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Net metering rolling credits vs. net billing buyback: An economic analysis of a policy option proposal for photovoltaic prosumers

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ABSTRACT

There is a need for a methodology that allows the prosumer to implement a policy of choosing different compensation mechanisms. Thus, we propose the economic equivalence between net metering rolling credit (NM-RC) and net billing buyback (NB-BB) by defining a breakeven price (BP) for NB-BB that equals the Net Present Value (NPV) of these two options and using Discounted Payback Time (DPBT) as a tiebreaker metric. The Brazilian scenario was used for validation. When using the retail price, the NPV values for the NM-RC mechanism were lower in all scenarios (mean NPV of US$ 3958.66 in NM-RC against US$ 4372.17 in NB-BB). It is possible to observe that the BP that equalizes the two mechanisms is generally lower than the tariff charged by the utility (mean BP is US$ 0.1111 while mean tariff is US$ 0.1838), which reveals that offering this choice option does not burden the system. The NM-RC was selected in four cities, and the NB-BB was chosen in three cities. This policy could encourage potential prosumers, who often feel reluctant to invest in PV-DG owing to the long payback period. Thus, the political schemes complementing the compensation mechanism are relevant, especially for continental-sized countries with many utilities.

1. Introduction

The growth in energy demand in recent decades and the need for sustainable energy generation have motivated engineers, investors, regulators, and consumers to develop new energy alternatives [1–3]. A popular alternative in several countries is distributed generation (DG) from renewable energy sources (RES) [4,5]. The most attractive aspects of integrating the RES-DG are the deregulation of electricity markets in several locations, the potential for reducing greenhouse gas emissions, the low level of load losses in the network, and the maturation of appropriate technologies for DG [6–8]. Compensation-based policies for prosumers are crucial for this generation's viability and accelerating technological learning gains (spillovers) [9–11].

Net metering (NM) and net billing (NB) are incentive policies that are increasingly popular worldwide and are based on financially compensating the prosumer for the surplus energy provided by them to the grid [12–15]. By the end of 2019, 70 countries had implemented some form of these mechanisms, compared to only 14 countries in 2010 [16,17]. The possibility of producing part or all the energy consumed and being compensated for the surplus generated has been fundamental to the growth of photovoltaic DG (PV-DG). Due to their small size, PV cells become suitable for installation in homes and commercial establishments [18–20].

Brazil implemented an NM mechanism in the last decade through normative resolution no. 482/2012 [21]. The Brazilian NM was created to eliminate barriers to RES-DG growth for low-voltage systems [22]. However, faced with low acceptance by prosumers, the normative resolution underwent revisions in 2015 (normative resolution no. 685/2015) and 2017 (normative resolution no. 786/2017), increasing

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Nomenclature, acronyms, and abbreviations

BP	Breakeven Price
CAPM	Capital Asset Pricing Model
DG	Distributed Generation
DPBT	Discounted Payback Time
FIT	Feed-in Tariff
GHI	Global Horizontal Irradiance
ICMS	Goods and Services Circulation Taxes
IRR	Internal Rate of Return
LCOE	Levelized Cost of Electricity
NB	Net Billing
NB-BB	Net Billing Buyback (NB-BB)
NM	Net Metering
NM-RC	Net Metering Rolling Credit
NPV	Net Present Value
PBT	Simple Payback Time
PV-DG	Photovoltaic Distributed Generation
RES	Renewable Energy Sources
ROE	Return on Equity

Symbols

A	area (m^2)
ACo_m	amount consumed in month m
ACr_m	accumulated credit in month m
b_m	bill amount in month m
β	investment risk (dimensionless)
CF_t	cash flow in a given period t (US$)
E_{PV}	PV electricity (kWh)
E^*_{PV}	PV electricity discounted degradation rate (kWh)
I	monthly global horizontal irradiance average (kW/m^2)
i	discount rate (%)
k_e	equity cost (%)
η	efficiency (%)
p_r	retail price (US$/kWh)
p_s	special price for the surplus generated (US$/kWh)
ρ	performance rate (%)
r_f	risk-free rate (%)
$(r_m - r_f)$	market risk premium (%)
T	investment planning horizon (years)
Φ	degradation rate (%)

the opportunities and incentives for new prosumers [22,23].

After the revisions, the regulatory framework of the Brazilian NM has the following main characteristics: a 60-month term for the use of credits; a maximum period of 34 days for the approval of new systems; and systems with less than 75 kW termed as mini-generation systems, and between 75 kW and 5 MW termed as microgeneration systems [24]. In addition, remote self-consumption, shared generation, and multiple consumer units have emerged [25].

Another significant complementary incentive was the creation of the ICMS Agreement no. 16/2015, whereby all Brazilian states gradually established an exemption from Goods and Services Circulation Taxes (ICMS) for these systems. The states of Paraná and Santa Catarina grant exemptions only for the first four years [26]. According to Rocha et al. [19], this tax exemption has been important for promoting PV-DG systems in Brazil.

This set of measures helped increase the number of prosumers, with the installed capacity of PV-DG systems growing from 191 to 2987 MW from 2016 to 2019 [27]. Crucially, more incentives can be given to PV-DG prosumers. The current regulation does not allow them to choose between a compensation mechanism based on rolling credits or an alternative in which the avoided cost is offset by a buyback from the utility in the same period the surplus is produced. Notably, the difference in the definition of financial compensation directly impacts the prosumer's net present value (NPV) and the discounted payback time (DPBT). This is because the benefit's contribution to the cash flow in a future period (rolling credits) produces cash balances different from those provided by immediate compensation (buyback).

Thus, this study presents and evaluates a proposal whereby the prosumer can choose a compensation mechanism. The study makes this possible based on how the Net Billing Buy Back mechanism defines the prosumer's compensation price. This price is defined in an optimized way through the breakeven price calculation. In this case, the Breakeven Price is determined based on the estimated Net Present Value for the prosumer under the Net Metering Rolling Credits regime. To the best of our knowledge, there is no established methodology in the literature that allows the prosumer to implement a policy of choosing different compensation mechanisms where the Net Present Value of the compensation alternatives is equivalent, and the choice is defined by the Payback Time. Therefore, the proposal for a methodology that will enable implementing this type of policy represents the study's novelty and an essential contribution to the literature.

To this end, the example of Brazil, which adopts NM as a compensation policy for PV-DG, was used. However, despite the chosen country as the application scenario, the methodology proposed here can be implemented in any country, supporting public policymakers in improving their internal compensation mechanisms and facilitating the viability of implementing PV-DG projects worldwide.

The rest of the article is organized as follows: Section 2 presents the central incentive policies for RES-DG and a literature review. Section 3 outlines the methodology. Section 4 presents the results and discussions. Finally, Section 5 presents the conclusions of this study.

2. Theoretical background

This section will explain and detail the Net Metering (NM) and Net Billing (NB) compensation systems and their main differences. Next, the main criteria for making decisions on investments in energy generation from renewable sources will be presented. Finally, studies on the feasibility of DG from the perspective of compensation systems will be presented, both from a global perspective and in the Brazilian scenario.

2.1. NM-RC and NB-BB compensation mechanisms

Historically, financial compensation programs for RES-DG based on NM and NB have been an alternative to the feed-in tariff (FIT) regime, which is also famous for encouraging large-scale RES generation [28]. Under the FIT regime, the energy producer receives a fixed long-term tariff compatible with the energy source, reducing investment risks [11,29].

However, FIT policies can be expensive and challenging to implement in countries with unstable macroeconomic and regulatory conditions and high tax burdens. Their main advantage is the contractual stability provided to RES electricity producers [30]. In addition, the regulator may offer much higher compensation to a certain RES that exceeds the technology costs for that generation system, thereby imposing a high final cost to all consumers. An example is the high value of micro-FIT applied to PV microgeneration in Ontario (Canada) in 2009 [31].

A more economical alternative capable of stimulating the entry of prosumers into DG is the NM/NB mechanism, which compensates producers for the surplus RES electricity injected into the network. In these mechanisms, compensation is made for the tariff charged by the utility (in the case of credits) or a special tariff, which may be higher, lower, or equal to the retail tariff (in the case of buybacks) [32–34].

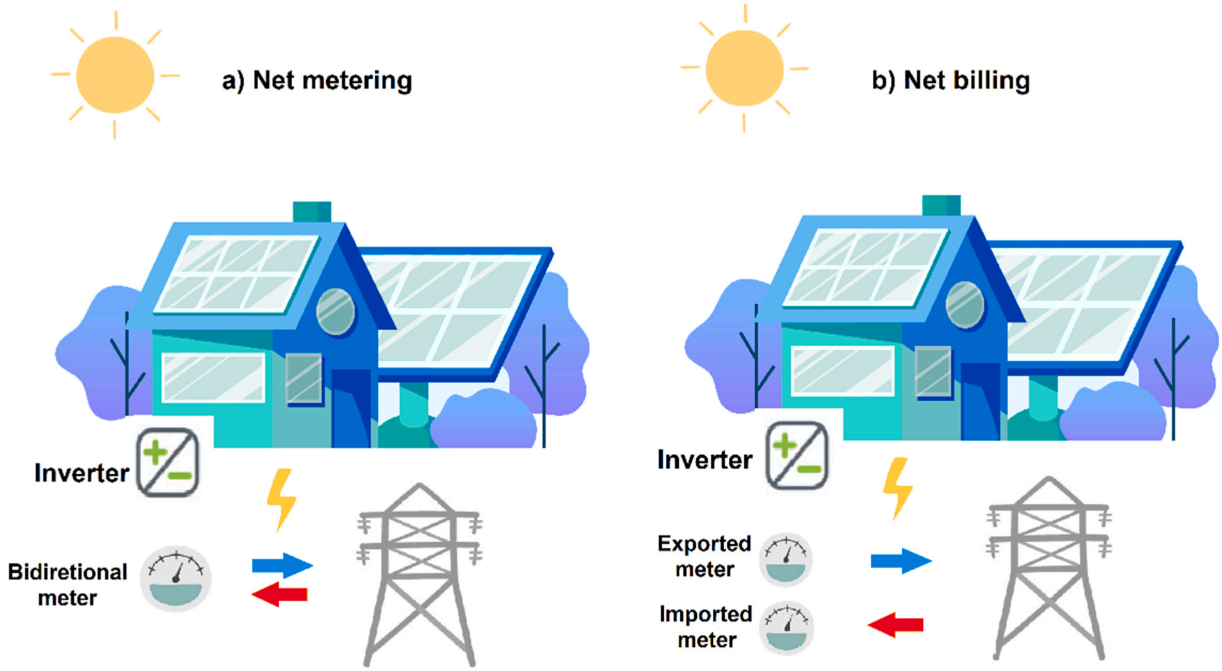

Fig. 1. The NM and NB schemes.

As illustrated in Fig. 1, the net measurement is made from a bidirectional meter that registers the energy flow under NM. Specifically, the meter turns forward when more energy is used from the grid and backward when the prosumer produces a surplus. This makes it easy to apply this mechanism when the prosumer is compensated through credits adjusted against the retail price. Meanwhile, 2 m are used in the NB, one to measure the electricity consumed from the electricity grid and the other for the electricity generated by the prosumer's system, which is supplied to the grid. This allows the establishment of remuneration based on a special tariff for all the energy produced by the prosumer [12,33].

Under NM and NB, the prosumer's benefit can be simplified, in which case the prosumer only obtains the benefit of paying only what they consume from the network without receiving a premium when they produce a surplus. However, the most attractive compensation models reward the prosumer for the surplus produced through credits or buyback [12,35]. In Brazil, the NM-RC model has been applied. Specifically, when prosumers produce surplus electricity above what they consume, they receive a premium in the form of future credits in the energy bill [6,19,36].

Tables 1 and 2 list the different variants of the NM-RC and NB-BB mechanisms, respectively. The key assumptions are that the service fee for using the system is US$ 5, the retail energy price is 0.1 US$/kWh, and the avoided cost remuneration for NB-BB is 0.06 US$/kWh. Without the PV-DG system, the prosumer would spend US$ 412.00 on energy in the first year. Under an NM-RC, the energy bill would decline from US$ 412.00 to US$ 102.50; under NB-BB, the decline would be US$ 98.90. The savings under the two mechanisms differ, which may impact the prosumer's return.

2.2. Investments analysis methods

The decision criteria provide a guideline on the feasibility and attractiveness of a given investment. When making electricity generation investment decisions, different criteria can be used depending on the particularities of the problem [37,38]. This study uses three decision criteria: NPV, Breakeven Price (BP), and DPBT.

NPV is an essential decision criterion as it indicates the financial return a given investment provides in monetary terms [39]. This criterion represents the sum of future cash flows formed by cash inflows and outflows discounted at a given discount rate [40]. It can compare different generation technologies or the financial return on a technology's investment in other contexts (localization, policy schemes, taxes, etc.). Eq. (1) describes the NPV calculation method [41,42]:

$$NPV = \sum_{t=0}^{T} \frac{CF_t}{(1+i)^t} \tag{1}$$

where CF_t is the cash flow in a given period t; T is the investment planning horizon; and i is the discount rate representing the minimum attractiveness expected by the investor.

This study uses the NPV to identify the prosumer returns in PV-DG under both NM-RC and NB-BB. For the latter, the benefits are priced at the same tariff charged on the energy bill. Thus, the differences in NPV for the prosumer in the two contexts are first compared.

BP is traditionally calculated to estimate the price that makes the NPV of a given investment equal to zero [43,44]. However, in this study,

Table 1
NM-RC example.

Month	1	2	3	4	5	6	7	8	9	10	11	12
Generation (kWh)	300	310	350	280	280	270	270	275	350	400	410	300
Usage (kWh)	450	420	350	300	250	250	300	300	300	350	400	450
Net usage (kWh)	150	110	0	20	−30	−20	0	5	−50	0	−10	140
Credits (kWh)	0	0	0	0	30	50	20	0	50	0	10	0
Bill ($5 service tax + $/kWh 0.1) (in US$)	20	16	5	7	5	5	5	5.5	5	5	5	19

Table 2
NB-BB example.

Month	1	2	3	4	5	6	7	8	9	10	11	12
Generation (kWh)	300	310	350	280	280	270	270	275	350	400	410	300
Usage (kWh)	450	420	350	300	250	250	300	300	300	350	400	450
Net usage (kWh)	150	110	0	20	−30	−20	30	25	−50	−50	−10	150
Bill ($5 service tax + $/kWh 0.1 or – $/kWh 0.06 per excess) (in US$)	20	16	5	7	3.2	3.8	8	7.5	2	2	4.4	20

the BP is obtained for the value of the special tariff that compensates for the benefit of the prosumer under the NB-BB mechanism. Specifically, BP takes the NPV of the prosumer to be equal to that obtained in the NM-RC, whose remuneration is defined by the same tariff charged for the energy consumed.

The interpretation of this result for the case analyzed can be described as a special price that leads to remuneration by the NB-BB up to a target NPV (NPV obtained by the NM-RC). This value can be achieved by projecting the prosumer cash flows in the context of NM-RC and NB-BB in an *MS Excel®* worksheet and then applying the goal-seek function.

PBT is a criterion that calculates the time required for accumulated cash flows to equal the amount of capital invested [45]. The PBT calculated in its simple form considers only the sum of cash flows in each period and the initial investment. Meanwhile, DPBT presents the same calculation more realistically because it updates the value of money over time from the discount rate [46]. Therefore, this study uses DPBT. Specifically, it is used as the tie-breaker criterion, indicating which mechanism is the most advantageous to the prosumer. DPBT is represented in a complementary form by Eqs. (2) and (3) [47].

$$DCF_t = \frac{CF_t}{(1+i)^t} \quad (2)$$

$$DPBT = t^* + \frac{\left|\sum_{t=0}^{t^*} DCF_t\right|}{DCF_{t^*+1}} \quad (3)$$

where CF_t is the cash flow in period t, and i indicates the discount rate. Moreover, t^* is the last period with a negative discounted cumulative cash flow (an integer in years); $\left|\sum_{t=0}^{t^*} DCF_t\right|$ is the absolute value of discounted cumulative cash flow at the end of the period t^*; and DCF_{t^*+1} is the discounted cash flow during the period after t^*.

The discount rate is usually quantified through the weighted average cost of capital, which provides the weighted average between the debt and equity costs [48]. However, financing decisions depend on the preferences and capacity of each prosumer to raise credit. Hence, this study only considers equity financing for the PV system. Because the discount rate is the same in both contexts, there is no impact on assessing which alternative policy is more advantageous for the prosumer.

The Capital Asset Pricing Model (CAPM) by Sharpe [49], Lintner [50], and Mossin [51] is commonly used to estimate equity cost [52,53] and has been used in DG-related studies [19,48]. The CAPM formula is presented in Eq. (4).

$$k_e = CAPM = r_f + \beta \times (r_m - r_f) \quad (4)$$

where k_e is the equity cost; r_f is the risk-free rate; $(r_m - r_f)$ is the market risk premium; and β is the investment risk in relation to the market.

2.3. Financial evaluation of policies for PV-DG

The literature presents several studies that use investment decision criteria to evaluate the impact of PV-DG policy schemes. Mills et al. [54] evaluated the effect of the savings on the energy bill provided by an NM implemented in California. They concluded that the policy positively affected commercial PV systems in high-load-consuming establishments.

Righter and Vidican [55] used the NPV to estimate an ideal FIT in the Chinese context. Li et al. [56] analyzed the feasibility of residential PV systems in Ireland under a premium payment added to the energy selling price. Cellura et al. [57] presented an economic analysis of FIT and NM for PV-DG in Italy.

Poullikas [11] compared FIT and NM policies in the context of the Cyprus market to assess their impact on investment in PV systems. Cherrigton et al. [58] also analyzed the effect of FIT on PV-DG domestic consumers in the UK. After implementing a FIT policy, Squatrito et al. [59] used various decision criteria to investigate the viability of PV systems in Italy.

Cadavid et al. [60] analyzed five configurations of PV systems considering the availability of storage and connection in the Colombian national grid and the impact of NM. Ghosh et al. [61] used the levelized cost of electricity (LCOE) to investigate the effect of political incentives, such as FIT, NM, carbon credit trading, and capital subsidies, on the profitability of PV rooftops of varying escalations in Bengaluru, India.

Orioli and Gange [62] analyzed the impact of the FIT policy in effect until July 2013 and tax credits in different scenarios and regions in Italy in densely urbanized contexts. Comello and Reichelstein [63] compared the impact of excess tariffs on the LCOE to assess the effects of these tariffs on the future sizes of PV systems in California, Nevada, and Hawaii. Ye et al. [64] analyzed FIT's impact on China's PV generation from 2011 to 2016 using the NPV and internal rate of return (IRR). Camilo et al. [65] investigated the profitability of residential PV systems in Portugal under the different scenarios of compensation policy mechanisms and considering the presence of storage technology.

Koumparou et al. [66] presented a methodology based on the LCOE to identify an ideal NM scheme compatible with local conditions. They examined new political configurations aimed at PV systems in six regions of the Mediterranean. Haegermark et al. [67] conducted an economic feasibility study of PV rooftops in the context of incentive policies and market conditions in Sweden.

Cucchiella et al. [68] proposed a financial analysis based on NPV, LCOE, and DPBT, performed sensitivity analyses on the prices of purchase and sale of energy, and a proposal for tax subsidy in the Italian context. Nikolaidis and Charalambous [69] financially analyzed the impact of an NM scheme from the perspectives of both the prosumer and state energy providers. Virtic and Lukman [13] analyzed the financial viability of PV systems under the NM system adopted in Slovenia.

To provide a decision-making guide to policymakers, Ellaban and Alassi [12] presented an integrated economic adoption model report for PV-DG using several decision criteria for investment analysis and the Monte Carlo Simulation, and analyzed its applicability for a case study in Australia. Shaw-Williams and Susilawati [70] also focused on the Australian context and performed an NM assessment for the community housing sector using investment analysis criteria and the Monte Carlo simulation.

Coria et al. [71] performed a profitability analysis using the NPV for residential PV systems by comparing an NB mechanism in Argentina with the FIT structures applied in other countries. Londo et al. [18] analyzed policy options with NM, FIT alternatives, and investment subsidies for residential PV systems based on their impact on simple payback time (PBT).

In the Brazilian context, recent studies have addressed the impact of incentive mechanisms for PV-DG based on the investment decision criteria. Holdermann et al. [36] used discounted cash flows to analyze the impact of NM on the viability of residential and commercial PV systems for 63 distribution networks in Brazil. Miranda et al. [72] evaluated the technical-economic potential of PV systems in Brazilian rooftops under NM using technical-economic simulation tools integrated with a geographic information system.

Rodrigues et al. [73] investigated the feasibility of rooftop PV systems ranging from 1 kW to 5 kW in different countries, including Brazil. Rocha et al. [19] presented a feasibility analysis using the stochastic NPV calculated by Monte Carlo simulation in four Brazilian cities and then assessed the impact of the tax exemption provided by Agreement 16. Vale et al. [74] performed an economic analysis using NPV and IRR to evaluate the feasibility of PV-DG NM for housing built through a social program in Brazil.

Specifically, regarding the comparison between NM and NB, several studies in the literature can be presented. Dufo-López and Bernal-Agustín [33] used various decision criteria to evaluate whether the proposed NM and NB in Spain in 2012 would be financially attractive for new investments in PV systems. Watts et al. [14] compared the NPV of PV generation projects of different scales in Chile, considering NM and NB mechanisms. The authors reveal that under prevailing market conditions, small-scale projects become profitable with these compensation mechanisms.

Prol and Steininger [75] investigated the impact of a new regulation in Spain whereby surplus generation for prosumers would not be remunerated. They compared it with the NM/NB while analyzing the IRR for prosumers. Pacudan [76] assessed the effect and compared the FIT and NM/NB policy options for residential PV generation in Brunei Darussalam using the return on equity (ROE) measure. Chaianong et al. [77] evaluated the economic benefits of PV-DG investments for four different groups of consumers by comparing, among other things, the NM and NB compensation schemes in Thailand. Gamonwet and Dhakal [78] investigated the economic advantages of investments in PV-DG with storage systems, comparing NM and NB.

As presented in this section, several studies in the literature have carried out feasibility analyses and economic comparisons of different compensation schemes. However, there is a need for methodologies to help public policymakers implement initiatives in which prosumers can determine their compensation scheme. Therefore, this study proposes an alternative methodology in which the PV-DG prosumer can choose the compensation mechanism. To this end, we propose the economic equivalence between NM and NB by defining a BP for NB that equals the NPV of these two options and using DPBT as a tiebreaker metric.

3. Materials and method

To investigate the impact of the proposed options on the prosumer, this study considers a typical consumption curve for a family of three people. It analyzes it in seven cities in São Paulo state, Brazil: Ilha Solteira, Ourinhos, Presidente Prudente, São Carlos, São José dos Campos, São Paulo, and Sorocaba. Each city is served by a different distribution utility, as illustrated in Fig. 2.

Besides cities with different expected monthly solar radiation values (Table 3), the National Electric Energy Agency defines a specific energy sales tariff for each utility (Table 4). Thus, the prosumer's energy-saving benefits are remunerated under particular conditions at each location.

This study considered a system composed of 25 PV modules with a power of 135 W of the Kyocera KD135SX-UPU model to satisfy the consumption curve shown in Fig. 3.

The technical specifications of the modules (Kyocera KD135SX-UPU) are Area (A) = 1.002 m^2 and Efficiency (η) = 11.85 %. Possible performance losses caused by losses in inverters and cabling, dirt and shading on PV modules, efficiency reduction due to high temperatures, losses due to unavailability, and differences in the characteristic curves of PV modules [81] were discounted. Considering a performance rate (ρ) = 81 %, according to Rocha et al. [19] and Pires et al. [82], the monthly energy production was estimated from Eq. (5).

Fig. 2. Cities and their respective utilities.

Table 3
Solar radiation (kWh/m^2) in each city.

Month	Ilha Solteira	Ourinhos	Presidente Prudente	São Carlos	São José dos Campos	São Paulo	Sorocaba
January	5.85	5.71	5.88	5.60	5.33	5.28	5.44
February	5.82	5.57	5.76	5.52	5.25	5.24	5.43
March	5.49	5.26	5.42	5.21	4.73	4.81	4.99
April	5.07	4.87	4.85	4.83	4.25	4.37	4.50
May	4.28	3.99	3.90	4.02	3.52	3.60	3.70
June	4.02	3.77	3.63	3.80	3.34	3.45	3.52
July	4.32	4.06	3.97	4.08	3.51	3.66	3.77
August	4.92	4.73	4.65	4.78	4.19	4.33	4.46
September	5.24	5.10	4.96	5.09	4.27	4.48	4.70
October	5.67	5.69	5.60	5.67	4.83	5.04	5.29
November	6.03	6.07	6.16	5.91	5.18	5.35	5.68
December	5.95	5.98	6.14	5.83	5.40	5.51	5.77

Source: NASA [79].

Table 4
Retail prices in each city.

City	Latitude	Longitude	Utility	Retail price (US $/kWh)
Ilha Solteira	−20.431	−51.338	*Elektro Redes*	0.1875
Ourinhos	−22.983	−49.856	*CPFL Santa Cruz*	0.1907
Presidente Prudente	−22.127	−51.385	*Energisa Sul Sudeste*	0.1752
São Carlos	−22.015	−47.891	*CPFL Paulista*	0.1934
São José dos Campos	−23.179	−45.887	*EDP – São Paulo*	0.1854
São Paulo	−23.548	−46.638	*ENEL*	0.1819
Sorocaba	−23.506	−47.455	*CPFL Piratininga*	0.1727

Source: ANEEL [80].

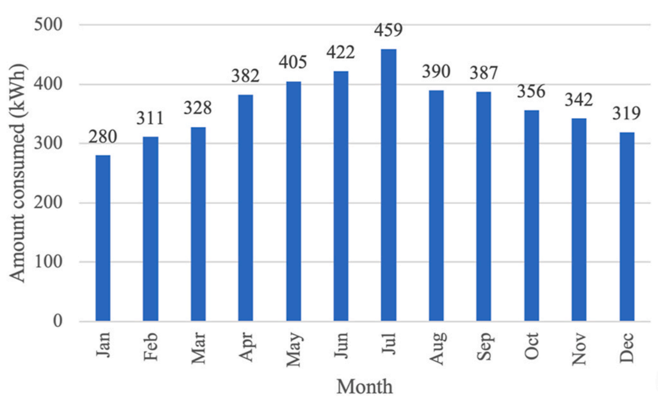

Fig. 3. The amount consumed by prosumers.

$$E_{PV} = A \times \eta \times I \times \rho \tag{5}$$

where E_{PV} is the PV electricity; and I is the monthly global horizontal irradiance (GHI) average (kW/m^2).

A system degradation rate equivalent to 0.02 % per month was considered based on Jordan et al. [83]. Thus, Eq. (6) contains the PV electricity estimate discounting the panel's degradation over time.

$$E^{*}_{PV} = E_{PV}(1-\varphi)^{m} \tag{6}$$

where E^{*}_{PV} is the PV electricity discounted degradation rate; and φ is the degradation rate.

The average market value of equipment cost for residential photovoltaic systems of 1.21 US$/W was considered [72]. O&M costs are approximately 0.5 % of the initial investment in a PV system [36]. Energy savings correspond to the amount paid on the energy bill before the PV system installation minus the amount paid by the prosumer under the compensation mechanisms.

The annual amount paid for the electricity bill after the system's installation corresponds to the sum paid during the 12 months of the year. The rate for distribution services (a fixed portion of the energy bill) is US$ 11.21. The formulae for the portion of energy purchased considering the NM-RC and NB-BB mechanisms are described in Eqs. (7) and (8), respectively.

$$\begin{cases} \left(ACr_{m} + E^{*}_{PV_{m}} - ACo_{m}\right) > 0, b_{m} = 11.21 \\ \left(ACr_{m} + E^{*}_{PV_{m}} - ACo_{m}\right) \leq 0, b_{m} = 11.21 + \left(ACr_{m} + E^{*}_{PV_{m}} - ACo_{m}\right) \times p_{r} \end{cases} \tag{7}$$

where ACr_{m} is the accumulated credit in month m; ACo_{m} is the amount consumed in month m; b_{m} is the bill amount in month m; and p_{r} is the retail price.

$$\begin{cases} \left(E^{*}_{PV_{m}} - ACo_{m}\right) > 0, b_{m} = 11.21 - \left(E^{*}_{PV_{m}} - ACo_{m}\right) \times p_{s} \\ \left(E^{*}_{PV_{m}} - ACo_{m}\right) \leq 0, b_{m} = 11.21 + \left(ACo_{m} \times p_{r}\right) - \left(E^{*}_{PV_{m}} \times p_{s}\right) \end{cases} \tag{8}$$

where p_{s} is the special price for the surplus generated.

Current market parameters were considered to estimate the discount rate from the CAPM, which are listed in Table 5. The risk-free rate and beta parameters were obtained from the *Economática*® software database. The final discount rate estimated by the CAPM, discounting the average inflation of 4.31 % [84], is 6 % annually.

The impact analyses of the choice between NM-RC and NB-BB for each of the seven cities comprise three stages. First, the difference between the NPV of the PV-DG is checked when the remunerations in the NM-RC and NB-BB are based on the consumption rate charged by the utility at each location. The second step involves calculating the BP for the remuneration in NB-BB, which results in the NPV for that mechanism being equivalent to NM-RC remunerated by the fee charged by the utility. After finding the BP of the NB-BB that matches the two option policies, in the third step, the DPBT is calculated to assess which of the two mechanisms helps the prosumer recover the PV-DG investment most quickly. Fig. 4 illustrates the flowchart of the step-by-step analysis.

Table 5
Discount rate parameters (i).

Parameter	Value	Proxy
r_f	3.50 %	Treasury Brazil (30-year maturity)
β	0.70	Electricity companies (Brazil)
$(r_m - r_f)$	3.57 %	FGV [85]
k_e (CAPM)	6.00 %	Eq. 4

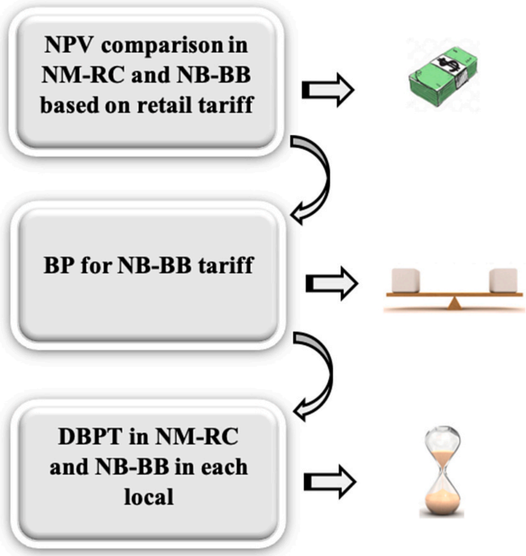

Fig. 4. Step-by-step analysis of the choice between NM-RC and NB-BB.

4. Results and discussions

4.1. NPV for retail price compensation

Table 6 shows the NPV for the prosumer when the compensations under both NM-RC and NB-BB are based on the tariff each utility charges. NB-BB provides a higher NPV to prosumers in all seven cities than NM-RC.

One of the reasons for the NPV being lower in the NM-RC mechanism may be that the use of credit occurs months after the surplus is produced. In the analyzed cities, Table 3 shows that the radiation level drops considerably during the autumn/winter (from April to August). This increases the need for the prosumer to use the credits obtained through the excess electricity produced in the summer in these months. Thus, the savings in the energy bill only appear in future periods, reducing the NPV.

Furthermore, the consumption of credits during the generation deficit months is insufficient to offset an NB-BB policy with remuneration at the retail price. However, this result cannot be generalized. In cities located in regions with a more severe winter than in the state of São Paulo, radiation levels may drop sharply in the cold months and demand faster consumption of accumulated credits.

Among the analyzed cities, the one closest to this context is São José dos Campos, which has the lowest level of radiation between April and August and the lowest difference between NPVs under NB-BB and NM-RC (US$ 269.81). The city with the second lowest level of radiation between April and August is São Paulo; it also reports the second lowest difference between NPVs (US$ 356.18). Therefore, it is worth highlighting that future studies need to consider cities with low radiation levels in autumn/winter (for example, Southern Brazil) to verify the possibility of the NPV in NM-RC being higher than in NB-BB when the remuneration of both is at retail price.

Table 6
NPV results when NM-RC and NB-BB are compensated by retail price.

City	NPV (NB-BB)	NPV (NM-RC)	NPV (NB–BB) – NPV (NM-RC)
Ilha Solteira	US$ 5300.75	US$ 4682.95	US$ 617.81
Ourinhos	US$ 5153.55	US$ 4719.91	US$ 433.64
Presidente Prudente	US$ 4245.80	US$ 3844.04	US$ 401.76
São Carlos	US$ 5252.32	US$ 4803.50	US$ 448.81
São José dos Campos	US$ 3562.62	US$ 3292.81	US$ 269.81
São Paulo	US$ 3614.08	US$ 3257.90	US$ 356.18
Sorocaba	US$ 3476.08	US$ 3109.48	US$ 366.60

4.2. BP for NB-BB special price

The second stage investigates the prices that remunerate the avoided costs under the NB-BB mechanism. For this, the NPV obtained under NM-RC with the remuneration through the retail price is considered the target NPV. Setting this as the target in the goal seek function in *MS Excel*® provides the remuneration price for the prosumer under the NB-BB mechanism. Table 7 summarizes the results for the BP under equal NPVs for the existing NM-RC and proposed NB-BB options.

In the context presented in Table 7, the BP remuneration for the prosumer in the proposed NB-BB system is equivalent to the remuneration obtained from NM-RC in Brazil. Thus, it was possible to formulate two equivalent alternative policies, leaving it up to the prosumer to decide on which mechanism they wish to be remunerated. Notably, the NB-BB alternative with remuneration by the BP provides an option to the prosumer without damaging the utility. When the remuneration rate is below the retail price, the present value paid by the utility to reward the prosumer is equivalent in both mechanisms. Thus, no stakeholder is burdened with the creation of the policy option, as no excess costs are borne by the utility or externalized to the other grid users.

A complementary correlation analysis reveals a weak correlation of 0.38 between BP and retail price. Thus, in cities with high retail prices, the BP value can tend to be higher, although this is not the only determining factor. As shown in the first stage of the analysis, the radiation level throughout the year in each location influences the level of financial return of the prosumer in both mechanisms. Thus, it also plays an essential role in calculating the BP since the target NPV to estimate is the NPV in the context of the NM-RC, which was calculated in the first step of the analysis.

4.3. Tiebreaker DPBT for NM-RC and NB-BB

The last step is determining which option policy is more advantageous to the prosumer when the NPV for NM-RC and NB-BB are equivalent. The DPBT can be used as a tiebreaker criterion between the two options. It is a metric widely considered by PV-DG prosumers. This decision criterion allows the evaluation of the DPBT of the investment in PV-DG in each analyzed city.

In Table 8, the cities are ranked from the highest to the lowest NPV value along with the DPBTs for both NM-RC and NB-BB, and the preferred policy for the prosumer in each location is indicated. In four cities, São José dos Campos, Ilha Solteira, Ourinhos, and São Carlos, the most attractive policy for the prosumer is the existing NM-RC; in three cities, Sorocaba, Presidente Prudente, and São Paulo, the preferred

Table 7
BP and retail price when NB-BB is equivalent to NM-RC.

City	BP (US $/MWh)	Retail price (US $/MWh)	NPV (NB–BB) – NPV (NM-RC)
Ilha Solteira	0.1038	0.1875	0.00
Ourinhos	0.1278	0.1907	0.00
Presidente Prudente	0.1219	0.1752	0.00
São Carlos	0.1231	0.1934	0.00
São José dos Campos	0.1077	0.1854	0.00
São Paulo	0.0905	0.1819	0.00
Sorocaba	0.1026	0.1727	0.00

Table 8
NPV and DPBT results for each city.

City	NPV (NM-RC = NB-BB) (US$)	DPBT (NM-RC) (years)	DPBT (NB-BB) (years)	Best scheme
São José dos Campos	4803.50	8.39	9.27	NM-RC
Ilha Solteira	4719.91	7.07	8.07	NM-RC
Sorocaba	4682.95	12.37	9.87	NB-BB
Ourinhos	3844.04	7.18	7.59	NM-RC
São Paulo	3682.95	12.37	9.63	NB-BB
Presidente Prudente	3292.81	8.87	8.67	NB-BB
São Carlos	3257.90	7.34	7.48	NM-RC

option is NB-BB.

Allowing the prosumer to choose a compensation mechanism may lower the payback period, as in São Paulo and Sorocaba. Practically, the prosumer will undertake the investment planning with the company's support to install the PVsystem. They will insert this information onto a standard platform the regulator provides, which will estimate the PV system's energy production over its lifetime. The prosumer can automatically see the expected NPV and DPBT comparisons between the two mechanisms using this input.

A regulatory option with these characteristics can incentivize new prosumers, who are often discouraged from investing in PV-DG because they consider the payback time too long. In addition, it does not require direct or indirect subsidies for microgeneration, with only two proposed options that have an equal financial impact on both the prosumer and other stakeholders.

Some additional considerations emerge regarding the results of the comparison of financial returns and investment recovery periods for each city. Regarding the investment's NPVs, Table 8 shows that the city with the largest NPV is São José dos Campos, while São Carlos has the lowest NPV.

Meanwhile, using the DPBT criterion in any condition other than that considered here, such as having different NPVs for the two alternatives, could complicate the identification of the city where the PV system is the most financially advantageous. For instance, Table 8 shows that in São Carlos, the DPBT of investment is lower than that in São José dos Campos under both NM-RC and NB-BB. This DPBT-based ranking would rank São Carlos above São José dos Campos for PV-DG investments.

This would be an incorrect ranking since the PV-DG investment in São José dos Campos provides an additional return of US$ 1545.6 compared to that in São Carlos. Thus, to analyze investments in PV-DG, the DPBT criterion is appropriate only as a tiebreaker for alternatives with equal NPVs, as is the case with the two options explored in this study.

In large countries or states with different utilities, compensation can be valuable for the prosumer, who can choose a mechanism to recover the invested capital faster. In the study, it is possible to observe that the BP that equalizes the two mechanisms is generally lower than the tariff charged by the utility, which reveals that offering this choice option does not add any cost to consumers. It is observed that the case analyzed in the state of São Paulo proves that in the same region where there are differences in solar radiation potential and tariffs charged by different utilities, the choice of a mechanism may be different in each area.

The present study focused only on validating the relevance of the possibility of choosing a mechanism for the prosumer. It is worth highlighting that the objective of a family or a company when investing in microgeneration is to reduce costs, that is, to create economic value. In this case, the NPV, as it is a criterion that indicates the return on investment in monetary values, offers a superior guideline than the DPBT for deciding to invest, as it considers all periods of cash flow during the life cycle of the PV system. By tying the NPV between the two mechanisms, the DPBT method becomes valuable in indicating which alternative leads to a faster capital recovery in a scenario where the financial return is the same regardless of the prosumer's choice.

5. Conclusion

The purpose of this study goes beyond the economic evaluation of incentive policies, like most articles in the literature related to DG policy schemes. The study proposed a regulatory alternative in which PV-DG prosumers can choose between two mechanisms with equivalent NPV, evaluating the one that offers the shortest period for recovering the invested capital, estimated by DPBT.

Economic analyses were carried out for seven cities in São Paulo, Brazil, with different retail prices and solar radiation, to validate the hypothesis that choosing between two compensation alternatives is valuable for the prosumer. The possibility of choosing the compensation mechanism is beneficial to the prosumer since, in four cities, the NM-RC was selected, and in three cities, the NB-BB was selected. Moreover, it can encourage potential prosumers, who often feel reluctant to invest in PV-DG owing to the long payback period. Thus, the political schemes that complement the compensation mechanism are relevant, especially for continental-sized countries or countries with many utilities.

Crucially, the two compensation options produce an NPV equal to the prosumers. Therefore, there is no win-lose relationship with this energy policy. In other words, the proposed regulatory option does not impose additional costs on the utility or other consumers who are not users of the PV-DG.

Future studies should analyze the impact of the proposed regulatory option in other geographical contexts, mainly where PV generation falls considerably during the fall/winter. In such cases, the special price of the NB-BB remuneration may exceed the retail price. Another pertinent research area is the impact of this energy policy on microgeneration through other RES, such as wind, biogas, and biomass.

CRediT authorship contribution statement

Giancarlo Aquila: Writing – original draft, Validation, Supervision, Software, Resources, Project administration, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Paulo Rotella Junior:** Writing – review & editing, Visualization, Validation, Software, Resources, Project administration, Methodology, Investigation, Formal analysis. **Luiz Célio Souza Rocha:** Writing – review & editing, Visualization, Validation, Software, Resources, Methodology, Investigation, Formal analysis, Data curation. **Pedro Paulo Balestrassi:** Visualization, Supervision, Project administration, Methodology, Formal analysis. **Edson de Oliveira Pamplona:** Visualization, Validation, Supervision, Project administration. **Wilson Toshiro Nakamura:** Visualization, Validation, Resources, Methodology.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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