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RESEARCH ARTICLE

Strategic Integration of Second-Life Batteries: Incentive Mechanisms for Boosting Community Energy Self-Consumption

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ABSTRACT Energy storage systems (ESS) can provide flexible and reliable energy management due to the rapid development of distributed renewable energy systems (RES). Second-life batteries (SLB) can overcome the environmental concerns and high investment costs related to fresh battery production. However, the integration of storage-based RES poses several challenges regarding optimal control strategy, power quality, and participation in the energy market. These questions can be listed as follows: Which economic strategy favors the integration of SLB-based storage? Which policy among the individual financial strategies can further improve the decision criteria in favor of the prosumer without causing power quality issues? Which measures should be taken, and which hybrid incentive mechanism should be proposed to complement the lacking feasibility performance of individual economic plans? To fill this gap, this study evaluates the feasibility of different incentive policies, individual or hybrid, considering prosumers' self-consumption. Moreover, sensitivity analyses consider carbon tax (CT) and investment subsidies (INVs) for prosumers. The results show that the high purchase price of SLBs can be eliminated, provided that the 20% above investment subsidy for prosumers purchasing cheaper electricity. Adopting 1 \$/t CT could reduce carbon emissions by up to 1.9 t/yr, and a 1% total investment subsidy could increase photovoltaic panel (PV) capacity by 11.28 kW. The prosumer benefit under net metering can be maximized if the total INV and CT are managed at 20% and 40 \$/t in Türkiye. This study encourages investors and prosumers to sensibly plan a shared ESS in individual and hybrid incentive mechanisms.

INDEX TERMS Carbon tax, feed-in tariff, investment subsidy rate, net billing, net metering, renewable energy.

I. INTRODUCTION

Electric vehicles (EVs) and renewable energy sources (RES) can support sustainable climate for global temperature concerns. Due to the intermittent nature of renewable energy, integration with ESS is critical to meet the growing demand [1], [2]. Therefore, microgrids focus on minimizing the cost of energy storage systems used to increase the use of renewable energy without degrading power quality [3]. Lithium-ion batteries are often used in ESS applications and perform better than their peers, but concerns need to be addressed regarding their production and operation costs. For example, producing 1 kWh of lithium-ion batteries consumes 50-65 kWh of electricity and causes 55 kg of carbon

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emissions [4]. Moreover, approximately 250 tons of mineral ores or 750 tons of mineral-rich brine are collected to produce 1 ton of lithium-ion, and 1,900 tons of water is consumed [5]. Furthermore, the recovery of high-value metal content, especially after EV use, is 40-50% of the EV battery investment [6]. Considering the lower return on recycling, SLBs extend the lifespan of EV batteries, eliminating the laborious and concerning processes related to production for different application areas. In addition, the higher purchase prices related to new production are significantly reduced with SLBs with lower performance and lower capacity or SOH. HPS integrates clean energy and conventional sources, and ESSs support optimal system operation thanks to SLBs and can provide the basis for carbon-neutral policies. SLBs can reduce peak-time energy use by up to 39%, especially for PV-fed buildings that trade energy [7]. It can also reduce carbon footprint by up to 17% [8] and increase self-sufficiency for behind-the-meter uses by up to 3% [9] by extending economic life by 3 to 5 years [10]. Compared to the FB, SLBs can reduce upfront costs by up to 35.7% [11], levelized cost of energy (LCOE) by 35-41% [12], [13], and CO_2 by 15-31% [14], [15]. Despite many proven advantages, the impact of economic policies such as net metering, net billing, carbon tax, and investment subsidies for SLBs on microgrid or HPS feasibility has not been evaluated. On the contrary, FBs are often included in these economic policies. However, citizens seeking maximum RES benefits may not favor new installations due to current policies [16], [17].

Although pure incentive policies focus only on encouraging the adoption of specific renewable energy technologies, they have little flexibility to adapt to changing market conditions [18]. Regulatory mandates, such as renewable portfolio standards or carbon pricing mechanisms, restrict emissions reductions or financial requirements to increase renewable energy production [19]. Although these measures are powerful tools to drive the transformation of energy production and consumption, they may face many challenges, political or economic. They may also be less flexible in adapting to regional differences or technological innovations. Direct investment by governments in renewable energy projects can reduce energy investment costs. However, relying solely on direct investment can strain government budgets. Market-based mechanisms (cap-and-trade systems, carbon taxes) can create fiscal incentives to invest in cleaner technologies. Although these mechanisms can provide incentives consistent with environmental goals, they may not eliminate barriers that reduce the diffusion rate of renewable energy technology and may not promote prosumers' equitable access to renewable energy. Although investing in research and development is critical to reducing the cost of renewable energy investment in the long term, R&D financing alone is insufficient to overcome market barriers. In contrast, hybrid incentive policies can use multiple incentives simultaneously to promote a more resilient energy environment. It can complement regulatory mandates by providing additional incentives and flexibility to achieve policy objectives [20], [21]. A more efficient and sustainable incentive policy can be produced by supporting investments with targeted incentives where needed, and public resources can be used with less waste. On the other hand, it can complement market-based mechanisms by providing additional support to disadvantaged communities or promoting specific technologies with high social or environmental benefits. Moreover, hybrid incentive policies can close the gap between R&D and commercialization by providing incentives to implement new technologies and increase production [22]. However, it is crucial to assess the feasibility and effectiveness of hybrid incentive policies fully, considering potential barriers or challenges. Some common barriers and challenges in implementing such policies are policy and regulatory complexity, budget constraints, market distortion, technology and infrastructure limitations, equity and distributional impacts, monitoring, reporting and verification, policy uncertainty and investor confidence, and interactions with existing policies [23].

Implementing hybrid incentive policies often requires coordination between government agencies, the legislature, and stakeholders. Political difficulties, regulatory uncertainty, and political interests can complicate the process and delay implementation. Fiscal austerity policies implemented by countries due to their economic decline may lead to limited incentives or subsidies for clean energy production. On the other hand, high subsidies and tax credits can create artificial demand, leading to market distortions [24]. Moreover, it can unintentionally distort energy markets by making certain renewable energy technologies or energy companies preferable over others. Technology and infrastructure limitations are other critical parameters that directly affect hybrid incentive policies' effectiveness [25]. Promoting clean energy technologies that are uneconomic or do not have the necessary infrastructure leads to inefficient use of resources. Low-income households and rural communities may face many challenges in accessing incentives or participating in clean energy programs. The success and legitimacy of hybrid incentive policies, providing equal opportunities to the entire society and simultaneous expansion, are vital. Inadequate monitoring, reporting, and verification systems can undermine the reliability and effectiveness of incentives. This can lead to misuse of incentives, fraud, and abuse. On the other hand, rapid policy changes or political inconsistencies reduce investor confidence and may deter investment in clean energy projects. In addition, current energy policies and the dynamics of market mechanisms may interact disruptively with hybrid incentive policies. Conflicting or overlapping policies may create insecurity, inefficiency, or undesirable consequences beyond the targeted policies. To overcome these barriers and challenges, policymakers can increase the effectiveness and sustainability of hybrid incentive energy policies in driving the transition to a cleaner and more sustainable energy future by anticipating potential barriers. Many studies have been conducted in the literature to eliminate these potential obstacles or difficulties.

Investment subsidies can increase the revenues of citizens supporting clean energy and encourage them to become prosumers [26]. However, governments should appropriately direct and determine the investment subsidy to achieve short-term system economics [27]. In addition, prosumers' willingness to participate in renewable energy must be increased to transition to a low-carbon society [28]. Government subsidies may not be necessary at low latitudes, high solar radiation, and competitive electricity purchase prices [29]. A well-managed subsidy could increase the share of renewables in the local mixed energy system from 2.4-3.2% to 17.5% [30]. Although high subsidization effectively reduces CO_2, it can prevent optimal system design and operation [31]. Even if PV and ESS investment is subsidized in many New Jersey and New York buildings, the high payback period (PP) reduces economic activity [32]. However, the Italian government has significantly reduced the impact of battery investment costs on financial profitability with a 110% subsidized tax deduction [33]. Moreover, the effect of storage on total cost is significantly lower at current storage prices for renewable penetrations (PR) below 65% [34]. Also, promoting PV SCR is the most effective policy to help batteries increase system resilience [21].

In contrast, the other economic policy, net metering, can store excess electricity from the grid for prosumers to use anytime. Therefore, credit payments to prosumers for net energy use were made considering retroactive management. No excess electricity is sold to the grid in a zero-export system, and net metering can increase revenue compared to this system [35]. Single-phase net metering (NM) was tested in households rather than three-phase NM. RES is injected into the grid, and the total CO_2 of the system is effectively reduced by 5% single-phase NM [36]. However, the mismanaged net-metering policy can cause governments to face significant financial crises [37]. Moreover, the proposed NM policies for residential prosumers with PV capacities of 11.76 kWp and below may not be profitable [38].

On the other hand, governments' support for a CT could increase the potential for RES in the long term. Although the total cost rises to 2.18% [39], CO_2 can be reduced between 20.7-31.3% [40], and the LCOE can be reduced to 0.24 \$/kWh [41]. In addition, RES PR could rise to 14% in the local energy system with a 50% increase in the CT [42]. However, neglecting non-CO_2 greenhouse gases could reduce developing countries' Gross Domestic Product (GDP) by over 1.52% [43]. Therefore, CT needs to be well managed and analyzed. After analyzing CTs in five different EU countries, increasing the CT by 1 €/t reduced annual CO_2 per capita by 11.58 kg [44]. Considering residents' costs and individual characteristics, gradual subsidization is unnecessary for low-capacity PV investments [45]. An optimal CT assessment is more critical than ever. For example, an optimal CT of 845 \$ could reduce CO_2 by up to 56,345 kg/yr [46]. Moreover, the carbon penalty's function can provide higher reliability, and the annual electricity bill can be reduced by 10.08%, considering the time of use (TOU) in the function [47]. Subsidizing prosumers to reduce CO_2 can increase CT policy efficiency and reward prosumer altruism. Accordingly, an optimal subsidy of 43 \$/kg.CO_2 could increase renewable PR by 42.6% and reduce CO_2 by 80.7% [22]. However, carbon reduction subsidies are user-friendly as long as they do not change the optimal design and do not significantly increase capacity [48].

FITs are as valuable as capital subsidies in achieving sustainable climate goals as another economic policy [24]. Higher FITs in a distributed energy system increase the investment (ROI) while the optimal battery capacity and degradation can be reduced by 4.55% [49]. The break-even point for rooftop PV can be reduced to 6.4 years for self-sufficient grid-connected systems [50]. A governance model that encourages cooperation between prosumers in the community has been defined, supporting renewable production and the decentralized self-sufficiency of prosumers to balance demand [51]. Also, the economic benefit of tariff increases and production costs can be reduced by up to 28% under variable time and geographical conditions [52]. Neglecting geographical, topographical, and climatic conditions can affect the optimal minimum FIT policy, especially in residential buildings [53]. Accordingly, a PP-based methodology meeting end-user expectations can increase the rate of ROI [54]. Technological development gradually reduces RES investments and FIT policies yearly due to declining investment levels. A low FIT policy could support the ESS trend by accelerating the decisions of governments and investors [55]. However, wrong choices should be avoided due to quick decision-making. It is also foreseen that the gradual FIT reduction can no longer be sustained after a certain point [56]. A mismanagement of the process could reduce the financial advantage by 70.8% [57]. Therefore, modest FIT policies should also be determined for lower RES capacity to prevent wrong choices [58], [59]. The financial advantage in developed countries could be maximized by maintaining current FIT policies for a few years and then abolishing them [60]. However, this regulation may change targeted RES investment plans for electricity generation in undeveloped countries [61]. A retroactive subsidy change could discourage excessive investment in countries affected by sudden policy changes [62]. Peer-to-peer (P2P) trading, the equal priority distribution of tasks and workloads, could be a promising revenue stream rather than subsidization [63], [64]. On the other hand, hybridizing incentives can solve individual policies' shortcomings and provide prosumers with many advantages. For example, the hybridization of net metering and CT can reduce annual operating costs by up to 36.55% [65]. Moreover, the FIT and battery investment subsidy hybridization can shorten the PP by up to 3 years [66]. Including the smart export guarantee scheme, load shifting, and the economy 7 strategy in the hybrid incentive mechanism could increase electricity bill savings by 1142 £per year [67].

In the literature, there are several policy studies for microgrids that minimize consumer cost and maximize government benefit, categorized as investment cost subsidy (INV) [45], [48], carbon tax (CT) [68], feed-in tariff (FIT) reduction [69], [70], [71], net metering (NM), and net billing (NB) [72] presented in Table 1. Most of these studies have not evaluated the economic decision criteria for optimal microgrid design from a simultaneous policy perspective. Moreover, the SLB has not been considered in the microgrid, although it reduces environmental and economic concerns in battery production. Also, optimal individual and hybrid economic policies are not evaluated considering power quality issues in the distribution grid.

A. MOTIVATION AND CONTRIBUTIONS

This study evaluates the feasibility of different incentive policies, individual or hybrid, for prosumers using shared SLB in the distribution network. It considers self-consumption to assess the optimal incentive policies and carbon tax. There is also an assessment of the potential for policy hybridization and suggestions for the most appropriate individual or hybrid incentive mechanisms. The main contributions of the study can be summarized as follows:

- The initial focus was on the optimal sizing and investigation of hybrid power systems' technical, economic, and environmental performance with a minimum cost objective for prosumers in the microgrid.
- Optimal economic policy suggestions for individual and hybrid plans are aimed to be determined by considering net metering, net billing, feed-in tariffs, investment subsidies, and carbon tax.
- A total investment subsidy of more than 20% could eliminate the high initial cost of SLBs, especially for prosumers in countries with low electricity prices.
- A FIT policy of 0.0274 $/kWh could maximize the benefits to the government and prosumers without causing power quality issues.
- Subsidizing the total investment by 1% could reduce CO_2 by 892.35 kg/yr. Moreover, a 1 $/t carbon tax could increase PV capacity by 0.55 kW and reduce CO_2 by 72.28 kg/yr.
- A 20% total investment subsidy and a 40 $/t carbon tax could maximize the prosumer benefit of net metering.

This article is organized as follows. Section I introduces the literature review and contributions. The mathematical modeling, assumptions, objective function, and decision criteria are explained in the material and methodology in Section II. It also describes the billing mechanisms that will be analyzed for their feasibility performance and presents the SLB and HPS parameters and the scenarios considered. The feasibility results of the economic-based strategies obtained for the purpose and scope of the study are evaluated and compared in Section III.

II. MATERIAL AND METHODOLOGY

A. PHOTOVOLTAIC PANELS

Irradiance, temperature, tilt angle, and many other variables affect PV production. Variable PV production is evaluated at multiple energy consumption points through Equation (1). Moreover, the cell temperature and the maximum efficiency of the PV panel at each time step are calculated by Equation (2)-(3) [79].

$$P_{PV}(t) = f_{PV}.Y_{PV}.\frac{G_T(t)}{G_{T,STC}}.\left[1+\alpha_P.\left(T_C(t)-25\right)\right] \quad (1)$$

$$T_C(t) = T_a(t) + \frac{G_T(t)}{G_{T,NOCT}(t)}.\left(T_{op}-T_{amb}\right) \quad (2)$$

$$\eta_{PV} = \frac{Y_{PV}}{A_{PV}.G_{T,STC}} \quad (3)$$

where $P_{PV}(t)$ shows PV panel output power (kW), f_{PV} is PV derating factor (%), Y_{PV} is the rated PV capacity under standard test conditions (STC) (kW), $G_T(t)$ is the solar radiation (kW/m^2), $G_{T,STC}$ is the incident radiation at STC (kW/m^2), $G_{T,NOCT}(t)$ is the solar radiation under normal operating cell temperature (kW/m^2), α_P is the temperature coefficient of power (-%/°C), $T_C(t)$ is PV cell temperature (°C), $T_a(t)$ is the ambient temperature (°C), T_{op} is the normal operation cell operating temperature (°C), T_{amb} is the normal operation ambient temperature (°C), η_{PV} is the maximum efficiency of the PV panels at STC (%), and A_{PV} is the area of the PV panel (m^2).

B. CONVERTERS

Converters are essential for transferring DC power generation from PV to AC load or charging ESSs. A discharged ESS contributes to the system's balance of DC and AC energy production and consumption through the converter. The inverter and rectifier operating mode power can be calculated by Equation (4)-(5).

$$P_{inv}(t) = \eta_{inv}.P_{DC}(t) \quad (4)$$

$$P_{rec}(t) = \eta_{rec}.P_{AC}(t) \quad (5)$$

where $P_{inv}(t)$ is the power output of the inverter (kW), $P_{rec}(t)$ is the power output of the rectifier (kW), $P_{DC}(t)$ is DC operating power of the DC bus (kW), $P_{AC}(t)$ is AC operating power of the AC bus (kW), η_{inv} is the inverter efficiency (%), and η_{rec} is the rectifier efficiency (%).

C. ENERGY STORAGE SYSTEMS

Using residual energy from the hybrid system in ESSs before electricity sales is a strategy to increase self-consumption. ESSs are modeled with a lithium ion-based advanced storage model (ASM), improving supply-demand balance and reliability. The 80% SOH (0.8 kWh) is generally preferred for SLBs due to increased economic efficiency and renewable potential. This study considers the 1 kWh energy capacity for FBs. Four Arrhenius-based sub-aging procedures were considered: functional curve, temperature versus relative capacity curve, depth of discharge (DOD)-dependent

TABLE 1. Comparison of related studies regarding motivation.

Ref.	Location	Motivation					Aim & Finding	
		INV	*CT*	*FIT*	*NM*	*NB*	*Aim*	*Finding*
[45]	China	✓	-	✓	-	-	Determining the appropriate incentive policy for prosumers in the distributed residential PV market using the Stackelberg game approach	With an optimal subsidy of 0.00444 $/kWh, government revenues increase by 79%.
[48]	Tongli, Tongzhou, China	✓	✓	-	-	-	Planning multi-energy systems in low-carbon regions with high renewable energy penetration	The 40% CO_2 reduction target increases the CO_2 reduction subsidy by 390 CNY/tCO_2 or 79.2%. It also leads to significant capacity increases below 300 CNY/tCO_2 of the carbon reduction subsidy.
[60]	China	-	-	✓	-	-	Achieving grid parity on the supply side with a renewable portfolio standard (RPS) based on the problem of gradual FIT reduction	Grid parity for residential and commercial customers can be reached in 4-7 and 5-8 years, respectively.
[68]	Seul, South Korea	-	✓	-	-	-	Technical, economic, environmental, and social analysis of optimal renewable microgrids with a sustainable data-driven analytical roadmap	If new jobs of more than 7500 $ each can be created, the CT is kept below 83 $/ton.$CO_2$-eq policies could shift in favor of HPS.
[69]	North-east, north, and north-west China	✓	✓	✓	-	-	Impact of CT and trade permits on wind energy investment	A CT of more than 30 yuan per ton or a free CO_2 quota of less than 50% could shift the trend from coal-fired power to wind power.
[70]	Darwin, Australia	-	-	✓	-	-	Determining the minimum applicable FIT based on SCR by questioning good and bad behavior	The optimal 14.4 c/kWh FIT and 30% SCR extend the financial break-even point of residential prosumers by 4 years and reduce clean energy adoption by 40%.
[71]	Iran	-	-	✓	-	-	Investigation of grid-connected PV feasibility considering dynamic FIT and economic decision criteria	PV with 5-20 kWp capacity and a minimum FIT of 0.11 $/kWh maximizes revenue for commercial businesses.
[72]	Darussalam, Brunei	-	-	✓	✓	✓	Comparison of FIT, net-metering, and net-billing for residential rooftop PV	The average additional cost for FIT, net metering, and net billing are 0.17 $/kWh, 0.10 $/kWh, and 0.14 $/kWh.
[73]	Northern Italy	-	✓	-	-	-	Optimization of renewable energy subsidy and CT considering two-level programming in small and medium-scale multi-energy systems	Although the total annual cost increased by 10%, the carbon reduction subsidy of 157-174 €/tCO_2, in addition to the optimal CT, reduced CO_2 by up to 25%.
[20]	Germany, Spain	-	-	-	-	-	The impact of subsidizing renewables on carbon reduction and short-term direct program costs	The CO_2 abatement cost for PV and WT subsidies is 411-1944 €/t and 82-276 €/t.
[74]	China	✓	-	-	-	-	Evaluation of a dynamic and production-based subsidy model integrated with a financial learning curve in different regions, consumer types, and IRRs.	The subsidy for CO_2 reduction at high and low solar irradiance is 0.031-0.044 yuan/kWh and 0.578-0.958 yuan/kWh.
[75]	England, Germany	-	✓	-	-	-	Assessing the effectiveness of carbon pricing or subsidizing renewable energy sources against CO_2 reduction	Carbon pricing is superior to subsidized WT or PV power. Even a modest carbon price (~30 €/tCO_2) can eliminate the use of dirty coal for cleaner power plants.
[76]	China	-	✓	-	-	-	Analyzing the impact of carbon pricing and renewable electricity subsidies on the direct cost of electricity generation	Increasing the renewable subsidy by 5.5% reduces carbon intensity by 1%. In addition, increasing the carbon price by 9.5-11.6 Yuan RMB/tCO_2 or increasing the share of RES in total electricity generation by 1% would provide the same level of CO_2 reduction.
[77]	Iran	✓	-	✓	-	-	Determining the minimum FIT considering the policies implemented in Iran over the years and conducting financial and technical analysis for residential prosumers.	Regions with PV and WT capacity factors higher than 13% are eligible for investment under the minimum FIT.
[78]	China	✓	-	-	-	-	How should the government and consumers share a PV generation project's investment costs and benefits?	Subsidizing PV power generation by 0.42 yuan/kWh and PV investment by 30% could mobilize authorities to favor PV.
Our Study	Türkiye	✓	✓	✓	✓	✓	Comparative study of the feasibility of INV, CT, FIT, NM, and NB policies for prosumers. Suggesting the most feasible individual or hybrid incentive for Türkiye.	INV (%) and CT ($/t) for Türkiye can maximize prosumers' benefits under NM as follows: 20% and 40 $/t

cycle degradation curve, and temperature-dependent shelf-life curve. The instantaneous power loss and the theoretical capacity of the ESS are calculated by Equation (6)-(7).

$$P_{out}=V_0.I-R_0.I^2 \tag{6}$$

$$I_{Pout,max}=\frac{V_0}{2.R_0} \tag{7}$$

where P_{out} is the ESS output power (kW), V_0 is the ESS's nominal voltage (V), R_0 is the series resistance (Ω), and $I_{Pout,max}$ is the maximum battery output current (A).

The cycle degradation curve based on the temperature-dependent relative capacity and DOD in each cycle was modeled by Equations (8) using curve fitting parameters. Moreover, Equation (9) can be extended to Equation (10) for each time step. SLBs may not be used at some times. In addition to aging due to charging and discharging at the relevant times, they may lose capacity over their shelf life due to ambient temperature, according to Equation (11).

$$Cap\left(T\right)=Cap\left(T_{nom}\right).\left(d_0+d_1.T+d_2.T^2\right) \tag{8}$$

$$\frac{1}{N}=A.DOD^{\beta} \tag{9}$$

$$D=\sum_{i=0}^{N}\left(A.D_i^{\beta}\right) \tag{10}$$

$$k_t=B.e^{-\frac{d}{T}} \tag{11}$$

where $Cap\left(T_{nom}\right)$ is the ESS capacity at nominal temperature (kWh), $Cap\left(T\right)$ is the ESS capacity at temperature in the current time (kWh), d_0 is the constant term in quadratic fit (0.79515), d_1 is the coefficient of temperature in quadratic fit (0.011961), d_2 is the coefficient of temperature squared in quadratic fit (−0.00011212), d is Arrhenius constant (coefficient of the exponential term in the model, a stronger temperature dependence), N is the project lifetime (yr), A is the coefficient fit in the discharge depth, β is exponent fit from data, B is rate of shelf life in hours of the limit of reduction of capacity, D is the exponential coefficient, D_i^{β} is the exponent fit in the DOD, and k_t is the time-and-temperature degradation constant.

ESS's maximum charge and discharge power are calculated at each time step. The charging power determines whether surplus renewable electricity can be absorbed. The maximum charging and discharging powers vary from one time step to the next, according to the state of charge (SOC). Three different limitations are imposed on the maximum charging power of ESS. The first limitation comes from the kinetic battery model for determining the maximum discharge power in Equation (12). The second limitation, the maximum charging C-rate, can be calculated by Equation (13). The third limitation concerns the maximum charging current of ESS as determined by Equation (14). Finally, the maximum charging power is determined by Equation (15), minimizing the three limits. The maximum discharge power during a specific operating period is calculated by Equation (16). The maximum useful discharge power is determined by Equation (17) [80].

$$P_{batt,cmax,kbm}=\frac{k.Q_1.e^{-k.\Delta t}+Q.k.c.\left(1-e^{-k.\Delta t}\right)}{1-e^{-k.\Delta t}+c.\left(k.\Delta t-1+e^{-k.\Delta t}\right)} \tag{12}$$

$$P_{batt,cmax,mcr}=\frac{\left(1-e^{-\alpha_c.\Delta t}\right).\left(Q_{max}-Q\right)}{\Delta t} \tag{13}$$

$$P_{batt,cmax,mcc}=\frac{N_{batt}.I_{max}.V_0}{1000} \tag{14}$$

$$\begin{aligned}&P_{batt,cmax}\\&\quad=\frac{MIN\left(P_{batt,cmax,kbm},P_{batt,cmax,mcr},P_{batt,cmax,mcc}\right)}{\sqrt{\eta_{batt,rt}}}\end{aligned} \tag{15}$$

$$\begin{aligned}&P_{batt,dmax,kbm}\\&\quad=\frac{-k.c.Q_{max}+k.Q_1.e^{-k.\Delta t}+Q.k.c\left(1-e^{-k.\Delta t}\right)}{1-e^{-k.\Delta t}+c.\left(k.\Delta t-1+e^{-k.\Delta t}\right)}\end{aligned} \tag{16}$$

$$P_{batt,dmax}=\sqrt{\eta_{batt,rt}}.P_{batt,dmax,kbm} \tag{17}$$

where $P_{batt,cmax,kbm}$ is maximum charge power of the ESS for a specific period (kW), $P_{batt,cmax,mcr}$ is ESS charging power corresponding to maximum charging rate (kW), $P_{batt,cmax,mcc}$ is maximum ESS charging power corresponding to maximum charging rate (kW), $P_{batt,cmax}$ is the maximum ESS charging power (kW), $P_{batt,dmax,kbm}$ is maximum discharge power of the ESS for a specific period (kW), $P_{batt,dmax}$ is the maximum ESS discharging power (kW), k is the ESS rate constant (1/hr), Q_1 is the available energy in the ESS at the beginning of the time step (kWh), Q is the initial total energy of the ESS (kWh), c is the ESS capacity ratio, Δt is time step range (hr), α_c is the storage's maximum charge rate (A/Ah), Q_{max} is the total capacity of the ESS (kWh), N_{batt} is the number of batteries, I_{max} is the ESS's maximum charge current (A), and $\eta_{batt,rt}$ is the ESS's charging efficiency (%).

ESS charging and discharging processes direct the output (throughput) energy to positive and negative, respectively. The energy amount and SOC of the ESS are calculated considering the charge and discharge operation at each time step t by Equation (18)-(19).

$$\begin{aligned}&E_{ESS}\left(t\right)\\&\quad=\begin{cases}E_{ESS}\left(t-1\right)+\eta_{ch}.P_{ESS}\left(t\right).\Delta t & P_{ESS}\left(t\right)>0\\ E_{ESS}\left(t-1\right)+\frac{P_{ESS}\left(t\right)}{\eta_{dch}}.\Delta t & P_{ESS}\left(t\right)<0\end{cases}\end{aligned} \tag{18}$$

$$\begin{aligned}&SOC\left(t+1\right)\\&\quad=SOC\left(t\right)+\eta_{ch}.\sum_{i=0}^{t}\left(P_{ch}\left(t\right)\right)+\eta_{dch}.\sum_{k=0}^{t}\left(P_{dch}\left(t\right)\right)\end{aligned} \tag{19}$$

where $E_{ESS}\left(t\right)$ is the energy charged and discharged from the ESS (kWh), η_{ch} is the efficiency of charge cycles (%), $P_{ESS}\left(t\right)$ is the power output of ESS (kWh), η_{dch} is the efficiency of discharge cycles (%), $SOC\left(t\right)$ is the SOC of ESS (%), $P_{ch}\left(t\right)$ is ESS's charging power (kW), and $P_{dch}\left(t\right)$ is ESS's discharging power (kW).

D. ECONOMIC MODEL AND DECISION CRITERIA

The cumulative investment flow can be obtained by discounting the cash flows of the cost and revenue difference at the end of each year. The net present cost (NPC) can be calculated with Equation (20) by dividing the relevant sum by the capital recovery factor (CRF). Also, the capital recovery factor and the annual real discount rate can be calculated by Equation (21)-(22). The optimal sizing is realized with the minimum NPC objective function.

$$NPC = \frac{C_{ann,tot}}{CRF\left(i,N\right)} \tag{20}$$

$$CRF\left(i,N\right) = \frac{i.\left(1+i\right)^{N}}{i.\left(1+i\right)-1} \tag{21}$$

$$i = \frac{i'-f}{1+f} \tag{22}$$

where NPC is net present cost at the end of the project life (\$), $C_{ann,tot}$ is total annualized cost (\$/yr), $CRF\left(i,N\right)$ is capital recovery factor (%), i is annual real interest rate (%), i' is nominal interest rate (%), f is expected inflation rate (%), and N is project lifetime (yr).

The system's cumulative financial sum at the year's end is expressed by Equation (23). The initial investment Equations (24), maintenance Equations (25), replacement Equations (26), penalty from carbon tax Equations (27), electricity purchase cost Equation (28), and revenue from sales can be calculated by Equations (29). The sinking fund factor can scale the future value of a series of equal annual cash flows with Equation (30). The scale factor and remaining service life required for the economic analysis are calculated by Equations (31)-(32).

$$C_{ann,tot} = C_{inv} + C_{main} + C_{rep} + C_{tax} + C_{GP} - C_{GS} \tag{23}$$

$$\begin{aligned} C_{inv} &= CRF\left(i,N\right).\sum_{l=0}^{l_0}\left(IC\left(l\right).C_{cap}\left(l\right)\right) \\ &= CRF\left(i,N\right).C_{cap} \end{aligned} \tag{24}$$

$$C_{main} = \varepsilon.\sum_{l=0}^{l_0}\left(IC\left(l\right).C_{cap}\left(l\right)\right) = C_{cap}.\left(1+i\right)^{N} \tag{25}$$

$$\begin{aligned} C_{rep} &= C_{RC}.f_{RC}.SSF\left(i,N_{comp}\right) \\ &\quad - C_{RC}.\frac{N}{N_{comp}}.SSF\left(i,N\right) \end{aligned} \tag{26}$$

$$C_{tax} = CO_{tax}.\lambda.\sum_{t=1}^{8760}\left(E_{GP}\left(t\right)\right) = CO_{tax}.TCO_2 \tag{27}$$

$$C_{GP} = \sum_{t=1}^{8760}\left(E_{GP}\left(t\right).C_{buy}\left(t\right)\right) \tag{28}$$

$$C_{GS} = \sum_{t=1}^{8760}\left(E_{GS}\left(t\right).C_{sell}\left(t\right)\right) \tag{29}$$

$$SSF\left(i,N\right) = \frac{i}{\left(1+i\right)^{N}-1};$$

$$SSF\left(i,N_{comp}\right) = \frac{i}{\left(1+i\right)^{N_{comp}}-1} \tag{30}$$

$$f_{RC} = \begin{cases} 0 & if\ N_{RC} = 0 \\ \dfrac{CRF\left(i,N\right)}{CRF\left(i,N_{RC}\right)} & if\ N_{RC} > 0 \end{cases} \tag{31}$$

$$\begin{aligned} N_{rem} &= N_{comp} + N_{rep} - N \\ &= N_{comp} + \left(N_{comp}.INT\left(\frac{N}{N_{comp}}\right)\right) - N \end{aligned} \tag{32}$$

where C_{inv} is initial investment cost (\$/yr), C_{main} is total maintenance cost (\$/yr), C_{rep} is average annual replacement cost (\$/yr), C_{tax} is total carbon tax (\$/yr), C_{GP} is total cost of purchasing electricity (\$/yr), C_{GS} is revenue from selling electricity (\$/yr), $IC\left(l\right)$ is capacity of HPS's components (kWh), $C_{cap}\left(l\right)$ is capital cost of HPS's components (\$), C_{cap} is the capital cost of the current system (\$), ε is the maintenance factor of the HPS, C_{RC} is every component's replacement cost the end of the component's service life (\$), f_{RC} is scale factors, $SSF\left(i,N\right)$ is sinking fund coefficients (%), N_{comp} is service life (yr), CO_{tax} is carbon tax (\$/t), λ is CO_2 coefficient of electricity purchase (g/kWh), $E_{GP}\left(t\right)$ is the electricity purchased from the grid (kWh), $E_{GS}\left(t\right)$ is the electricity sold to the grid (kWh), TCO_2 is annual CO_2 (g/yr), $C_{buy}\left(t\right)$ is cost of electricity purchased (\$/yr), $C_{sell}\left(t\right)$ is the revenue from selling electricity (\$/yr), N_{rem} is remaining service life (yr), and N_{rep} is replacement service life (yr).

Like NPC, the LCOE needs to be minimized in the optimization framework. The cost per unit of energy, hence, the LCOE, can be calculated by Equation (33). Where $LCOE$ is levelized cost of energy (\$/kWh), and E_{served} is total electrical load served (kWh/yr).

$$LCOE = \frac{C_{ann,tot}}{E_{served}} \tag{33}$$

The SCR measures the beneficial use of clean energy production delivered directly to load in Equation (34). The self-supply ratio (SSR) measures the beneficial use in demand of clean energy production delivered directly to load in Equation (35). Equation (36) gives the renewable fraction (RF) for the share of clean energy use in demand.

$$SCR = \frac{E_{RES}^{cons}}{E_{RES}} \tag{34}$$

$$SSR = \frac{E_{RES}^{cons}}{E_{served}} \tag{35}$$

$$RF = \frac{E_{served} - E_{nonren}}{E_{served}} \tag{36}$$

where SCR is self-consumption rate (%), SSR is self-supply rate (%), E_{RES}^{cons} is annual RES energy supplied to demand (kWh/yr), E_{RES} is total RES production (kWh/yr), and E_{nonren} is electricity production from conventional energy sources (kWh/yr).

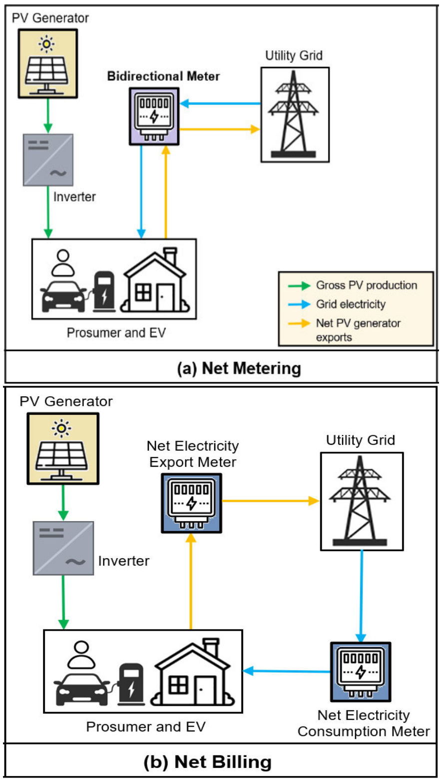

FIGURE 1. Net metering and net billing schemes.

E. NET BILLING AND NET METERING

The need for electricity from the grid and the beneficial use of solar energy demand varies as sunny periods oscillate over a narrow range between countries. To this end, governments have implemented different billing methods to raise public awareness of the beneficial use of variable grid operations. Net metering (NM) stands out among its peers for its ability to store excess electricity by selling it to the grid and reusing this power at a later operating period. Credits from the sale of electricity to the grid can be given directly when needed or deferred monthly, or electricity can be demanded from the grid for unused credits. Although it has the advantage of significant flexibility, limited grid capacity is its biggest drawback. On the other hand, credits earned from excess energy can be sold to the electricity company at wholesale prices through Net Billing (NB). The lower selling price of electricity in NB compared to the purchase price may encourage prosumers to use ESS. Although excess electricity is valuable, it affects the financial return and PP of PV systems. These two behind-the-meter schemes have different benefits for the government and the prosumer, and their basic plans are shown in Figure 1. Also, the current NM usage in countries can be seen in Figure 2 [81].

F. THE CURRENT POLICY OF INCENTIVES IN TÜRKİYE

The first legal regulation in Türkiye was made with the "Law on the Use of Renewable Energy Resources for Electrical Energy Production," enacted in 2005 to promote renewable energy [82]. Thus, various incentives for a certain period have been provided to facilities producing electricity from renewable energy sources in Türkiye through the Renewable Energy Resources Support Mechanism (YEKDEM) program. The contributions provided by this law can be listed as follows: Discount on energy transmission line usage fees, customs, and KDV exemption, 0.133 $/kWh fixed energy purchase guarantee for ten years, and incentives for using domestic products [83]. Thanks to these incentives, serious progress has been made in increasing the installed capacity of renewable energy power plants in Türkiye over the years. With the revision made in the Unlicensed Electricity Production Regulation on May 12, 2019, the way has been opened for the installation of unlicensed electricity production facilities based on renewable energy sources, without equipping a facility like a distribution facility, with production and consumption at the same measurement point [84]. On the other hand, public institutions and organizations have been that consumption facilities can establish unlicensed production facilities based on renewable energy sources on roofs, facades, and lands without the requirement that production and consumption be at the same measurement point, provided that they do not exceed the total contractual powers in the connection agreement [85]. It is now possible to sell the excess self-consumption of energy produced in power plants to be established up to 10 kW in residences and 5 MW in other businesses [86]. Regardless of the source type, production and consumption netting has started to be implemented monthly for those engaged in unlicensed production based on renewable energy sources. Moreover, it is emphasized that the relevant supplier company will collect the energy sales price for ten years based on the active electrical energy price announced by EPDK. On the other hand, many problems slow the investment and project implementation speed. The main ones are legislative and legal uncertainties, frequently changing energy policies, financing

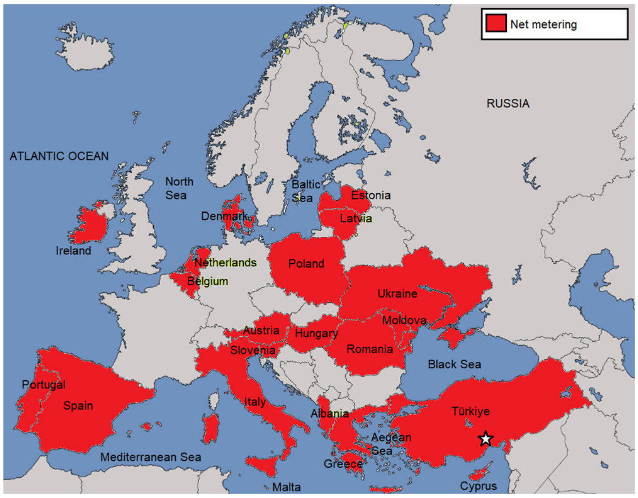

FIGURE 2. Net metering in European countries.

TABLE 2. System characteristics.

Specification	PV (Flat Type)	Converter (Inverter)	SLB ESS (Li-Ion ASM)	Grid
Capital cost	1500 $/kW	600 $/kW	385 $/kWh	**TOU:** 0.120 $/kWh **FIT:** 0.017 $/kWh
Replacement cost	1450 $/kW	600 $/kW	370 $/kWh	
Operation & Maintenance (O&M) cost	10 $/kW/yr	0 $/kW/yr	7 $/kWh/yr	
Lifetime	20 yr	15 yr	20 yr	
Efficiency	80%	95%	80%	**CT:** 0 – 20 – 40 $/t
Replacement degradation limit	-	-	37.5%	

TABLE 3. Scenarios of the study.

Step	Sensitivity				Individual policy analysis				Comparison of optimal individual policies	Sensitivity analysis of hybrid policy			Optimal hybrid policy points
	CT ($/t)	*SCR (%)*	*FIT ($/kWh)*	*INV (%)*	*NB*	*NM*	*FIT*	*INV*		*NM*	*CT ($/t)*	*INV (%)*	
(1)	0-100	-	-	-	✓	-	-	-	-	-	-	-	-
(2)		-	-	-	-	✓	-	-	-	-	-	-	-
(3)	20	10-90	-	-	-	✓	-	-	-	-	-	-	-
(4)		-	0.04-0.20	-	-	-	✓	-	-	-	-	-	-
(5)		-	-	0-50	-	-	-	✓	-	-	-	-	-
(6)	-	-	-	-	-	-	-	-	✓	-	-	-	-
(7)	20-100	-	-	0-80	-	-	-	-	-	✓	✓	✓	-
(8)	✓	✓	-	✓	-	-	-	-	-	-	-	-	✓

restrictions and insufficient financing, bureaucratic obstacles, technology and infrastructure inadequacies, and inadequate training [87]. Due to these difficulties and barriers, the spread of renewable energy power plants slows down. Countries are developing many hybrid incentive policies, considering regional dynamics, to eliminate these potential obstacles or challenges and ensure that participation in clean energy programs is offered to the entire society with equal opportunities and widespread [88]. In many developed countries, policies for installing rooftop PV systems are intensive, and incentive schemes have been prepared. In Türkiye, this situation is limited to fixed incentive policies for 10 kW rooftop PV systems designed with a self-consumption model, and tiered or hybrid incentive systems are not applied. Although steps are being taken in Türkiye to provide financial support, the main obstacle is high interest rates. The solution to this problem may be to shorten the payback period of investments through more effective use of foreign funds and direct investor interest in renewable energy investments. When all these incentives are evaluated, implementing portfolio standard practices in Türkiye, increasing FIT duration and amounts, or grading them according to regional development levels, including incentives for higher power rooftop PV systems, providing initial investment incentives and credibility opportunities for battery technologies. Moreover, developing hybrid incentive policies that increase self-consumption, considering the installed power level, will make achieving the desired sustainable energy and environment targets easier.

G. HYBRID POWER SYSTEM DESCRIPTION AND SCENARIOS

Each consumer in the system has its own PV production and electric vehicle charging. Moreover, the system uses shared energy storage, and meters communicate with incentives. In addition, the residual energy after ESS utilization is sold to the grid. Electricity is purchased from the grid to maintain demand reliability during periods of intermittent RES and low SOC batteries. HPS costs are shown in Table 2 [89], and the inflation rate (IR) data originate from [90]. However, the grid operator's time-based electricity purchase prices vary depending on the country's economy. Electricity prices sold to the grid are similar on average, and it is possible to see the CT (0 $/t, 20 $/t, 40 $/t) applied in this study.

The scenario procedure until the determination of optimal individual and hybrid incentive policies is shown in Table 3. First, step (1), the impact of NB, and step (2), the effect of NM on optimal sizing and feasibility outcomes is evaluated by considering CTs. The impact of a possible increase in SCR on NM policy is examined in step (3), especially considering power quality issues in the lower CT, and infeasible policy suggestions are determined. In step (4), the impacts of a gradual FIT are assessed, while step (5) elaborates on the significant contribution of investment cost subsidies. In step (6), individual economic policies are compared, and the most favorable strategies are proposed. In step (7), the performance of NM, CT, and INV policies is evaluated with simultaneous CT and investment rebates. In step (8), the multi-step

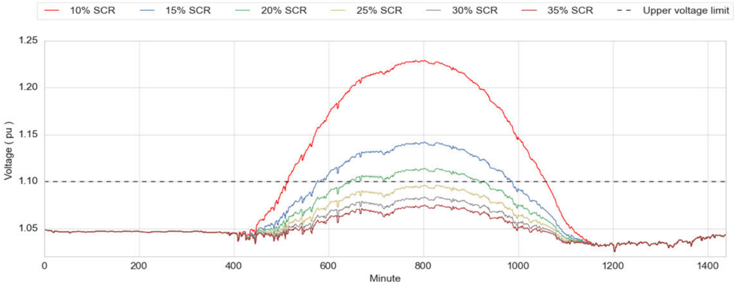

FIGURE 3. Voltage fluctuations at critical node 886 under SCR scenarios.

TABLE 4. Impact of NB and NM on prosumer under CTs (CT: 0-100 $/t).

CT ($/t)	Net Tariff	PV (kW)	SLB (kWh)	NPC (M$)	LCOE ($/kWh)	RF (%)	CO$_2$ (t/yr)	DP (yr)	ROI (%)	IRR (%)	SCR (%)	SSR (%)
0	Net Billing (NB)	309	-	2.51	0.070	57.3	191.5	12.46	-0.8	-	48.0	41.8
	Net Metering (NM)	293	-	2.18	0.062	56.4	193.7	10.59	0.5	0.8	49.8	41.1
20	Net Billing (NB)	326	-	2.71	0.074	59.0	189.2	11.93	-0.5	-	46.2	42.5
	Net Metering (NM)	295	-	2.38	0.067	56.5	193.5	10.05	0.9	1.7	49.6	41.2
40	Net Billing (NB)	349	-	2.89	0.076	61.0	186.5	11.55	-0.2	-	43.9	43.4
	Net Metering (NM)	309	-	2.57	0.071	57.7	191.5	9.72	1.2	2.2	47.9	41.8
60	Net Billing (NB)	375	-	3.08	0.078	63.1	183.8	11.28	0.0	-	41.7	44.2
	Net Metering (NM)	332	-	2.76	0.074	59.6	188.5	9.55	1.4	2.5	45.6	42.7
80	Net Billing (NB)	407	-	3.27	0.079	65.3	180.8	11.1	0.1	-	39.2	45.1
	Net Metering (NM)	330	-	2.95	0.079	59.6	188.7	9.12	1.9	3.2	45.8	42.7
100	Net Billing (NB)	425	-	3.45	0.081	66.5	179.2	10.8	0.3	-	37.9	45.6
	Net Metering (NM)	337	-	3.14	0.084	59.8	187.9	8.78	2.3	3.8	45.1	42.9

analysis determines the hybrid economic incentive policies and analyzes their advantages. The sensitive parameter, indicated here by INV (%), defines the simultaneous reduction of investments in the HPS.

All analyses were realized using Hybrid Optimization of Multiple Energy Resources (HOMER) software for optimal sizing with a minimum cost objective and subsequent evaluation of feasibility results.

III. OPTIMIZATION RESULTS

A. DISTRIBUTION NETWORK TEST AND POWER FLOW ANALYSIS

Voltage violations and power losses in low-voltage distribution networks are closely related to consumers' SCRs. This study uses Newton-Raphson power flow analysis to analyze the voltage fluctuation and losses due to the gradual and random increase in prosumer installed capacity on the IEEE European test network. The results clearly show the possible optimistic outcomes and power quality impacts of the individual and hybrid incentive mechanisms considered in this study. The results show that the overvoltage problem occurs in SCRs below 26%. It was found that up to 70% SCR can reduce the maximum voltage peaks by up to 18%, and values above 55% cause an increase in power losses. Voltage violations due to changes in the IEEE 906 bus low voltage distribution network (LVDN) SCRs are shown in Figure 3 for node 886. The analysis in the methodology section will be structured to clearly show the benefits of incentive mechanisms considering the LVDN results.

B. OPTIMIZATION RESULTS

Net billing (NB) can encourage prosumers to use batteries due to the lower selling price of electricity. In addition, prosumers can use RES on demand and sell excess electricity to the grid even if the electricity selling price is lower. The decline in clean energy investments and the resulting gradual reduction of the FIT has made NB a preferred option for the government. In this context, prosumer feasibility for NB by reducing TOUs in Türkiye has been evaluated technically, economically, and environmentally. On the other hand, storing excess electricity in the grid for the benefit of the prosumer and using it, especially during periods of high demand, saves on electricity bills. Therefore, NM is more profitable for prosumers than NB. Technical, economic, and environmental comparisons of NM and NB considering CTs are shown in Table 4. Due to lower grid sales under NB, Türkiye has low electricity purchase prices and can rely on traditional sources rather than high investment cost SLB. Therefore, the possible increase in CT could reduce CO$_2$ by up to 6.4%. However, the penalty on carbon emissions increases LCOE by up to 12.4% for NB and 30.65% for NM due to higher investment costs in NPC. While rises in NPC are not favorable for investors, an increase in RF by up to 8% and self-sufficiency by up to 3.3% reduces the DP by up to 1.8 years. Assuming demand

TABLE 5. NB's superiority over NM for the prosumer.

CT ($/t)	Increase						Decrease		Extend
	PV	*SLB*	*RF*	*SSR*	*NPC*	*LCOE*	*CO_2*	*SCR*	*DP*
0	5.5%	-	0.9%	0.65%	15.15%	12.90%	1.16%	1.73%	1.90 yr
100	26.11%	-	6.7%	2.70%	8.50%	-3.60%	4.65%	7.21%	2.02 yr

TABLE 6. Performance evaluation for NM considering SCR restriction (CT: 20 $/t, SCR: 10-90%).

SCR (%)	PV (kW)	SLB (kWh)	NPC (M$)	LCOE ($/kWh)	RF (%)	CO_2 (t/yr)	DP (yr)	ROI (%)	IRR (%)	CE (%)	SSR (%)
10	2000	-	3.86	0.036	89.60	140.62	20.00	-3.4	-	29.5	57.29
20	930	-	2.73	0.037	83.30	155.64	19.36	-2.3	-	4.65	52.73
30	570	-	2.51	0.049	73.70	169.21	13.51	-1.3	-	4.26	48.60
40	395	-	2.42	0.059	64.40	181.91	11.50	-0.2	-	3.69	44.75
50	290	-	2.38	0.067	56.10	194.16	9.98	1.0	1.80	1.90	41.03
60	215	-	2.42	0.077	47.40	208.42	8.84	2.2	3.60	0.63	36.69
70	160	-	2.57	0.089	38.60	223.85	8.21	2.9	4.80	0.16	32.01
80	120	-	2.81	0.102	30.60	239.39	8.14	3.0	4.90	0.13	27.29
90	80	-	3.06	0.115	21.20	262.06	8.08	3.1	5.10	0.09	20.40

does not change, curtailments will inevitably increase due to higher renewable capacity installations; therefore, the SCR will decrease by up to 10.1% for NB and 4.7% for NM. The SCR targeted for NB and NM policies can be achieved with higher PV, SLB capacity, and CT. However, RF and SCR are lower, and the total cost is 44% higher, making it non-competitive.

Table 5 compares the technical, economic, and environmental advantages of NB and NM without a CT and with a high CT. Blue indicates net billing, red NM superiority, and yellow neutral zone. In this case, NM is taken as the reference baseline. For example, how the advantages & disadvantages of NB over NM are shaped. The consumer trend is towards NM in red areas where NB is inferior. For NB, which is considered superior to NM, the - signs emphasize a decrease in the case of an increase and an increase in the case of a reduction. The benefits of the policy are reduced when the optimal limits of the CT are exceeded. Considering the lower electricity selling prices of the NB billing mechanism, clean energy is used in favor of the consumer. Thus, increased CT results in higher renewable capacity installations favoring NB, making NB's hegemony more dominant. However, high CT never encourages the usage of SLB. The advantage of up to 6.7% in RF is especially remarkable in the transition to clean energy. However, higher NPC and extended payback periods, especially in DP, lead to public opinion in favor of NM regarding economic performance. Although an increase in CT reduces the advantages regarding NPC, the payback period does not decrease as expected under Turkish conditions. The opposite is true for LCOE, as optimal carbon policy is exceeded due to an unfavorable high carbon tax. Overall, net billing leads prosumers to use as much electricity as they generate due to lower electricity selling prices, or excess energy can be sold to the grid even at a lower revenue. Therefore, a higher CT in this policy reduces CO_2 and SCR by increasing clean energy capacity and SSR.

The prosumers' technical, economic, and environmental analyses are compared in Table 6 according to the SCR limit. Prosumer benefits can be maximized with lower SCR, but the financial burden on governments increases and causes power quality problems in the distribution and transmission grid. Therefore, SCR below 30% will not ensure prosumer feasibility in line with the LVDN analysis. Prosumers in countries with lower electricity purchase prices, like Türkiye, have not adopted SLBs, even if they have reduced SCR. Also, higher clipped energy (29.5%) may not provide an effective optimal sizing. 50% SCR is the optimal decision threshold that minimizes NPC. Increasing the lower SCR to the optimal threshold based on the plans decreases the required PV capacity by 85.5% while reducing the curtailed energy by 27.6% and the DP by up to 10 years. However, increasing SCR would raise the promised energy cost by up to 86%, reducing the prosumers' interest in the policy. Worse, with renewable potential reduced by up to 33.5%, carbon emissions could increase by up to 38%, conflicting with clean energy targets. SCR limits above the optimal threshold result in worse feasibility outcomes.

Table 7 compares the technical, economic, and environmental aspects of prosumer feasibility considering FIT. Countries' policy shifts to gradually reduce the FIT due to declining renewable investment costs, reduced PV installation capacity, and increased grid dependency. Although grid dependency is decreased, inappropriate determination of the optimal FIT policy will cause unnecessary investments. However, power quality problems should not be caused at distribution busbars to improve the renewable potential. Therefore, SCR should be 30% at most. Considering economic benefits and grid constraints, an optimal FIT policy of 0.0274 $/kWh is proposed for Türkiye. Choosing the optimal FIT instead of the lowest FIT policy (0.02 $/kWh) increases PV capacity and, hence, initial investments by 90.8% but promises a lower NPC of up to 24.11%. However, due to

TABLE 7. Impact of FIT on prosumer feasibility (CT: 20 $/t).

FIT ($/kWh)	PV (kW)	SLB (kWh)	NPC (M$)	LCOE ($/kWh)	RF (%)	CO$_2$ (t/yr)	DP (yr)	ROI (%)	IRR (%)	SCR (%)	SSR (%)
0.02	364	-	2.67	0.0679	62.5	184.95	12.29	-0.7	-	42.63	43.82
0.025	476	-	2.59	0.0557	69.9	175.21	13.13	-1.2	-	34.80	46.78
0.03	753	-	2.45	0.0379	80.1	161.15	19.09	-1.8	-	24.02	51.05
0.035	1007	-	2.20	0.0273	84.8	153.70	19.12	-1.9	-	18.74	53.32
0.04	1078	-	1.92	0.0230	85.5	152.10	18.84	-1.7	-	17.66	53.80

TABLE 8. Impact of total investment subsidy on prosumers (CT: 20 $/t).

INV (%)	PV (kW)	SLB (kWh)	NPC (M$)	LCOE ($/kWh)	RF (%)	CO$_2$ (t/yr)	DP (yr)	ROI (%)	IRR (%)	SCR (%)	SSR (%)
0	326	-	2.71	0.074	59.0	189.2	11.93	-0.5	-	46.20	42.50
10	326	-	2.71	0.074	59.0	189.2	11.93	-0.5	-	46.20	42.50
20	326	-	2.71	0.074	59.0	189.2	11.93	-0.5	-	46.20	42.50
30	226	802	2.64	0.098	57.4	143.1	10.59	-0.6	-	88.38	56.43
40	230	850	2.55	0.095	58.5	139.1	10.24	-0.2	-	88.65	57.65
50	363	1500	2.35	0.083	82.2	63.05	17.03	-0.9	-	78.77	80.67

TABLE 9. Comparison of optimal individual incentive policies.

Incentive	CT ($/t)	SCR$_{\text{limit}}$ (%)	FIT ($/kWh)	INV (%)	PV (kW)	SLB (kWh)	NPC (M$)	LCOE ($/kWh)	RF (%)	CO$_2$ (t/yr)	DP (yr)	SCR (%)	SSR (%)
Net Billing	100	-	-	-	425	-	3.45	0.081	66.5	179.20	10.8	37.90	45.60
Net Metering (1)	100	-	-	-	337	-	3.14	0.084	59.8	187.93	8.78	45.11	42.91
Net Metering (2)	20	30%	-	-	570	-	2.51	0.049	73.7	169.21	13.5	30.00	48.60
Feed-In Tariff	20	-	0.0274	-	565	-	2.53	0.0484	74.2	169.48	13.64	30.39	48.52
Investment	20	-	-	50%	363	1500	2.35	0.083	82.2	63.05	17.0	78.77	80.67

investment costs, the payback period of capacity installations is extended by 5.2 years. A relevant proposal to accelerate investment in renewable energy within long-term policies increases RES by 11.3% and reduces carbon emissions by 10.25%. The goal of a self-sufficient consumer would be approached by 5.3%. However, considering that demand does not change, it can be emphasized that 12.7% of PV energy is not used efficiently compared to PV capacity. Higher FIT rates would significantly increase PV capacity, causing non-economic returns and financial imbalance.

The impact of the total investment cost on the technical, economic, and environmental outcomes of HPS was assessed, as shown in Table 8. A higher subsidy on the total investment cost increases clean energy investments. The above 20% investment subsidy for prosumers purchasing electricity at low prices could compensate for the high initial cost of SLB and increase SLB adoption. Expanding the investment subsidy above 40% will reduce the technical, economic, and environmental system benefits and complicate the efficient optimal sizing process. Considering that electricity prices and demand are unchanged, adopting the unnecessary investment subsidy does not increase PV capacity as much as expected (only 11.4%). Lower storage purchase prices lead to excessive capacity sizing, while higher investment costs in both PV and storage extend the payback period up to 5.1 years. Significantly increased storage capacity compared to PV capacity keeps the efficient utilization of PV energy production both in demand and guarantees up to 38% higher benefits. While higher investment subsidy rates are thought to bring countries closer to carbon neutrality, more extended payback periods would remove this attraction. To support SLB and avoid hindering economic development objectives, at least a 30% investment subsidy is proposed. At the optimal point, PV capacity can be assumed to be significantly reduced by SLB support, and the table shows that no investment subsidy policy causes an SCR of less than 30%.

A technical, economic, and ecological comparison of optimal individual incentive policies is shown in Table 9. Since considering SCR limits in NM changes the optimal incentive rates, two policies are defined for NM. Compared to other individual policies, the on-system investment subsidy policy promises an NPC up to 31.9% lower. Higher PV capacity offers prosumers up to 22.4% higher renewable potential and 66.5% lower carbon emissions. The system investment subsidy, the only policy incentivizing SLB deployment, improves the matching of increased storage capacity with PV capacity and demand. Thus, self-sufficiency rates increase by up to 37.8% and beneficial PV energy use by up to 48.8%. However, depreciation periods of up to 8.22 years due to initial costs will undermine confidence in the investment subsidy policy and encourage investors toward the NM policy. If lower energy prices are desired in the short term, adopting the optimal FIT policy is proposed, which results in savings of up to 42.4%, even though the payback period is high. As these proposals for investor benefits are based entirely on decision criteria, the interests of the grid operator, the prosumer, and eventually the nation should be considered. Limiting SCR to 30% would significantly increase the renewable potential, while the investment subsidy would maximize prosumer benefits at many points. Moreover, NM is reliable, improving economic benefits compared to NB. Still, due to its low renewable energy potential, the hybridization potential needs to be appropriately determined to consider policy measures or complement individual strategies' shortcomings. In this context, the benefit of hybridization with different policies should be determined to achieve optimal system performance. The NM policy is not compatible with NB and FIT because it manages prosumer economics differently and requires a new policy hybridization. Therefore, a total investment subsidy and CT integrated under NM can maximize prosumer benefits.

The impact of the hybrid incentive policy on prosumer feasibility is examined in the detailed sensitivity analyses in Figure 4. SLB capacity in the optimal configuration in Türkiye has increased with investment subsidies of 60% and above and CTs of 80 $/t and above. Moreover, low or high CT and total investment subsidies above 20% reduce the advantage of grid operators without providing optimal system design. Therefore, investment subsidies above 20% are not recommended. In addition, raising CTs without investment subsidies cannot affect SLB capacity and reduce grid dependency on energy supply. On the other hand, increasing the possible investment subsidies on the system in the low carbon tax policy affects the size, technical, economic, and environmental feasibility results more. Especially with the low carbon tax, the RF can increase by 39.7%, and the payback period can decrease by 3.12 years. However, the curtailed energy increases by up to 13.5% due to SCR and reduces by up to 21.9% due to increased PV capacity. In contrast, increasing the carbon tax at high investment subsidy rates does not significantly affect the optimal system performance. Instead, the hybrid system's electricity prices and total cost can increase by up to 12.7%, resulting in a sub-optimal system design with low economic performance. The higher price of the carbon tax, which is more beneficial at lower investment subsidy rates, is less dominant than the impact of the investment subsidy on the optimal feasibility results. Limiting the carbon tax could increase self-sufficiency by only 1.8%. It does not require implementing higher carbon prices of up to 3% for carbon emissions and up to 3.5% for RF. Considering the simultaneous increase of the carbon tax and the investment subsidy, the payback period could be shortened to 6 years. Moreover, with SLB, NPC can be reduced by up to 84.4% with minimal cost benefit. Despite the significant increase in renewable energy potential, a 13.2% growth of curtailed energy cannot be avoided. Also, proposing high-capacity installations in the current supply-demand relationship shows an inappropriate design.

Other perspectives require a focus on optimal breakpoints and their evaluation. Addressing the unit effect of relevant taxation and investment subsidy policies is also crucial. Finally, remarkable analyses are listed as follows:

- A 20% investment subsidy and increasing the carbon tax at the relevant rebate rates, except a 20% investment subsidy and a 20 $/t or 40 $/t CT, causes power quality issues due to lower SCR. Moreover, 40% and above investment subsidies cause the same problem independent of the carbon tax.
- A carbon tax higher than 60 $/t with a 60% investment subsidy significantly increases the NPC. The same applies to an investment subsidy above 60% in the carbon tax range of 20-60 $/t.
- Carbon tax policies of 80 $/t and above maximize SLB capacity when adopting a 60% investment subsidy. At 80% investment subsidy, capacity utilization is maximized independently of the carbon tax.
- If the investment subsidy is not implemented, higher carbon emissions will occur even if the carbon tax increases. If minimum carbon emissions are desired, this goal can be achieved under any carbon tax policy with an 80% investment subsidy or a carbon tax of 80 $/t and above, provided that the 60% investment subsidy is adopted.

As shown in Figure 4, a 20% total investment subsidy and a 40 $/t CT maximize the optimal prosumer benefit. In the optimal hybrid incentive mechanism, while using SLB is not possible, the 0.0525 $/kWh LCOE is guaranteed, and the PP is only 10.15 years. RF can be increased to 69.5% while carbon emissions are only 175.2 tons/yr. SCR is 34.8%, but the CE is only 1.5%.

IV. DISCUSSION

Neglecting the carbon tax in countries' zero carbon targets and energy economy plans, not evaluating different common policies, and relegating billing mechanisms such as net metering and net billing to the background does not guarantee a strong optimization plan. To properly assess the cost of reducing carbon emissions, a dynamic subsidy plan must also consider regional resource differences [74]. Given that subsidies for self-consumption were not considered in [75] and [76] and that no technical feasibility analysis was carried out, various additional policy proposals, such as capital subsidies and credit facilities [77], should also be considered. Storage needs to be included in investment subsidies for an appropriate self-consumption target. Considering SLBs as an alternative to high initial-priced batteries may facilitate economic goals favoring renewable penetration. However, the power quality problems in the common distribution bus caused by all these economic strategies should be evaluated by considering self-consumption rates. Many perspectives and power quality problems that are ultimately attributed are often ignored. On the other hand, some studies predict that the individual optimal incentive scenario will maximize profits and policy hybridization will not increase profits [45]. Especially noteworthy are the dynamic FIT subsidies, which

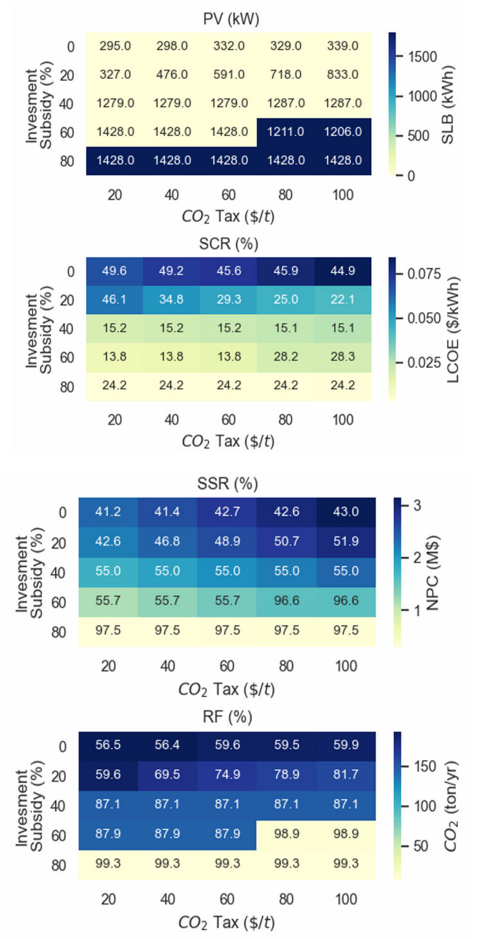

FIGURE 4. Effects of subsidy and carbon tax on net metering.

are updated yearly according to the retail price of goods and the relevant exchange rate, unlike FIT policies that do not change yearly and are based on electricity prices [71]. Focusing on economic interests while ignoring carbon emission concerns in incentive planning [45], [71] makes it difficult to achieve strategic financial goals. On the other hand, it would not be right to focus only on increasing renewable energy penetration or reducing environmental concerns, neglecting modern economic policies in the transition to a low-carbon society, as in [48]. Based on the relevant strategic objectives, this study investigated the technical, economic, and environmental effects of individual incentive policies such as feed-in tariffs, net metering, net billing, investment subsidy, and carbon tax. Optimal incentive plans that should be implemented individually and hybrid have also been determined. The results show that an optimal FIT policy of 0.0274 \$/kWh supports economic objectives in countries like Türkiye, where electricity purchase prices are low without causing power quality problems. A good knowledge of the country's economy is required to compare individual, or hybrid policies and the feasibility results obtained. Although the comparison environment cannot be fully established, 0.05–0.4 CNY/kWh in developed economies such as China [60] or 10.74–25.83 c/kWh [70] in other countries such as Australia is recommended for optimal FIT. However, considering the low electricity prices, the cost and carbon emissions advantage will be more prominent (CO_2 decreases by 5.3% and NPC by up to 24.11%). Planning an average increase of 0.0025 Yuan RMB/kWh in the direct cost of electricity generation can increase renewable penetration by up to 1% in Guangdong by improving the orientation towards FIT [76]. Considering that FIT policies will be gradually reduced and eventually canceled in the coming years, investment subsidies for the hybrid power system come to the fore. In Türkiye, where purchasing electricity from the grid is attractive, subsidizing the total investment by 1% will reduce environmental concerns by up to 892.35 kg/yr. Considering that under the 0.42 yuan/kWh incentive, the Chinese central government must subsidize 30% of the initial investments [78], total investment discounts above 50% are considered sufficient in Türkiye. Since providing investment subsidies would challenge the economic interests of governments, a traditional approach, such as a carbon tax, could be adopted. In this regard, while an 83 \$/ton carbon tax is required in more developed economies such as Korea regarding optimal feasibility performance [68], taxes are reduced by half in Türkiye. Above all, in China, which has a strong renewable infrastructure, a 30 yuan/ton carbon tax is sufficient to abandon coal-fired facilities [69]. The additional costs caused by CO_2 reduction to comply with net zero commitments also come to the fore. Enacting a 1 \$/ton carbon tax in Türkiye will increase residential PV capacity by 0.55 kW and reduce CO_2 by 72.28 kg/yr. In Tongli, CO_2 abatement costs increase by up to 79.22% to achieve 25% renewable penetration [48]. In northern Italy, specific government expenditures in the range of 157-174 €/tCO_2 can reduce CO_2 by up to 25%, although it increases consumer costs by 10% [73]. In Germany, under a 15 €/tCO_2 carbon tax, the marginal reduction cost of CO_2 is predicted to be 41 €/tCO_2 [75]. Additional costs will vary depending on different renewable energy technologies. Especially in countries such as Germany and Spain, extra costs of 411-1944 €/tCO_2 and 82-276 €/tCO_2 are estimated for solar and wind energy, respectively [20]. Another approach and the most critical first stage of reducing carbon emissions is implementing meter-based incentive strategies such as net metering and net billing to be applied to residents. Applying the relevant billing policies in Türkiye will promise LCOE to consumers in the range of 0.049-0.081 \$/kWh. Ultimately, considering the hybridization of all individual policies, integrating a 20% total investment subsidy and a 40 \$/ton carbon tax under a net metering policy will maximize technical, economic, and environmental performance. On the other hand, considering that researchers often neglect battery storage with high initial prices in economic plans, providing subsidies for the total investment is sufficient to adopt SLBs.

V. CONCLUSION AND FUTURE WORK

This paper evaluates the feasibility of prosumers using energy storage with shared SLBs in different individual or hybrid incentive policies. Within the scope of economic policies, net metering, net billing, feed-in tariffs, carbon tax, and investment subsidies are considered, while optimal sizing is realized with a minimum cost objective. The potential benefits of economic policies are maximized by simultaneous sensitivity analysis of carbon tax and investment subsidy. Moreover, power quality issues, especially from SCR, are considered, and unfavorable incentive policies are determined. Threshold and feasible economic policies that maximize the feasibility results are proposed.

The results show that the increase in carbon tax affects net metering more than net billing due to higher investment costs (e.g., the difference in LCOE is 18.3%). Even though it can increase the renewable energy potential by up to 6.7%, the net billing strategy is plagued by higher NPC and a more extended payback period, leading to public opinion favoring net metering. Choosing an optimal SCR limit of 50% provides an efficient utilization of PV energy based on capacity. It reduces clipped energy by up to 27.6%, shortening the payback period by up to 10 years. Another approach towards SCR limit, net metering, carbon tax, and net billing policies is the traditional FIT mechanism. The optimal FIT mechanism of 0.0274 $/kWh proposed under Turkish conditions ensures up to 24.11% lower NPC while bringing the self-sufficient consumer 5.3% closer to the carbon neutrality goal.

However, no policy supports using SLB so far. To encourage SLB deployment without undermining economic development objectives, an investment subsidy on the system cost of at least 30% should be implemented. While the advantages of individual incentive policies are undeniable, it is critical to determine the most appropriate policy measures or hybridization potential that will improve the feasibility results and consider the grid operator's concerns regarding power quality so that technical, economic, and environmental shortcomings can be addressed. To this end, a 20% total investment subsidy and a 40 $/t CT are proposed. Overall, the results prove, from many perspectives, the technical, economic, and environmental effects of individual and hybrid incentive policies for solving the climate crisis. A future study will provide a more comprehensive assessment of sustainable energy and environmental targets by evaluating the feasibility of incentive policies, individual or hybrid, addressing prosumer self-consumption for countries with different socio-economic and climatic characteristics.

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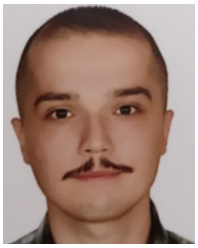

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