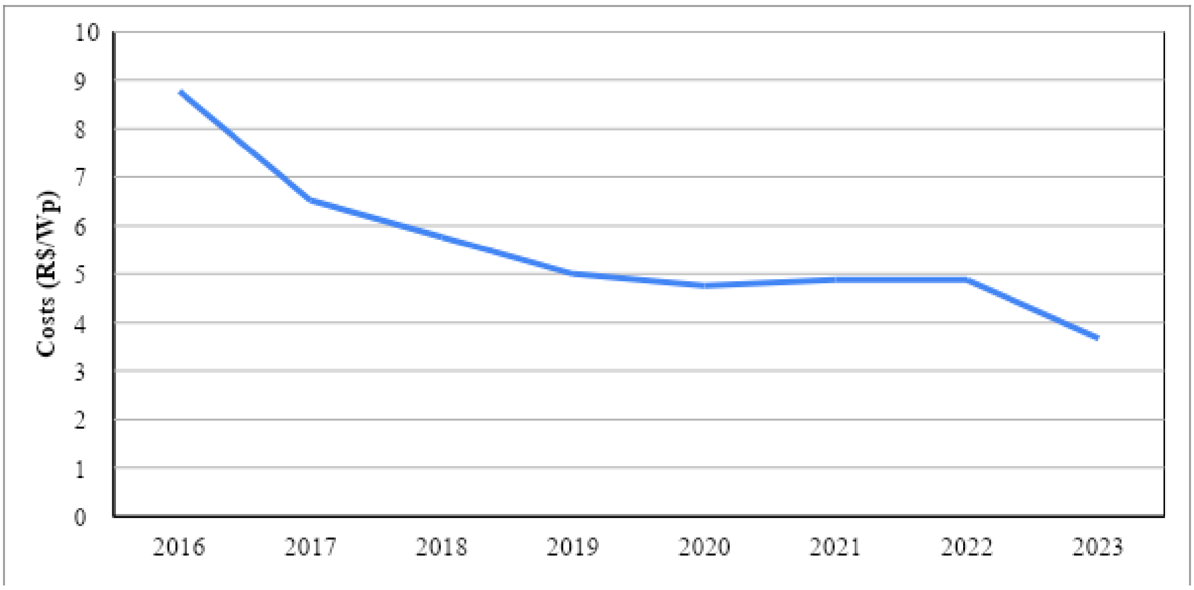
[5] This is a premise in the model.

(MDIC, 2018), but it is still in its early stages. Furthermore, with the decrease in dependence on imports and the development of domestic production of photovoltaic cells, there would be economic and social gains in the country, such as injecting financial resources into the national industry and creating jobs. In addition, regarding the carbon footprint of the production life cycle of a photovoltaic module, it is important to consider that this dynamic of importing solar cells while exporting silicon leads to increased indirect and avoidable environmental impacts, especially due to the GHG emitted during its transportation.

However, such a scenario is far from materializing in the country, given what has been observed in recent years and the incipient state of the domestic industry. In this sense, even though greater domestic production of cells and photovoltaic modules would be more advantageous for the country, it is concluded that the hypothesis "Considering the fact that the PV industry is still in early stages in the country, PVDG have favoured the energy sources which require technology importation" has a high likelihood of occurring for both the CPS and DDS scenarios, but more intensively for the last one.

2.2.1.3 Cheaper Technology

The technological development of photovoltaic modules in recent years and the advancement of decentralized generation in Brazil have led to economic gains and a considerable decrease in the final price of photovoltaic kits installation (PV kit and services altogether). Data from Greener (2023) indicate that from 2016 to 2023, there was an average reduction of 11% in the final price of the PV system (including required services)[6]. Figure 10 illustrates how the prices of kits and integration services have varied in recent years.



[6] Considering an average capacity for a residential PV system (with 4 kWp).

Figure 11 – Residential solar photovoltaic prices variation (kit+services)
Source: Greener (2023).

It is not possible to project the price of solar energy in future years to assess the hypothesis "as the policy fosters the sector, technological costs are expected to become lower" because it depends on other variables, such as inflation, market dynamics, exchange rates, input prices, and other factors that directly influence the Brazilian and global economy. However, it is evident that the price of the technology has decreased considerably since 2016, and it is expected that the incentive of public policy in the sector will contribute to maintaining this reduction, even if it is at a slower rate.

This expectation is also supported by what has been observed in other countries. Table 7 below shows that from 2010 to 2019 the installation costs of residential solar panels decreased significantly worldwide. The data from IRENA (2023) demonstrate that the reductions were not linear over the period, with distinct annual variations, as seen in India and Thailand, for example. The non-linearity in the price reduction highlights the difficulty of projecting future years, given that the market is still consolidating, and there are several variables affecting costs. In fact, no future price projections for solar panels were found in literature. However, it is observed that the price drop has slowed down over the years, indicating a stabilization in prices, supporting the expectation that such reduction will occur at a slower rate in the future. Nevertheless, albeit less accelerated, the reduction in prices of photovoltaic solar panels is expected to occur for both the CPS and DDS scenarios, but more intensively for the last one. Table 7 also indicates that there is room for price reduction in Brazil when comparing national costs with those of China and India in 2019.

Table 7 – Solar PV total installation cost in the residential sector (2019 USD/kW)

Market	Solar PV total installed cost in the residential sector (2019 USD/kW)									
	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Australia	7,715	6,126	4,301	3,670	3,424	2,198	1,988	1,738	1,557	1,380
Brazil				3,947	3,657	3,458	2,664	2,126	1,604	1,350
China			2,823	2,432	2,330	1,672	1,591	1,436	1,079	840
France		9,797	6,950	5,773	4,231	2,359	2,174	1,967	1,771	1,600
Germany	4,277	3,634	2,712	2,414	2,229	1,750	1,704	1,645	1,746	1,646
India				2,374	2,276	1,501	1,326	1,093	916	840
Italy	6,949	6,106	4,031	3,660	2,438	1,983	1,803	1,676	1,527	1,460
Japan	7,314	7,228	6,237	4,601	3,771	3,313	2,927	2,685	2,361	2,250
Malaysia				2,871	2,861	2,423	2,227	1,792	1,466	1,191
Republic of Korea				3,036	3,056	2,166	2,079	1,707	1,527	1,440
South Africa				4,140	3,684	3,109	2,916	2,602	2,231	1,843
Spain				2,871	2,438	1,758	1,633	1,509	1,445	1,410
Switzerland				3,864	3,440	3,216	3,022	2,716	2,421	2,173
Thailand				4,019	3,121	2,798	2,726	2,362	1,944	1,388
United Kingdom				3,300	3,475	3,007	2,668	2,692	2,597	2,566
California	7,756	7,325	6,323	5,475	5,155	5,231	5,053	4,529	4,294	4,096
Other US states	7,705	7,049	5,697	4,921	4,954	4,925	4,280	3,844	3,702	3,652

Source: Adapted from IRENA (2023).

2.2.1.4 New Businesses

The increase in decentralized generation in Brazil has followed the growth in the number of integrating companies[7] in the photovoltaic energy sector, with more suppliers of photovoltaic kits, as well as providers of installation and maintenance services. In Figure 12, it is possible to observe data from Greener on the quantity of integrating companies in the sector from 2017 to 2023.

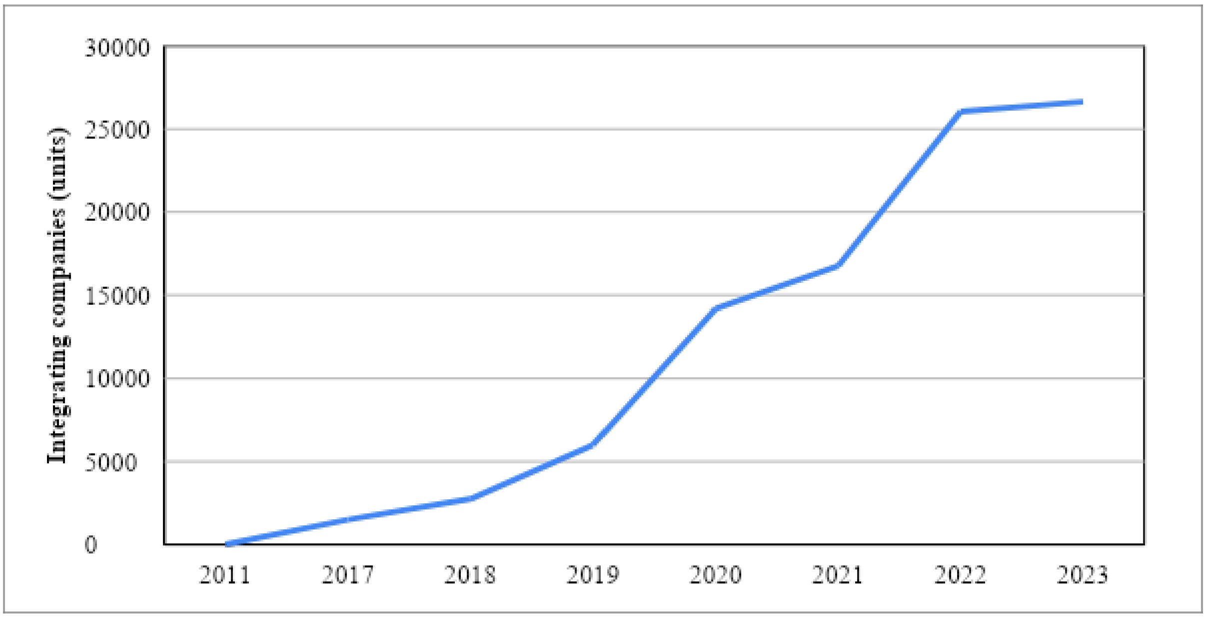


Figure 12 – Integrating companies from the energy sector
Sources: Greener (2017, 2018, 2019, 2020, 2021, 2022, 2023).

It is noticeable that since 2017, the number of integrating companies has significantly increased. However, the peak occurred in 2022, shortly after the enactment of the law of the decentralized generation framework. Law 14,300/2022 established deadlines for new generation units to receive benefits, leading to a surge in new businesses to meet the growing demand.

Similar to previous indicators, it is not possible to project the increase in the number of integrating companies in Brazil until 2050. It is understood that the solar energy market will continue to grow in the coming years; however, it cannot be asserted that this growth would follow the same trend as observed thus far. The current market momentum suggests that the increase in the number of integrating companies would grow at a slower rate over time, but there are various factors influencing market dynamics, making it difficult to project when the saturation of new companies would occur, and how the market would behave. Still, the likelihood of new businesses emerging in the coming years, driven by the decentralized generation framework, is high for both the CPS and DDS scenarios.

[7] The integrating companies, according to Greener (2023), are those that effectively conducted business in the evaluated years. These include companies that carry out installation projects for clients and, in addition to projects, install and maintain solar panels.

2.2.1.5 Energy Diversity

Energy diversity is an important aspect of energy security, as the reliance of energy provision in one energy source makes the energy system systematically vulnerable. As illustrated in Figure 2 and Figure 3, Brazilian electricity mix still relies heavily in hydropower generation. This has already posed many challenges for Brazilian energy system, particularly when the country is facing severe draughts. In 2001, for instance, Brazil has been affected by a severe energy crisis due to unfavourable climate conditions, which led many Brazilian regions without energy and required of the country the necessity to develop strategies such as energy rationing measures (SAUER, 2015). More recently, in 2021, Brazilian energy system has undergone another challenge caused by draughts. In this year the Natural Inflow Energy (ENA) – calculated considering the natural inflow to each hydroelectric plant and its equivalent productivity with 65% of the reservoir volume – with the worst performance in the historical series from 1931 to 2021, including the mentioned year 2001 (SOARES; COSTA, 2023).

Among the many consequences of these crises related to energy diversity, the most important being a more intensive operation of thermal power plants, which mostly consume fossil fuels. This activation leads to higher emissions but also, on a shorter term, to more expensive energy tariffs (BORGES, 2021).

Figure 13 illustrates the evolution of diversity in power generation normalized in Brazil and the expected diversity according to scenarios CPS and DDS. It is possible to observe an important evolution in diversity terms that is intrinsically related to PVDG expansion, considering its projected participation (Figure 2; Figure 3).

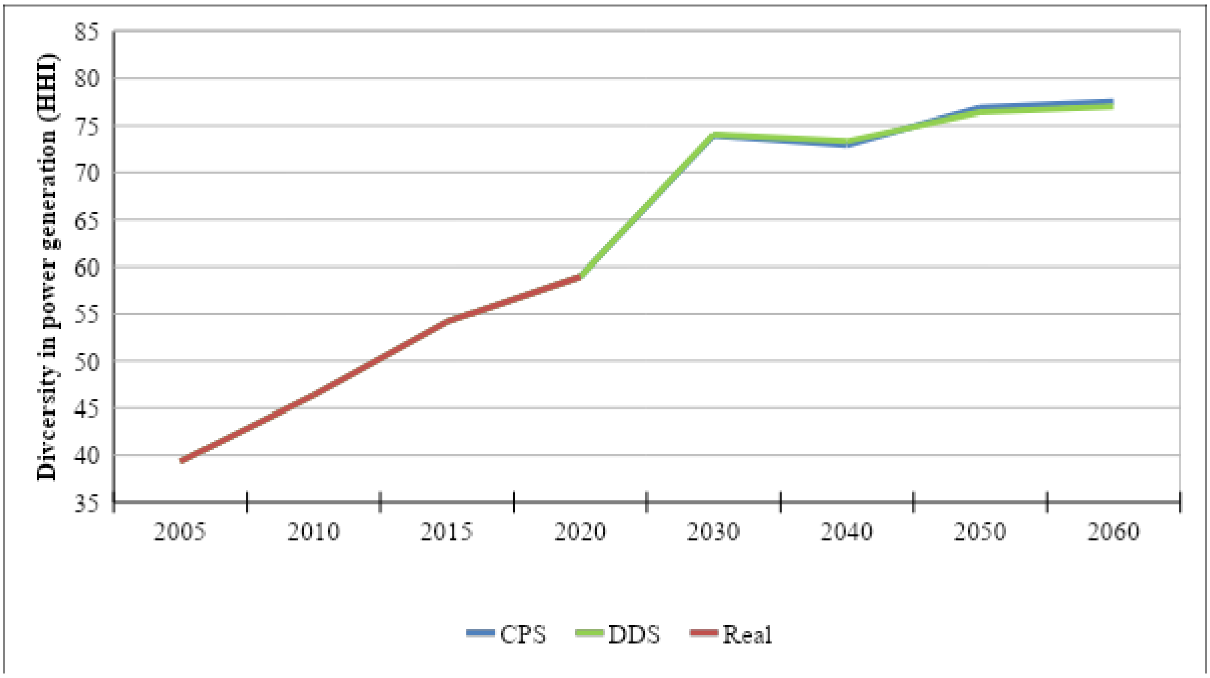


Figure 13 – Diversity in Power Generation

Source: Prepared by the authors.

2.2.1.6 Lower necessity for new investments

Considering that the more people are investing in generating their own energy and providing energy to the national energy system, the lesser need to invest in centralized installed capacity, Figure 13 illustrates the avoided cost related to power energy generation infrastructure required in 2050. The total cost would be around 269 billion and 311 billion reais.

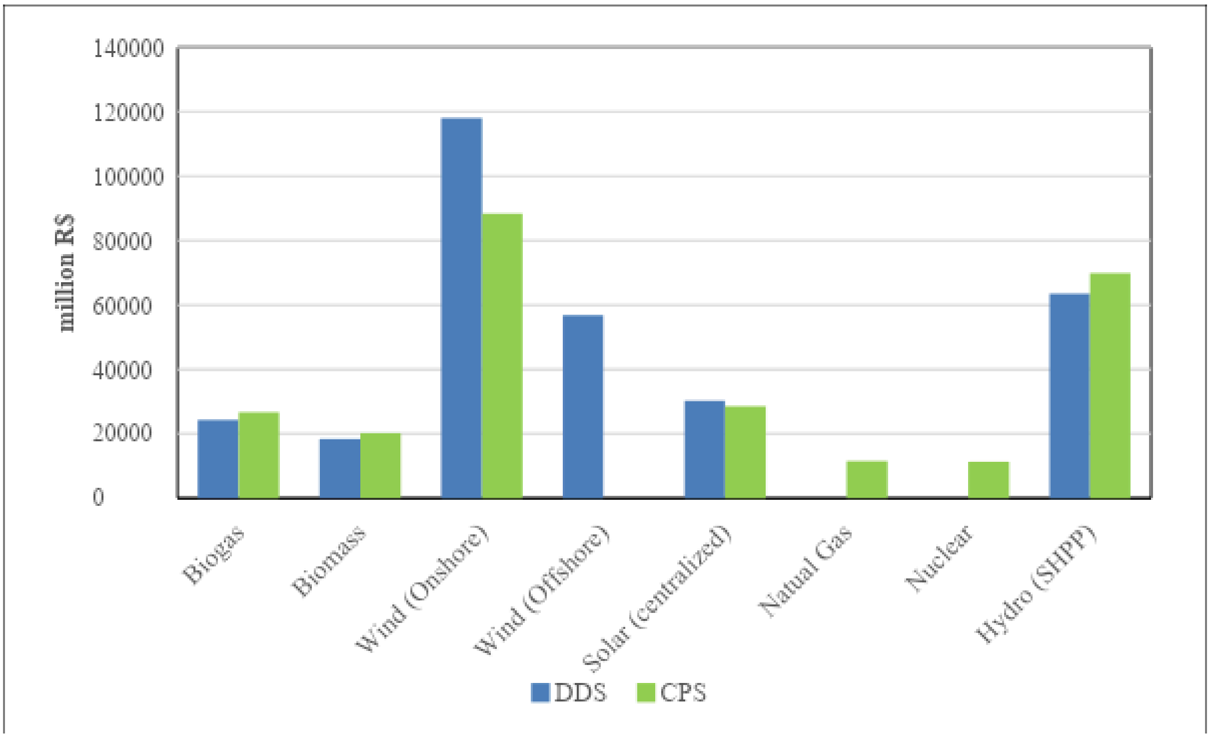


Figure 14 – Avoided costs related to centralized power generation capacity
Source: Prepared by the authors.

This indicator illustrates an important dimension associated to PVDG expansion, which is the impact final consumers may have in the energy infrastructure planning and budget. As individuals, the impact of the penetration of PVDG units in Brazilian energy system may not seem to have a high impact, but combined and with the proper energy planning, they may alter the dynamic of Brazilian energy portfolio.

2.2.1.7 Higher energy efficiency

Many studies have demonstrated that PVDG expansion is associated with lower levels of energy loss, given that the energy consumption occurs nearer to the energy production. Sharma and Koppal (2010), for example, indicate in their study that distributed generation (DG) presents a significant advantage in potentially lowering electrical line losses, especially during periods of high demand. When these losses occur, the utility company often spreads the resulting costs across all customers, leading to increased energy expenses for everyone. Thus, higher energy efficiency in the network also leads to a lower energy tariff for everyone.

However, the penetration profile of PVDG seems to be an important matter to assess the effect of PVDG expansion on energy loss. While small-scale systems aimed at self-consumption tend to reduce losses, larger remote systems connected to the grid to generate credits for different consumption units may increase them. This is due to their presence in low-consumption rural areas, leading to higher electrical currents and increased losses.

In sum, findings suggest that distributed generation has the potential to mitigate losses within the energy system by reducing the demand for energy flowing through transmission and distribution lines (PAATERO; LUND, 2007; PURVINS; L´ABBATE, 2017; RAZAVI et al., 2019; SINGH; MUKHERJEE; TIWARI, 2016). However, caution is warranted, as some studies warn about the importance of determining the optimal level of distributed generation installations connected to the grid. An excessive number of these installations may actually exacerbate energy losses instead of diminishing them (AMAN et al., 2017; MATEO; FRÍAS; TAPIA-AHUMADA, 2020; SHARMA; KOPPAL, 2010).

2.3 Social Dimension

2.3.1.1 Reduced Costs

One of the main incentives for people to invest in PVDG is the cost reduction related to energy consumption. As illustrated in Figure 5, throughout the years following the publication of the PVDG regulatory framework, the payback time has decreased significantly in Brazil. While people who invested in the sector in 2013 will only amortize their investment after around 19 years, people who invested in 2020 are close to it, considering that their payback was calculated to be around 5 years. Given the assumptions made and presented in Section 4.1.8, Figure 15 illustrates the expected expenditure reduction in 2050 for households who invested in the sector, as well as an estimate of the number of new PV systems (measured as households) included in the energy sector[8]. As illustrated, the maximum expenditure reduction in 2050 is expected for people who invested between 2016 and 2021, around 160000 BRL.

[8] Considering that the PV system average lifetime was 2030, the new wave of new systems after 2045, is explained by the model as people who reinvested in the sector after their system has failed.

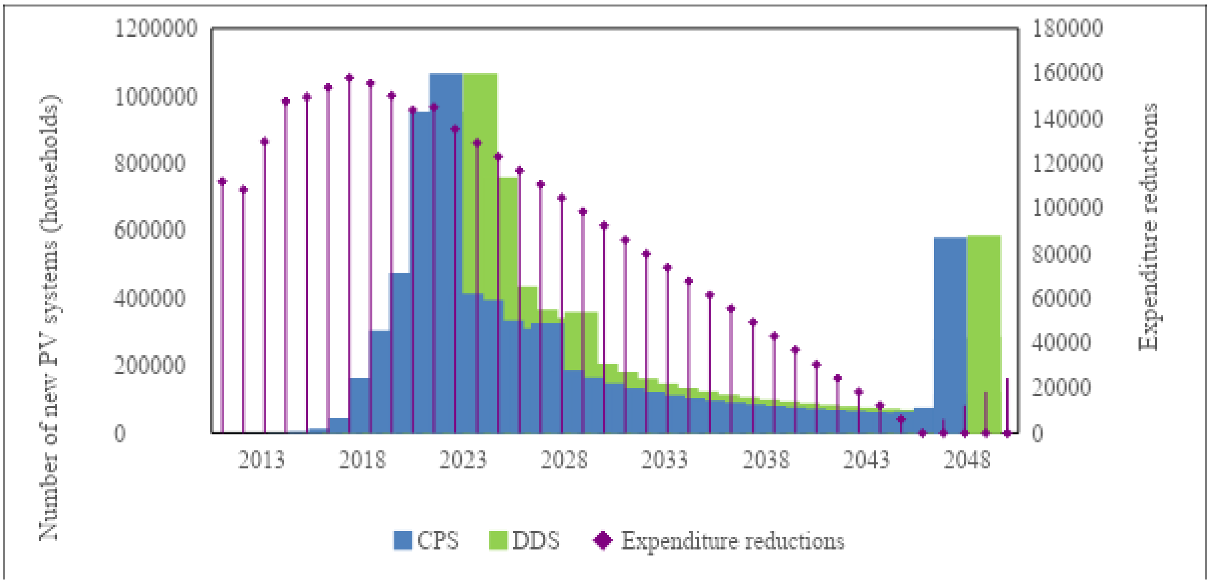


Figure 15 – Observed savings in 2050 relative to investment year

Source: Prepared by the authors.

2.3.1.2 Social Inequality

The costs of solar systems in Brazil remain out of reach for lower-income groups. Based on the premise that the policy is only accessible to higher-income groups (distributions of income groups in the country are presented in Table 8), this indicator measures the proportion of the minimum wage needed to purchase a solar system.

Table 8 – Brazilian socioeconomic stratification

Class	Family average income (BRL)	Family average income (USD)
A	21,800	4,300
B1	10,300	2,000
B2	5,700	1,100
C1	3,200	640
C2	1,900	400
D/E	900	200

Source: ABEP (2022)

It is observed in Figure 16 that since 2016 the panel kit costs are in fast decrease. However, in 2023 the purchase price was still eleven times higher than the Brazilian minimum wage (BRL 1,320.00), making it unattainable for lower-income groups.

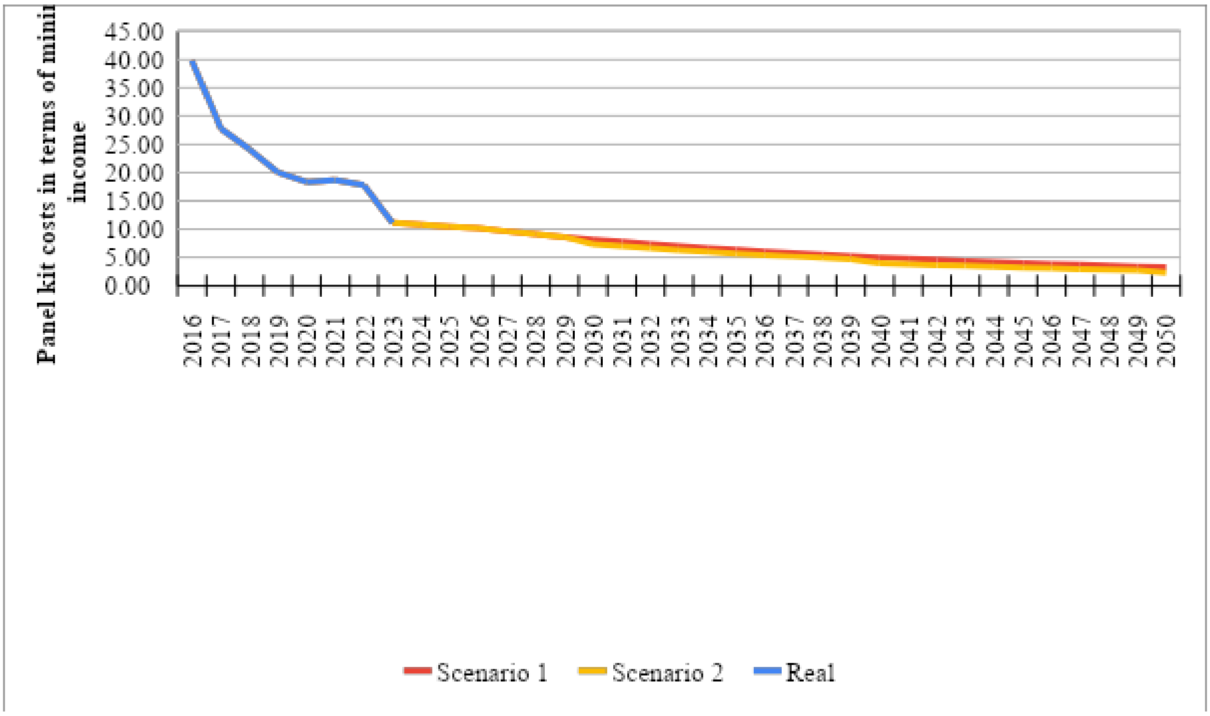


Figure 16 – Evolution of panel kit costs in terms of minimum wage
Source: Prepared by the authors.

Analyzing the two projected scenarios reveals that if the cost of solar systems continues to decline, and considering the anticipated increase in financing and incentive policies by 2050, there is a strong prospect that solar systems will become more affordable for families in the C/D socioeconomic classes. It is important to note that variables such as inflation, exchange rates, or imports can influence these projections. However, this indicator is still considered concerning in terms of the social impact of distributed photovoltaic generation (PVDG), as it primarily focuses on the market-driven effects to encourage PV adoption. In a society as economically disparate as Brazil's, the perceived benefits of PV systems by wealthier families over the years may exacerbate social inequality between those who can invest in PV systems and those who rely on standard energy tariffs. Therefore, it is crucial for PV policy frameworks to incorporate measures that ensure PVDG serves as a tool to mitigate social inequality rather than exacerbate it.

2.3.1.3 Job Creation

According to IRENA's 'Renewable Energy and Jobs Annual Review 2023', Brazil occupies the fourth position in the solar photovoltaic employment ranking - a two position increase compared to the previous year (IRENA and ILO, 2023). The introduction of Law 14300, along with the tax on small-scale distributed projects, triggered an installation rush in Brazil, making the country the second-largest export market for Chinese modules in 2022 (Chen, 2023). In this context, this indicator assesses the premise that the policy increases job offers.

The employment index was calculated based on the Profissionais do Futuro, Sistemas de Energia do Futuro and GIZ (2023) report. Figure 17 illustrates the results, indicating that, even with the learning curve considered, meaning that the study does not assume a constant growth of job offer, it is expected a considerable expansion of job opportunities in the sector throughout the period assessed. Figure 17 shows a decrease of the employability rate from 2030 onward, meaning that less people will be required in the sector given that experience and increased technical capacity leads to lower required time to do complete tasks. Still, around 34 thousand jobs are expected to be offered between 2040 and 2050, indicating that the sector is still likely to employ many people.

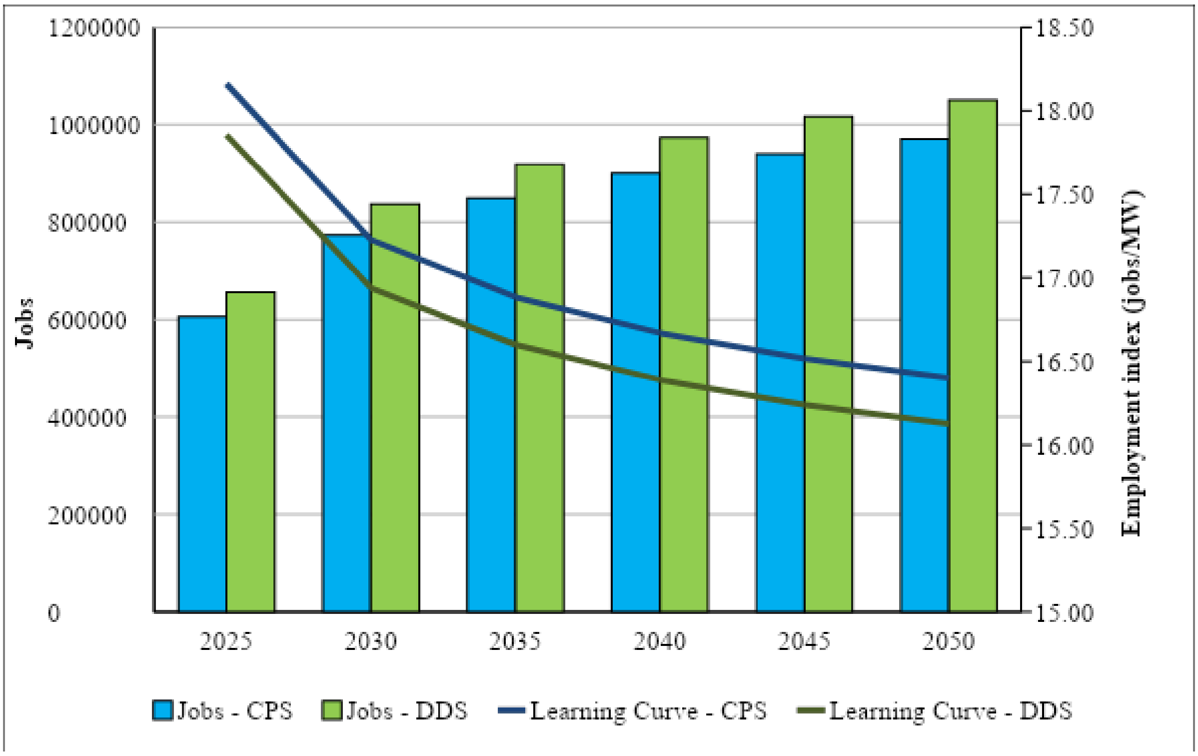


Figure 17 – Accumulated job generation estimate for both scenarios
Source: Prepared by the authors.

2.3.1.4 Integration of women on the workforce

The same study elaborated by GIZ demonstrated that the sector is mainly composed of males, representing 72% of the job offers in 2019 (Profissionais do Futuro, Sistemas de Energia do Futuro and GIZ, 2023). While comprehending the effect a policy has on gender equality is important, the PVDG policy framework has not put effort into this arena. In fact, as the study demonstrated, the rate of female share in the PVDG workforce has even decreased from 31% in 2012 to 28% in 2019 in Brazil (Profissionais do Futuro, Sistemas de Energia do Futuro and GIZ, 2023). Given that around 1 million jobs are still to be offered according to the expansion scenarios developed and that there is still an important gender gap in the employability of the sector, new policies or projects should focus on training the female workforce and providing opportunities for them in the PVDG sector.

2.3.1.5 New Socio-technical Arrangements

To test the hypothesis that PVDG Regulatory framework fosters new sociotechnical arrangements introducing multiple new stakeholders to the energy sector, data were collected from the report "Cooperatives of Distributed Generation in Brazil", produced in 2022 by The German Cooperative and Raiffeisen Confederation (DGRV) and Ideal Institute (DGRV and Ideal Institute, 2022).

The DG regulatory framework allows consumer groups for distributed generation through consortiums, cooperatives, consumer consortiums, voluntary civil condominiums or buildings, and any other form of civil association. Therefore, the expansion of the shared generation collaborative arrangements is expected and can be observed in Figure 18. Also, Figure 19 illustrates new arrangements in terms of the dynamics of credit sharing between final consumers, which means that, while a PVDG system may be installed in a household, the energy credits generated by this system can be shared with households virtually.

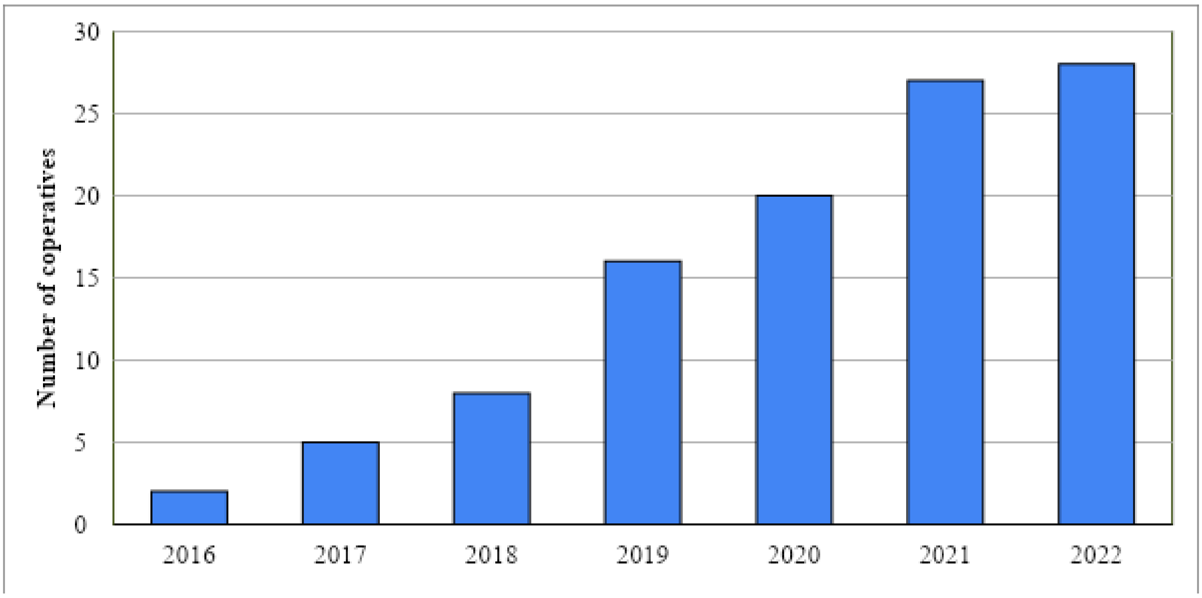


Figure 18 – Number of new cooperatives
Source: DGRV and Ideal Institute (2022).

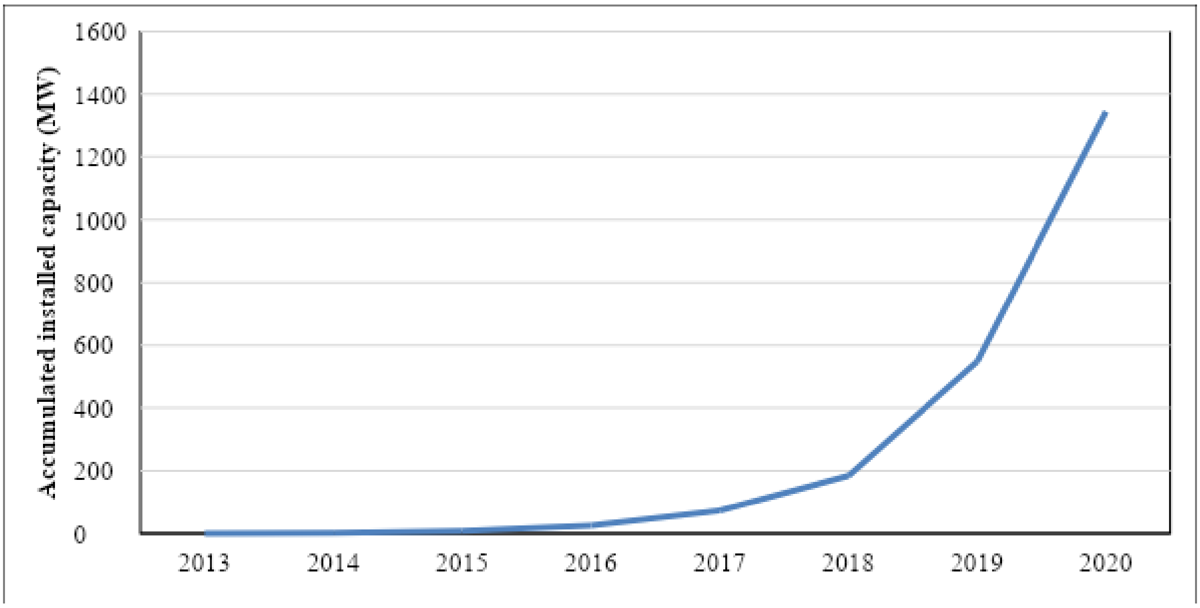


Figure 19 – Installed PVDG capacity under sharing credits mechanisms
Source: EPE (2024).

Even though projections were not proposed, given that fact that it is not possible to infer linearity in the expansion of this social contracts, it is possible to infer that this indicator will be significant, considering the ex-post analysis illustrated in Figure 18 and Figure 19.

2.3.1.6 Energy Literacy

Goulden et al. (2014) found that as individuals become energy prosumers, they play a more active role in electric power distribution networks. Additionally, since individuals serve as points of interaction for practices, it's highly probable that changes in practice are transmitted to and/or imitated by others (CARVALHAIS; PINTO, 2023). This argument has proven real in 2019, when Aneel opened a public audience to gather perspectives on the topic of energy tariff and DG. As Figure 20 illustrates, the number of contributions from final consumers was much higher than other audience, such as private companies. While this audience (001/2019) had 252 contributions, in the same year the average number of contributions per Aneel's audience regarding other energy themes was 12, with the second highest being 47 (Audience 022/2019).

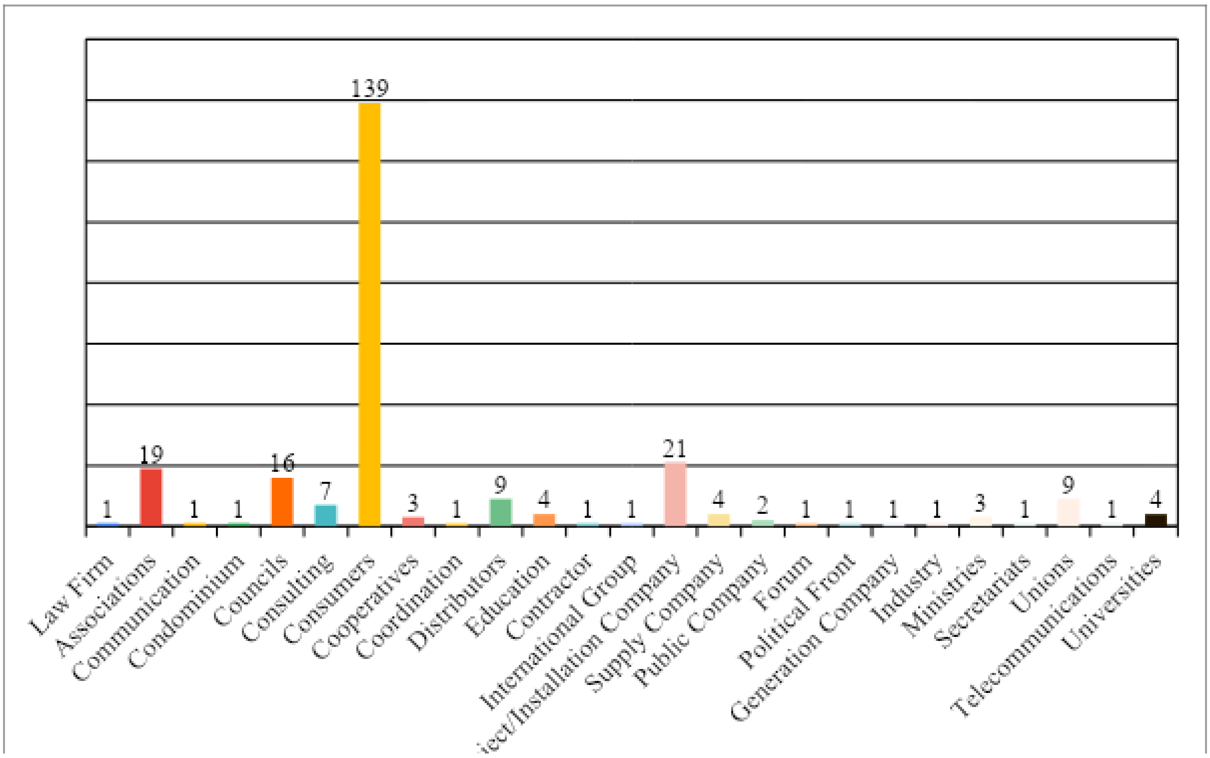


Figure 20 – Aneel's public audience contributions on DG tariff
Source: Prepared by the authors with information available at Aneel (2024).

Besides the added sense of political capital, the report by the Energy Research Office (EPE) on the expected final consumer (prosumer) behaviour, used to elaborate the Brazilian National Energy Plan (PNE 2050), also mentions higher environmental consciousness as an important indicator. In Brazil, a study conducted by ANEEL (2015) among early adopters of MMGD systems revealed that 45% of them cited "Sustainable development" as the primary motivation for installing DG. Another study that focused in interviewing prosumers in a particular city of the state São Paulo with a significant higher concentration of PVDG systems (Holambra city), pointed that investors fully agreed that investing in solar PVDG is important for the environment and that is an investment consistent with their personal values/beliefs/ideas/principles (SOARES; LAZARO, 2023).

2.4 Conclusion

In summary, the study's results demonstrate that the expansion of distributed photovoltaic generation in Brazil has multifaceted implications, positively impacting various Sustainable Development Goals, ranging from environmental conservation to economic growth and social well-being. The findings suggest that the transition to cleaner energy sources, as exemplified by decentralized PV generation, aligns with the broader global agenda for sustainable development. Figure 21 illustrates the synergies between the DG Regulatory Framework's impacts and SDGs.

Figure 21 – SDG’s and impact categories affected by the DG regulatory framework
Source: Prepared by the authors.

SDG 3 (Good Health and Well-being): The study underscores the direct impact of DGPV on air quality improvement, particularly in urban areas. Notably, the case of coal in the southern region of Brazil serves as a poignant example, where coal power generation has significantly impacted air quality, leading to adverse health effects.

SDG 4 (Quality Education): the expansion of PVDG is expected to enhance "energy literacy" among individuals, fostering a deeper understanding of the value of energy, its environmental implications, and the importance of adopting efficient energy practices. This aspect contributes to SDG 4's objectives of ensuring inclusive and equitable quality education, empowering individuals with knowledge about sustainable energy and preparing a competent workforce for the renewable energy sector.

SDG 5 (Gender equality): While comprehending the effect a policy has on gender equality is important, the PVDG policy framework has not put effort into this arena. As studies have demonstrated, the representation of women in the PVDG workforce has decreased over recent years. Given the significant number of jobs projected to be created according to the expansion scenarios and the persistent gender gap in the sector, new policies or projects should focus on training the female workforce and providing opportunities for them in the PVDG sector, aligning with the goals of SDG 5.

SDG 7 (Affordable and Clean Energy): The study's findings on "Energy Diversity" and "Cheaper Technology" directly align with SDG 7 by emphasizing the importance of clean and affordable energy solutions. The reduction in both the costs and the dependency on imported modules not only contributes to making solar energy more accessible but also underscores the significance of diversifying the energy mix. The promotion of decentralized photovoltaic (PV) generation in Brazil fosters energy diversity, a crucial aspect for ensuring a more stable and cost-effective energy supply. Diversification of energy sources reduces reliance on a single type of energy, promoting resilience and affordability in the long term. In this context, the study supports SDG 7's goal of ensuring access to affordable, reliable, sustainable, and modern energy for all, highlighting the role of energy diversity in achieving this objective.

SDG 8 (Decent Work and Economic Growth): The indicators "Creation of Jobs" and "New Businesses" align directly with SDG 8, highlighting the positive impact of decentralized PV generation on job creation and economic growth in the renewable energy sector, fostering decent and sustainable employment opportunities.

SDG 9 (Industry, Innovation, and Infrastructure): Both "National Industry" and "Imports" indicators directly align with SDG 9 by emphasizing the potential for industrial growth, innovation, and the need for resilient infrastructure in the context of decentralized PV generation.

SDG 10 (Reduced Inequalities): The indicators "Cheaper Technology" contributes indirectly to SDG 10 by addressing economic inequalities through reduced costs and increased accessibility of solar energy solutions. Indicators Reduced Costs and Social Inequality provide a deeper understanding of the risks associated with PVDG expansion once considered Brazilian social inequalities. While PV technology fosters energy independence and economic gains for those who invested in it, it , it remains unaffordable for economically vulnerable people.

SDG 11 (Sustainable Cities and Communities): The study's indicators "Cities' Air Quality" and "Land Use" are directly associated with SDG 11 by promoting sustainable urban development through improved air quality and the conservation of land. Additionally, Brazilian traditional communities have been denouncing the management and installation procedures of many renewable companies working on the expansion of centralized power generation in Brazil. Thus, the less necessity to expand Brazilian centralized power generation, the less probability these communities will be impacted.

SDG 12 (Responsible Consumption and Production): The indicator "PV Waste" directly aligns with SDG 12 by emphasizing the importance of responsible waste management and recycling practices in the photovoltaic industry. The indicator “Energy Diversity” and “Higher Energy Efficiency are positively related to SDG 12 because they imply lower necessity to invest in centralised infrastructure. The first one because PVDG expands energy offer in a private household landscape; and the second because the higher energy efficiency the lower need to increase energy offer. Finally, indicator “Lower necessity for new investments” is positively related with SDG 12 from an economical perspective, given that PVDG implies a lower necessity to invest in centralised infrastructure.

SDG 13 (Climate Action): Both "GHG emissions" and "Cities’ air quality" directly align with SDG 13, emphasizing the role of distributed PV generation in reducing greenhouse gas emissions, mitigating climate change, and improving air quality in the context of the coal-related challenges in the southern region of Brazil. Also, the indicator “Higher energy efficiency” is positively related to SDG 13 given that the lower need to expand energy offer, the lesser emissions will be associated with the energy sector.

SDG 15 (Life on Land): The indicator "Land Use" is directly associated with SDG 15, emphasizing the positive impact of decentralized PV systems on land conservation and mitigating potential conflicts related to traditional land use and ecological impacts that would be posed to local ecosystems with the installation of new power plants.

SDG 16 (Peace, Justice, and Strong Institutions): The indicator "Land Use" is indirectly associated with SDG 16 by highlighting the potential for minimizing conflicts related to land use through the deployment of decentralized PV systems.

SDG 17 (Partnerships for the Goals): The indicator "New Socioeconomic Arrangements" directly aligns with SDG 17 by emphasizing the importance of cooperative models and partnerships in the context of distributed PV generation.

PART 2: INITIAL STEPS FOR THE JUST TRANSITION MONITORING

As presented in Output 6, a just transition plan should take into consideration several steps, such as stakeholder engagement, the definition of the vision and goals of the just transition, and the identification of impact categories and monitoring indicators.

Regarding stakeholder engagement, it should be implemented from the very beginning of the process to ensure greater confidence in the outcomes, promote collaboration, allow learning from different experiences, and create a sense of belonging to the process. For engagement to be effective, it is important to promote spaces for multiple perspectives, ensuring that stakeholders feel comfortable sharing their ideas. Moreover, stakeholders should be asked about their specific social, economic, and environmental concerns, as these are relevant to determining the goals that are intended to be achieved.

Key recommendations for stakeholder engagement are: identification of stakeholders and communities at risk; setting up a committee to coordinate the process; building a coalition of stakeholders; develop a stakeholder engagement plan; and establish a grievance redress mechanism for stakeholders and affected communities.

For the definition of the vision and goals of the just transition step, creating a vision for just transition in the country is important because different stakeholders have different impressions and each country's context has its own particularities, which should be reflected in its own vision. The just transition vision represents the overall goal that the country wishes to achieve as it decarbonizes the economy in a fair, equitable and inclusive manner. Important elements to consider in developing a vision for just transition are integrate the basic principles of just transition into the vision; develop the vision with stakeholders; and incorporate the contributions and finalize the vision on just transition with stakeholders.

As for the goals, it should address the concerns expressed by a heterogeneous group of stakeholders. While the vision should be broader and cover a wide range of equity and other considerations, the goals help translate the vision into specific, measurable, achievable, relevant and time-bound indicators. When designing the goals, some key considerations are: alignment with the vision on just transition, use of different categories of goals, participation of stakeholders, and pursuit of good practices.

Finally, the identification of impact categories and monitoring indicators step is important to understand the potential risks and opportunities resulting from the transition to a low-carbon economy and, where possible, quantify and monitor these impacts. Impacts can be identified for disaggregated categories, as economic, social, and environmental dimensions, as effects of climate policies varies through different perspectives.

Regarding monitoring indicators, different types can be used for different purposes. Just transition-related indicators can be divided here into four types, as input indicators, activity indicators, output indicators, and outcome indicators. While selecting indicators, some recommendations must be considered, such as establishing a scope for monitoring; selecting impact categories based on their potential to be significantly affected by climate transition policies and their relevance to the just transition vision and objectives, the national context, and stakeholder priorities; and choosing and monitoring indicators for the selected impact categories based on the desired outcomes in specific impact areas.

2.5 Workshop

As part of this project efforts to contribute to planning a just transition assessment and monitoring in Brazil, CBC planned and hosted the workshop "Diálogos para uma transição justa no Brasil" (Dialogues for a just transition in Brazil). For this workshop, ICAT Stakeholder Participation Methodology was applied to map and engage key stakeholders.

The workshop, which was attended by 55 participants in addition to the CBC and Centro Clima technical teams, was an important moment to consolidate the engagement with the government and public sector, especially the Ministry of Environment and Climate Change, the Ministry of Mines and Energy, and the Ministry of Foreign Affairs, whose interest in developing just transitions perspectives for Brazil were manifested throughout the project. Furthermore, it enabled the establishment of a partnership network with other relevant stakeholders from different governance spheres, namely, the academy, private sector, civil society, and traditional communities, including Indigenous Peoples, Quilombolas, and others.

Mostly all the stakeholders that took part in the workshop were related to the expansion of renewable energy. However, their relationship with the theme varied due to their participation in the sector. Thus, the ICAT Stakeholder Participation Methodology and the engagement with stakeholders enabled the reunion of different points of view and perspectives regarding energy just transitions for Brazil in the workshop.

During the workshop, three rounds of dialogue were conducted with stakeholders. In the first round, which focused on the energy sector, questions were raised regarding relevant aspects of a just energy transition in the country. Discussions revolved around the ways in which sectors are impacted by or impact the just energy transition, as well as which policies and plans should be monitored to ensure that Brazil's energy transition is equitable.

During the first round of dialogue between sectors, the formation of rooms allowed for the identification of diverse societal participation in the workshop. Participants chose rooms based on the institutions they represented. Civil society had the highest representation with 15 participants (37% of the total), followed by the public sector with 14 participants (34%). The academic group was represented by 5 individuals (12%), while the private sector had 4 representatives (10%). Additionally, 3 representatives from indigenous peoples, quilombolas, and traditional communities were present, comprising 7% of the stakeholders. It's noteworthy that these numbers varied throughout the workshop due to participants joining at different times and/or eventually encountering technical difficulties.

In the second round of dialogue, also focused on the energy sector but with representatives from different sectors mixed in groups, questions were posed regarding priority agendas, key challenges, and principles for a just energy transition. Finally, the third round of dialogue shifted the discussion focus to other sectors of the economy: agriculture; forests; industry; urban planning; waste management; and others. Once again, questions were posed regarding relevant aspects, challenges, and which policies and plans should be monitored. And attendees were given the choice to choose the room of discussion based on their theme interests.

2.6 Main results

The workshop “Diálogos para uma transição justa no Brasil” (Dialogues for a just transition in Brazil) shed light on some of the participants' perceptions of the just transition in Brazil. Several key insights emerged, including disbelief about the feasibility of a just transition and the perception that just transition must ensure that existing inequalities are not exacerbated. It was observed that participants used several terms to refer to "just transition” and indicated the term "energy poverty" as one of the existing consequences of an unjust transition. Also, the recognition that the concept of just transition in Brazil is different from international perspectives was an important insight, highlighted by the ministries and other stakeholders.

Regarding the three rounds of dialogue, in the first round, the relevant aspects of just energy transitions in the country identified were grouped into five themes: i) justice and rights; ii) participation and governance; iii) sustainability; iv) jobs; and v) energy access/exclusion. Regarding the policies and plans to be monitored, responses were grouped into: i) decarbonization; ii) energy access/exclusion; iii) security; iv) participation; and v) rights of traditional peoples.

In the second round, the identified priority agendas were grouped into the following themes: i) energy access and/or exclusion; ii) renewable energies; iii) education; iv) participation and governance; v) impacts of the energy transition; vi) national autonomy; vii) alternatives for promoting a just energy transition; and viii) intersection of energy agendas with other sectors. Contributions regarding challenges for the transition were organized into seven themes: i) energy access and/or exclusion; ii) equity; iii) economy; iv) energy security; v) corporatism; vi) participation and governance; and vii) job provision.

Lastly, the fundamental principles for a just transition pointed out by the participants encompass a wide range of topics. These varied from universal access to clean energy to national sovereignty, including issues of decentralization of generation, distribution of benefits, gender equity, popular participation, and technology transfer.

In the third round, when other sectors were discussed, it was observed that there are indeed sector-specific characteristics that must be taken into account in the transition to a low-carbon economy. This round of dialogue contributed to understanding that planning a just transition in Brazil needs to focus on all sectors and considerate the different reality of each sector, and how each of them will be impacted by an energy transition.

Overall, the main result achieved was that the workshop was a starting point to discuss just energy transitions in Brazil among different stakeholders related to the country's energy sector. The event promoted important discussions between these stakeholders and the gave light to the perception that the energy transition in Brazil is far from being just and that this needs to be addressed. Although the participants were aligned on the thought that Brazil's development needs to transition to a low-carbon economy, the workshop demonstrated that there is still no consensus on the paths, mechanisms, and tools that should be employed to ensure a just transition in the country. Thus, an important result was the perception of CBC, stakeholders, and ministries that the topic needs to be further developed in the country, promoting a greater understanding of what constitutes a just transition and what needs to be done to achieve it.

3 Next Steps

The efforts made by CBC team regarding planning, monitoring and discussing just energy transitions in Brazil and especially the workshop "Diálogos para uma transição justa no Brasil" (Dialogues for a just transition in Brazil) has enabled the CBC to be recognized as a reference for just transition in Brazil. This sparked the interest of ministries in having the CBC develop the cross-cutting axis of just transition for the Plano Clima (Climate Plan) that is being coordinated by the Ministry of the Environment and Climate Change.

This interest and the proper timing to align government climate planning with other policies focused in addressing urgent social issues culminated in the extension of this project to assess socio-economic impacts of Brazil's mitigation plans and develop the basis for a just transition roadmap. The ICAT Just Transition Project for Brazil will aim to support Brazil, under the guidance of its Ministry of Environment and Climate Change (MMA), to:

1. Assess the sustainable development and macroeconomic impacts of the proposed sectoral climate target and policies. This assessment will use the ICAT Sustainable Development Methodology and an existing modelling framework; and

2. Develop elements of a just transition strategy that can help address some of the potentially negative impacts identified. The strategy will have as a core an M&E framework with indicators to define the just transition and enable its monitoring.

The work plan of this project extension will be expanded to cover not only the energy sector, but all relevant sectors, including transport, agriculture, land-use change, industry, and waste.

The extension of the project will consist of three steps. On the first step of the project, the team will define the assessment framework for both objectives of the project. This step requires identifying and engaging with stakeholders in each sector to define sectoral visions and principles of the Just Transition and identify the main socio-economic and socio-environmental impacts of the proposed sectoral measures to be assessed.

The second step of the project will consist of assessing the potential socio-economic and socio-environmental impacts of the sectoral measures proposed in the modelling of the Climate Plan's sectoral targets, which will have to be considered in the Just Transition monitoring plan. This stage will be conducted by applying ICAT's Sustainable Development Methodology.

Finally, the third step of the project will be to develop a plan for monitoring the Just Transition in the sectors. This will be designed in collaboration with the sectoral stakeholders, for whom the results will be presented to at the end of the project.

References

BRASIL. **Law NO. 12.305, August 2, 2010**. Establishes the Brazilian National Solid Waste Policy (PNRS). Presidency of the Republic, 2010. Available at: <https://www.planalto.gov.br/ccivil_03/_ato2007-2010/2010/lei/l12305.htm>.

BRAZILIAN ASSOCIATION OF RESEARCH COMPANIES (ABEP). **Economic classification criteria Brazil**. [S.l: s.n.], 2022.

BRAZILIAN ELECTRICITY REGULATORY AGENCY (ANEEL). **Pesquisa ANEEL de satisfação dos consumidores com geração distribuída**. Nota Técnica n° 0017/2015-SRD/ANEEL – ANEXO III. [S.l: s.n.], 2015.

BRAZILIAN ELECTRICITY REGULATORY AGENCY (ANEEL). **Audiências públicas**. [S.l: s.n.], 2024. Available at: <https://antigo.aneel.gov.br/audiencias-publicas?p_p_id=participacaopublica_WAR_participacaopublicaportlet&p_p_lifecycle=1&p_p_state=normal&p_p_mode=view&p_p_id=participacaopublica_WAR_participacaopublicaportlet&_participacaopublica_WAR_participacaopublicaportlet_javax.portlet.action=visualizarParticipacaoPublica&_participacaopublica_WAR_participacaopublicaportlet_ideParticipacaoPublica=2301>.

BRAZILIAN PHOTOVOLTAIC SOLAR ENERGY ASSOCIATION (ABSOLAR). **Photovoltaic Solar Energy in Brazil: ABSOLAR Infographic nº 14**. [S.l: s.n.], 2019. Available at: <https://www.absolar.org.br/wp-content/uploads/2021/02/2019.12.13%20Infogr%C3%A1fico%20ABSOLAR%20n%C2%BA%2014.pdf.>.

BRAZILIAN PHOTOVOLTAIC SOLAR ENERGY ASSOCIATION (ABSOLAR). **Photovoltaic Solar Energy in Brazil: ABSOLAR Infographic nº 26**. [S.l: s.n.], 2020. Available at: <https://www.absolar.org.br/wp-content/uploads/2021/02/2020.12.17%20Infogr%C3%A1fico%20ABSOLAR%20n%C2%BA%2026.pdf>.

BRAZILIAN PHOTOVOLTAIC SOLAR ENERGY ASSOCIATION (ABSOLAR). **Photovoltaic Solar Energy in Brazil: ABSOLAR Infographic nº 38**. [S.l: s.n.], 2021. Available at: <https://www.absolar.org.br/wp-content/uploads/2021/12/2021.12.14-Infografico-ABSOLAR.pdf>.

BRAZILIAN PHOTOVOLTAIC SOLAR ENERGY ASSOCIATION (ABSOLAR). **Photovoltaic Solar Energy in Brazil: ABSOLAR Infographic nº 47**. [S.l: s.n.], 2022. Available at: <https://www.absolar.org.br/wp-content/uploads/2022/09/2022.09.09-Infografico-ABSOLAR-n%C2%B0-47.pdf>.

BRAZILIAN PHOTOVOLTAIC SOLAR ENERGY ASSOCIATION (ABSOLAR). **Photovoltaic Solar Energy in Brazil: ABSOLAR Infographic nº 62**. [S.l: s.n.], 2023. Available at: <https://www.absolar.org.br/mercado/infografico/>.

CALDEIRA, J. G. "**Coal resources, production and use in Brazil**". In The Coal Handbook: Towards Cleaner Production (p. 118-147), 2013. Woodhead Publishing.

CARVALHAIS, R. L., & PINTO, M. R. "**From consumer to prosumer of energy: The adoption of distributed generation from the practice theory**". Brazilian Journal of Marketing (BJMkt), 2023.

CARVALHO, P. S. L. D., MESQUITA, P. P. D., & ROCIO, M. A. R. **A rota metalúrgica de produção de silício grau solar: uma oportunidade para a indústria brasileira?** BNDES, 2014.

CHEN, R. **China's module exports hit high in 2022**. InfoLink Consulting, 2023. Available at: <https://www.infolink-group.com/energy-article/solar-topic-Chinas-module-exports-hit-high-in-2022>.

DE SOUSA, N. M., OLIVEIRA, C. B., & CUNHA, D. **Photovoltaic electronic waste in Brazil: Circular economy challenges, potential and obstacles**. Social Sciences & Humanities Open, 7(1), 100456, 2023.

DGRV, IDEAL & SISTEMA OCB. **Distributed generation cooperatives in Brazil**. [S.l: s.n.], 2022.

ENERGY RESEARCH OFFICE (EPE). **Brazilian Energy Balance 2021**. [S.l: s.n.], 2021.

ENERGY RESEARCH OFFICE (EPE). **Caderno de Preços da Geração 2021**. [S.l: s.n.], 2021.

ENERGY RESEARCH OFFICE (EPE). **Micro and Minigeneration Distributed Data Panel**. [S.l: s.n.], 2024.

FRITZ, K. B. B., & WAQUIL, P. D. "**A Percepção da População do Município de Candiota sobre os Impactos Sociais, Econômicos e Ambientais Decorrentes da Produção e Emprego do Carvão Mineral**". Teor. e Evid. Econ, p. 119-134, 2003.

GOULDEN, M., BEDWELL, B., EGGLESTONE, S. R., RODDEN, T., & SPENCE A. "**Smart grids, smart users? The role of the user in demand side management**". Elsevier, 2014.

GOZGOR, G., & PARAMATI, S.R. "**Does energy diversification cause an economic slowdown? Evidence from a newly constructed**". Energy Economy, p. 109, 2022.

GREENER. **Analysis of the Distributed Generation Photovoltaic Market - 2nd Semester 2017**. [S.l: s.n.], 2017. Avaiable at:

<https://www.greener.com.br/estudo/estudo-estrategico-mercado-fotovoltaico-de-geracao-distribuida-2-semestre-de-2017/>.

GREENER. **Strategic Study of the Distributed Generation Photovoltaic Market - 1st Semester 2018**. [S.l: s.n.], 2018. Avaiable at: <https://www.greener.com.br/estudo/estudo-estrategico-mercado-fotovoltaico-de-geracao-distribuida-1-semestre-de-2018/>.

GREENER. **Strategic Study of the Distributed Generation Photovoltaic Market - 4th quarter of 2019**. [S.l: s.n.], 2019. Avaiable at: <https://drive.google.com/file/d/1hKkkfHJ8Gco1Uz7z1100hTW6a5qWbgYM/view?usp=sharing>.

GREENER. **Strategic Study of the Distributed Generation Photovoltaic Market - 1st Semester 2020**. [S.l: s.n.], 2020. Avaiable at: <https://www.greener.com.br/estudo/estudo-estrategico-mercado-fotovoltaico-de-geracao-distribuida-1-semestre-de-2020/?doing_wp_cron=1699648310.4321060180664062500000>.

GREENER. **Srategic Study of the Distributed Generation Photovoltaic Market - 1st Semester 2021**. [S.l: s.n.], 2021. Avaiable at: <https://www.greener.com.br/estudo/estudo-estrategico-mercado-fotovoltaico-de-geracao-distribuida-1-semestre-de-2021/?doing_wp_cron=1702993800.5447490215301513671875>.

GREENER. **Srategic Study of the Distributed Generation Photovoltaic Market - 1st Semester 2022**. [S.l: s.n.], 2022. Avaiable at: <https://www.greener.com.br/estudo/estudo-estrategico-geracao-distribuida-2022-mercado-fotovoltaico-1-semestre/?doing_wp_cron=1699648412.6767449378967285156250>.

GREENER. **Srategic Study of the Distributed Generation Photovoltaic Market - 1st Semester 2023**. [S.l: s.n.], 2023. Avaiable at: <https://www.greener.com.br/estudo/estudo-estrategico-geracao-distribuida-setembro-2023-dados-do-1o-semestre-2023/?doing_wp_cron=1702993857.9138069152832031250000>.

GREENHOUSE GAS EMISSIONS AND REMOVALS ESTIMATION SYSTEM (SEEG). **Plataforma SEEG**. [S.l: s.n.], 2021. Available at: <https://plataforma.seeg.eco.br/?highlight=br-net-emissions-by-sector&_gl=1*njjo3j*_ga*MTE4ODAzMTI1Ny4xNzE2OTkyMjU3*_ga_XZWSWEJDWQ*MTcxNjk5MjI1Ni4xLjAuMTcxNjk5MjI1Ni4wLjAuMA>.

INSTITUTO DE ENERGIA E MEIO AMBIENTE (IEMA). **Inventário de Emissões Atmosféricas em Usinas Termelétricas: geração de eletricidade, emissões e lista de empresas proprietárias das**

termelétricas a combustíveis fósseis e de serviço público do Sistema Interligado Nacional (ano-base 2020). [S.l: s.n.], 2022.

INTERNATIONAL RENEWABLE ENERGY AGENCY, ABU DHABI (IRENA) AND INTERNATIONAL LABOUR ORGANIZATION, GENEVA (ILO). **End-of-Life Management: Solar Photovoltaic Panels**. [S.l: s.n.], 2016.

INTERNATIONAL RENEWABLE ENERGY AGENCY, ABU DHABI (IRENA) AND INTERNATIONAL LABOUR ORGANIZATION, GENEVA (ILO). **Renewable energy and jobs: Annual review 2022**. [S.l: s.n.], 2022.

INTERNATIONAL RENEWABLE ENERGY AGENCY, ABU DHABI (IRENA) AND INTERNATIONAL LABOUR ORGANIZATION, GENEVA (ILO). **Renewable energy and jobs: Annual review 2023**. [S.l: s.n.], 2023.

INTERNATIONAL RENEWABLE ENERGY AGENCY, ABU DHABI (IRENA) AND INTERNATIONAL LABOUR ORGANIZATION, GENEVA (ILO). **Renewable power generation costs in 2022**. [S.l: s.n.], 2023.

JONES, FRANCES. **O destino dos painéis solares ao fim da vida útil: Descarte e reciclagem de módulos fotovoltaicos trazem desafios ambientais e oportunidades no contexto da transição energética.** Revista Pesquisa FAPESP, 2024. Avaiable at: <https://revistapesquisa.fapesp.br/o-destino-dos-paineis-solares-ao-fim-da-vida-util/>.

LOGCOMEX. **Importação de painéis solares: vantagens, mercado e dados relevantes**. [S.l: s.n.], 2023. Available at: <https://blog.logcomex.com/importacao-paineis-solares/>.

MINISTRY OF SCIENCE, TECHNOLOGY AND INNOVATION (MCTI). **Fator médio - Inventários corporativos.** [S.l: s.n.], 2024. Available at: <https://www.gov.br/mcti/pt-br/acompanhe-o-mcti/sirene/dados-e-ferramentas/fatores-de-emissao>.

MINISTRY OF DEVELOPMENT, INDUSTRY AND FOREIGN TRADE (MDIC). **Final Report of the Photovoltaic Solar Working Group (12/05/2017 to 03/05/2018)**. [S.l: s.n.], 2018.

MINISTRY OF LABOR AND EMPLOYMENT (MTE). **Projeções financeiras e atuariais para o regime geral de previdência social – RGPS**. [S.l: s.n.], 2022.

OSWALDO CRUZ FOUNDATION (FIOCRUZ). **RS – Complexo Termelétrico de Candiota prejudica saúde da população.** FIOCRUZ, 2023. Available at: <https://mapadeconflitos.ensp.fiocruz.br/conflito/rs-complexo-termeletrico-de-candiota-prejudica-saude-da-populacao/>.

PORTAL SOLAR. **Energia Solar na Construção – Preparando a propriedade**. [S.l: s.n.], 2024. Available at: <https://www.portalsolar.com.br/energia-solar-na-construcao-do-imovel.html>.

PROFESSIONALS OF THE FUTURE, FUTURE ENERGY SYSTEMS & DEUTSCHE GESELLSCHAFT FÜR INTERNATIONALE ZUSAMMENARBEIT (GIZ) GMBH. **Workforce in the Productive Chain of the Brazilian Solar Sector**. Ministry of Education, Ministry of Mines and Energy and GIZ, 2023.

SAUER, I. L. "**A gênese e a permanência da crise do setor elétrico no Brasil"**. Revista USP, (104), 145-174, 2015.

SOARES, R. S., & LAZARO, L. L. B. "**Factors That Contribute to Diffusion of Solar PV Energy: Evidence from Holambra in São Paulo Macrometropolis, Brazil"**. In: Energy Transitions in Latin America (pp. 265-283). Springer, 2023.