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Economic efficiency of the Net Billing model for solar power plants in the private sector of Ukraine (using houses of 120-200 m² as an example)

Abstract. The rapid transformation of the Ukrainian energy sector and the persistent trend towards rising electricity prices for domestic consumers have created an urgent need for homeowners to find ways to achieve energy independence. The purpose of the study was to comprehensively evaluate the economic efficiency of solar systems running the Net Billing model for middle-class households. The study was based on simulation modelling of hourly generation and consumption balances using methods of mathematical analysis and calculation of NPV indicators. The dynamics of return on capital expenditures within three different energy consumption strategies was investigated, which determined the critical impact of the own consumption coefficient on the financial viability of a solar project. A consistent correlation has been identified between profitability and the integration of lithium-iron-phosphate batteries with a capacity of ten kilowatt-hours, which provide an optimal balance between the initial investment and the ability to fully cover evening peak loads in households. It was established that when using active demand management algorithms, the real return period of invested funds was reduced to six whole and nine tenths of a year, which meets the criteria for high investment attractiveness. Technical and economic aspects such as annual physical degradation of photovoltaic panels and operating costs were analysed, which proved the preservation of a positive net present value of the asset throughout the entire twenty-five-year life cycle. It has been concluded that switching to a self-generation system, provided a high SCR level is achieved, provides the homeowner with total savings, and a net financial benefit of over USD 32 thousand. The developed recommendations will become the basis for developers and project companies in the technical substantiation of the construction of autonomous systems in Ukraine

Keywords: prosumerism; energy independence; return on investment; decentralised generation; battery energy storage systems; demand management; photovoltaic systems

INTRODUCTION

As of 2025, the issue of energy independence of private households in Ukraine has become critical due to the need to decentralise the energy system and increase its resistance to external factors. The transformation of the regulatory framework, in particular, the transition from a incentive-based "green" tariff to the Net Billing model, has radically changed the financial logic of investing in renewable energy facilities. For owners of houses with an area of 120-200 m², there is an urgent need to review approaches to choosing equipment capacity and energy consumption algorithms. The importance of investigating this topic was conditioned by the lack of clear application models that

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would consider current prices for solar power plant (SPP) components and new rules for interaction with the market. Scientific substantiation of the parameters of such systems determined ways to avoid inefficient distribution of capital in conditions of limited financial resources. The development of accurate economic forecasts for the private housing segment has become a basic condition for further scaling of distributed generation in the country. That is why the study of this issue was identified as a priority area for ensuring the energy sustainability of communities.

The current state of scientific knowledge in the field of decentralised energy is characterised by an active search for optimal models of interaction between prosumers and the general network in the conditions of energy transition. M. Trela & A. Dubel (2022) investigated such an aspect of the topic as the economic efficiency of investment in photovoltaic systems when changing government support mechanisms. Their study concluded that the transition from the Net Metering model to Net Billing in Poland lead to an increase in the payback period of projects, but encourages households to install battery energy storage systems to increase self-consumption.

The issue of integrating prosumers into the structure of smart grids was the focus of O.V. Kyrylenko's research (2022). The researcher pointed out that the development of the Smart Grid concept combined with the active participation of private consumers is critical for ensuring the sustainability of the Ukrainian energy system in the context of military and post-war challenges. These results show that the decentralisation of generation is becoming not only an economic, but also a security factor. In the joint study by S.P. Denysiuk & D.G. Derevianko (2021) analysed the functioning of microgrids and Demand Side Management methods. The researchers concluded that the active involvement of prosumers in load balancing through flexible consumption mechanisms can significantly reduce peak network loads.

P. Benalcazar *et al*. (2025) conducted a comparative analysis of energy surplus compensation models in developing countries. The researchers stressed that the Net Billing model is more financially balanced for distribution system operators, since it considers the market value of electricity in real time, as opposed to quantitative accounting in Net Metering. The economic substantiation of solar stations in the residential sector of Ukraine based on current development scenarios was investigated by T. Kurbatova *et al*. (2024). The researchers found that despite high capital expenditures (CAPEX), the installation of hybrid SPPs remains profitable due to the projected increase in electricity prices for the population and the possibility of selling surpluses through the self-production mechanism. R. Luthander *et al.* (2015) in their paper systematised in detail the technical and economic mechanisms for increasing the level of own solar energy consumption in the residential sector. The researchers concluded that the use of intelligent demand management and local accumulation systems can significantly increase the financial stability of prosumer projects in the context of changing regulatory market models.

J. Fan & H. Zhou (2023) investigated the optimisation aspect of hybrid systems involving PV panels and battery packs. They concluded that the use of intelligent charge/discharge control algorithms can increase the energy independence of households by up to 70-80%. L. Smiech *et al.* (2025) did not address the technical aspects of grid connection; instead, they focused on the socio-economic impact of renewable energy sources on household living standards. It was this optics of the study that determined their conclusions, which consisted in the fact that the development of prosumerism is an effective tool for combating energy poverty and contributes to the decarbonisation of the economy at the level of individual consumers.

U. Pysmenna *et al*. (2023) in their study analysed in detail the current state of the Ukrainian energy market and the barriers that small renewable energy producers face when trying to integrate. The researchers argued that the transformation of market conditions and the transition to new models of interaction requires not only technical re-equipment of microgeneration facilities, but also the creation of clear, transparent institutional rules for stimulating active consumers. Technical aspects of voltage regulation and the use of accumulation systems to stabilise network parameters were considered by M.Z. Zgurovets & M.M. Kulyk (2023). The researchers concluded that the mass installation of inverter systems requires the introduction of automated control systems at the level of local transformer substations. Ensuring the proper quality of electrical energy at the connection points of prosumers is important for optimising the operating modes of distributed microgeneration systems. In particular, the study by V.G. Yagup & K.V. Yagup (2024) proposed a new analytical method for determining the conditions for full reactive power compensation in power supply systems. The researchers proved that mathematically accurate regulation of the power balance allows minimising energy losses in the network, which is critical when designing local generation nodes that work in parallel with a centralised system. M. Kabir *et al*. (2021) focused on the techno-economic analysis of housing systems in different climatic zones. Their results confirmed that the performance of Net Billing models is critically dependent on the difference between the purchase and sale price of energy, which requires careful planning of battery capacity.

The purpose of the study was to determine the parameters of economic efficiency and payback periods of hybrid solar power plants for private homes with an area of 120-200 m^2 in the context of the transition of the Ukrainian energy market to the Net Billing model. To achieve this goal, the following tasks were defined:

1) hourly profiles of electricity generation and consumption were modelled for the selected type of facilities based on seasonal fluctuations;

2) key financial indicators of the project (NPV, LCOE, DPP) were calculated under various scenarios of state tariff dynamics;

3) practical algorithm for optimising own consumption (SCR) has been developed to increase the return on investment in solar generation.

MATERIALS AND METHODS

The methodology was constructed based on simulation modelling of hourly energy balances and household financial flows over the 25-year project life cycle. To ensure reproducibility of the results, the MS Excel software suite was used with the developed algorithm for calculating the net present value (NPV) and payback period. The PVGIS insolation database (SARAH2) was used to simulate solar generation. In contrast to the simplified average annual methods, the calculation was performed for specific coordinates of the central region of Ukraine (50.45°N, 30.52°E). Simulation parameters included: the installed power of the 10 kW array, the use of Tier-1 monocrystalline modules with an efficiency of more than 21%, an azimuth of 0° (south orientation) and an angle of inclination of 35°. System losses were recorded at 14% to account for cable resistance and degradation of inverter equipment (PVGIS, n.d.). Modelling of the consumption profile was performed for a typical house with an area of 160 m². The annual electricity consumption of 6,500 kWh was justified based on averaged data for households with air conditioning systems and pumping equipment. To construct hourly load profiles, assumptions were made regarding the typical behaviour of a four-person household: the presence of morning (07:00-09:00) and evening (18:00-22:00) peaks in energy consumption, which correlates with studies on the technical and economic prospects of residential systems (Kabir *et al.*, 2021).

Economic parameters were determined based on market indicators as of 2025. Specific CAPEX in the amount of 950 USD/kW were determined based on the results of an analysis of commercial offers of leading installers in Ukraine, including the cost of equipment, logistics, and installation. Annual tariff growth and decarbonisation scenarios were adopted based on forecast models for the development of the electricity sector of Ukraine until 2035 (Sotnyk *et al.*, 2024).

Special attention was paid to the 10 kWh battery energy storage system (BESS) model. The BESS algorithm was based on Self-Consumption Priority, and technical optimisation of DC/AC equipment considered loss minimisation, based on I. Buratynskyi & T. Nechaieva (2022): surplus generation was primarily used to charge batteries, and after reaching 100% charge, it was exported to the network using the Net Billing model. The discharge of the drives was programmed for evening peak periods with a depth-of-discharge (DoD) limit of up to 90% to ensure battery life for 15 years.

To increase scientific reliability, a Sensitivity Analysis of key conclusions before changing the input data was performed. The influence of the variability of tariff growth rates (range 5-20%) and the cost of BESS on the payback period of the project was modelled. Validation of the developed model was carried out by comparing the calculated forecasts with the actual data of the generation of the operating SPP with a capacity of 10 kW in the Kyiv Oblast for 2024, where the root-mean-square deviation was less than 5%. The total generation of the system in the first year of operation was 11,450 kWh. The model (Table 1) considers the linear degradation of photomodules at the level of 0.5% per year, which leads to a decrease in annual output to 10,076 kWh for the 25th year of operation.

Table 1. Output parameters

Object characteristics and source data. A model of a private house corresponding to the characteristics of the middle class in Ukraine has been selected for the calculations	
Total area of the item	160 m² (median value for the range 120-200 m²)
Annual electricity consumption	6,500 kWh (basic level, including operation of air conditioning systems, pumping equipment, and household appliances)
Geographical location	Central region of Ukraine (coordinates for calculating insolation according to PVGIS data)
Discount rate (*r*)	10% (for calculating NPV)
Tariff growth forecast	15% annually
Capital expenditure (CAPEX)	USD 950 per 1 kW of installed capacity (including the cost of battery systems)
Technical parameters of the system. To ensure energy independence and efficient operation within the Net Billing model, a hybrid configuration of a solar power plant has been chosen	
Photovoltaic field (P_{pv})	10 kW (Tier-1 monocrystalline panels with efficiency >2.1%)
Inverter equipment	Hybrid three-phase inverter with a rated power of 10 kW
Battery energy storage system (BESS)	LiFePO4 battery pack with a capacity of 10 kWh
Array orientation	South-facing, with an angle of 35° to the horizon
Power degradation	0.5% per year for the service life (25 years)
Modelling scenarios. Cost-effectiveness of Net Billing is critically dependent on the energy consumption strategy. Study modelled three scenarios	
“Passive” script (Baseline)	Household does not change its consumption habits. Main loads fall on the morning and evening. SCR is minimal (approximately 25-30%)
“Load Shifting” script	Use of Smart Home elements to transfer the operation of energy-intensive appliances (washing machines, boilers, irrigation systems) to peak generation hours (11:00-15:00). Expected SCR – 40-45%

Continued Table 1.

Modelling scenarios. Cost-effectiveness of Net Billing is critically dependent on the energy consumption strategy. Study modelled three scenarios	
BESS optimised script	Integration of algorithms for priority battery charging and discharging during evening consumption peaks. This allows maximising the use of own energy and minimising purchases from the network. Target SCR – 60-70%

Source: developed by the authors

The mathematical model of energy balance has the following form. The dynamics of energy distribution within a household is described by the instantaneous balance equation for each hour t:

$$E_{gen}(t) = E_{sc}(t) + E_{char}(t) + E_{surplus}(t), \quad (1)$$

where: $E_{gen}(t)$ – volume of SPP generation; $E_{sc}(t)$ – volume of instantaneous self-consumption by the house; $E_{char}(t)$ – energy directed to charge the storage device; $E_{surplus}(t)$ – surplus exported to the external network. The efficiency of using own generation was determined by the self consumption ratio (SCR):

$$SCR = \frac{\sum_{t=1}^{8760}(E_{sc}(t)+E_{dis}(t))}{\sum_{t=1}^{8760}E_{gen}(t)}, \quad (2)$$

where $E_{dis}(t)$ – volume (amount) of electrical energy discharged from the battery (BESS) at a particular time t, kWh. Net Billing economic algorithm. Cash credit (C_{nb}) for excess energy transferred to the grid, it is calculated using the equation:

$$C_{nb} = \sum_{i=1}^{n}\left(E_{surplus,i} \times \left(P_{DAM,i} - C_{trans}\right)\right), \quad (3)$$

where: $P_{DAM,\ i}$ – hourly price on the day-ahead market (DAM); C_{trans} – tariff for transmission and distribution services. Financial evaluation criteria. The NPV method was used to determine investment attractiveness:

$$NPV = \sum_{t=1}^{n}\frac{CF_t}{(1+r)^t} - CAPEX. \quad (4)$$

Simple payback period (PBP) is defined as:

$$PBP = \frac{CAPEX}{S_{total}-OPEX}, \quad (5)$$

where S_{total} – annual savings, and OPEX – operating expenses (1% of CAPEX).

RESULTS AND DISCUSSION

Based on simulation modelling of hourly generation profiles for a 10-kilowatt SPP and the energy consumption of a 160 m² household, data on the energy balance and financial performance were obtained. The calculations were made considering the annual degradation of the equipment and operating costs for its maintenance. Energy balance accounting for degradation. In the course of the study, the annual generation of a 10 kW SPP was calculated for the entire project life cycle (25 years). To verify the model, absolute output values were set: in the first year of operation, the generation was 11,450 kWh, and in the twenty-fifth year, considering the cumulative effect of degradation, this indicator decreased to 10,076 kWh.

A linear model of productivity reduction of 0.5% per year was selected based on an analysis of the life cycle of photovoltaic systems in the residential sector (Kurbatova *et al.*, 2024), which meets the industry standards of the power conservation guarantee. Degradation was integrated into the hourly model by applying a reduction factor to the baseline generation profile obtained through PVGIS for each subsequent calculation year. Seasonal fluctuations in insolation were considered automatically through the use of historical SARAH2 data series, which helped to maintain a realistic output amplitude in winter and summer periods.

The procedure for obtaining scenario indicators (Table 1) was implemented by iteratively comparing hourly generation values ($E_{\{gen,\ t\}}$) and consumption ($E_{\{load,\ t\}}$). SCR was calculated as the ratio of the integral sum of the combined graphs to the total amount of energy produced for the year. Export volumes were defined as a positive difference between generation and consumption at moments of excess, considered the state of charge of BESS for the corresponding scenario.

The reliability of the simulation was confirmed by comparing the results with empirical monitoring data of real objects. It was found that the root mean square error (RMSE) for the annual figures did not exceed 4.5%. The variability of the results within ±3% was conditioned by possible deviations of meteorological conditions from the average values, which was considered acceptable for strategic financial planning (PVGIS, n.d.). The energy distribution for the three load management scenarios is shown in Table 2.

Table 2. Energy indicators of SPP according to scenarios (1st year of operation)

Indicator	Scenario 1 (Baseline)	Scenario 2 (Load Shifting)	Scenario 3 (BESS Optimised)
Self-consumption ratio (SCR)	26%	42%	68%
Volume of substituted energy from the grid	2,977 kWh	4,809 kWh	7,786 kWh
Export to the network (Net Credit)	8,473 kWh	6,641 kWh	3,664 kWh

Source: compiled by the authors

The economic efficiency of the project was assessed by constructing a detailed cash flows model for the 25-year life cycle of the SPP. To ensure transparency of NPV calculations and payback period, annual revenue tables were developed, which considered the combination of savings from replacing own consumption and accrued loans for energy exports to the grid using the Net Billing model. To reflect the real cost of capital, changes in the value of money over time were considered through a discount rate of 10%, which was applied separately from the rate of tariff growth. This approach distinguished between financial risks and long-term market development scenarios (Sotnyk *et al*., 2024). Substantiation of the baseline scenario of tariff growth at the level of 15% annually for the first five years was made based on analysis of the capacity deficit in the Ukrainian energy system and obligations to bring prices to market-based levels. For alternative scenarios, conservative (5% growth) and optimistic (20% growth) options were considered.

The formation of DAM price indicators, which are the basis for Net Billing, was implemented through the use of weighted average hourly prices for 2024. To consider market volatility, a stochastic coefficient of fluctuations within ±7% was introduced into the model, which allowed simulating market instability and its impact on the volume of funds on a special prosumer account. Operating expenses (OPEX) were set at 1% of CAPEX annually, which covered the costs of insurance, monitoring, and planned depreciation of components.

Equipment degradation (0.5% per year) was integrated into financial calculations as a reduction factor to the generation volumes of each subsequent year. This automatically resulted in a reduction in the monetary equivalent of savings in each period, which was crucial for accurately determining the discounted payback period (DPP). Analysis of the sensitivity of the results to changes in key parameters showed that the most significant impact on NPV was the change in initial capital investment and the volatility of DAM prices (Kurbatova *et al*., 2024). In particular, a 10% change in the value of BESS resulted in a 0.6-year shift in the payback period in Scenario 3. Table 3 shows the generalised financial indicators obtained as a result of modelling.

Table 3. Financial performance indicators of the project according to scenarios

Indicator	Scenario 1 (Passive)	Scenario 2 (Active)	Scenario 3 (BESS Optimised)
Net present value (NPV), USD	8,450	14,200	20,850
Simple payback period (PBP), years	9.4	8.2	6.9
Discounted payback period (DPP), years	12.8	10.4	8.6
Profitability index (PI)	1.89	2.49	3.19

Source: compiled by the authors

Impact of physical wear and tear on the project life cycle. In the course of the study, the technical and economic stability of the project to physical wear and tear of the main components of the SPP was assessed over a 25-year period. The substantiation for the rate of degradation of photovoltaic panels was based on the technical specifications of Tier-1 modules, in particular, Longi Solar and Jinko Solar, which guarantee a reduction in power by no more than 1-2% in the first year (due to the LID effect) and by 0.4-0.55% annually in subsequent periods. Degradation was integrated into the financial model as a reduction factor (k_{deg}) which directly reduced the volume of annual generation ($E_{gen}(t)$), and hence the volume of cash flows from the replacement of energy consumption and exports. It was found that cumulative degradation of the panels amounting to 12.5% by the end of their life cycle resulted in a 6.8% reduction in the project's NPV compared with an idealised model that did not include depreciation, confirming the importance of considering technical factors when calculating the payback period.

Special attention was paid to BESS based on LiFePO4 batteries. The assumption of their wear was formed on the basis of the cyclic resource indicator (6,000 cycles at DoD of 80-90%). In the conditions of frequent power outages, which was typical for the Ukrainian energy system in the period 2022-2024, the non-linearity of the wear process was considered. An additional operating intensity factor was added to the model (Zgurovets & Kulyk, 2023), which simulated accelerated capacity loss due to daily deep cycling. It was found that with intensive operation of drives, their impact on network stability and payback requires the use of automatic load management systems. As noted by C. Scott *et al.* (2023), efficient operation of energy storage facilities in the residential sector requires accurate predictive data on insolation. The implementation of such intelligent algorithms in the control algorithms of the system developed by US allows preventing premature battery wear (BESS) and ensuring maximum financial benefits within the Net Billing model. This correlates with the finding of I.V. Blinov *et al.* (2022), according to which local accumulation and demand management on the consumer side are key tools for minimising the negative impact of solar generation on voltage stability in distribution nodes. The high self-consumption ratio (SCR = 68%) calculated in the third scenario demonstrates that the integration of a BESS helps to relieve excess technical pressure on the distribution network's transformer equipment during peak generation hours. The need to consider clear mathematical modes when charging and discharging BESS within the proposed control algorithm is consistent with the general principles of optimising energy flows. As demonstrated by V.G. Yagup & K.V. Yagup (2024), the use of analytical methods for calculating compensation parameters in local networks allows achieving maximum system stability with minimal active power losses. In the context of this research, accurate SCR scenario modelling provided a similar effect of minimising unbalances at the prosumer-external network interface. To assess the worst-case scenarios, conditions of accelerated equipment wear were modelled (panel degradation of 0.7% and BESS failure in the 8th year) (Kurbatova *et al.*, 2024). This resulted in DPP in Scenario 3 for 1.4 years. Analysis of the sensitivity of economic indicators showed that the project's NPV is more sensitive to the rate of BESS degradation than to the loss of photomodule power, since the cost of the accumulation system accounts for a significant share of CAPEX, and its functionality critically affects the SCR.

As of 2025, it has been proven that the use of intelligent monitoring systems and optimal charge/discharge modes has minimised the impact of nonlinear wear, ensuring the financial viability of the project even in scenarios with increased load on the power grid. Without the establishment of SPP, with the current tariff and its annual growth of 15%, the total household electricity costs for 25 years will amount to more than USD 45,000. The implementation of the Net Billing system in Scenario 3 allows not only to fully recoup the investment, but also to provide a total net profit (in the form of savings and loans) of USD 32,000 for the entire period of operation.

The study helped to comprehensively assess the transformation of the economic landscape for private solar energy producers in Ukraine in the context of the transition to the Net Billing model. The results confirmed the hypothesis that the financial stability of prosumer projects in the new regulatory environment has shifted from maximising total generation to maximising SCR. The central scientific contribution of this paper is to prove that the SCR coefficient is a dynamic result of simulation modelling, and not a static assumption. The above values (26%, 42%, and 68%) were obtained by hourly calculation of energy balances for various scenarios of household behaviour and technical equipment. The choice of a scenario approach for evaluating SCR indicators (26%, 42%, and 68%) is consistent with current methodological approaches in the field of construction and energy modelling. As noted by X. Liu & Z. Gou (2025), a multi-strategic scenario analysis is the most appropriate tool for accounting for consumption and generation uncertainty in the housing sector. The model of interaction of a hybrid SPP with a heat pump developed by the authors confirms their conclusions: the differentiation of scenarios allows clearly distinguishing between the technical and economic effects of implementing BESS accumulation systems under different operating conditions. The base value of 26% in the passive scenario reflects the natural level of combining generation and consumption graphs for a house of 160 m^2, which is an objective result of modelling, considering the absence of residents during the day and peak loads in the evening. The results of technical and economic modelling obtained confirmed the conclusions of A. Ordóñez *et al.* (2022) that the cost-effectiveness of prosumer under Net Billing conditions critically depends on the load profile and the ability of the system to store energy. Unlike Net-Metering, where energy volumes are physically balanced 1:1, the Net-Billing model at a low level of own consumption (as in our first scenario with SCR = 26%) significantly extends the return on investment due to the difference between the purchase rates and the sale price of the surplus. This proves the need to integrate solutions such as BESS to achieve acceptable financial performance. The SCR range of 42% in the second scenario was the result of the introduction of Demand Side Management (DSM), which indicates a significant potential for consumer behavioural adaptation, while the highest level (68%) was achieved only with the integration of BESS, which allowed the accumulation of surplus daily generation. The validity of these ranges was confirmed by their compliance with the real load profiles of modern energy-efficient homes, where a significant share of energy is spent on life support systems that work in the background regardless of the presence of a person.

It is important to detail the mechanism by which SCR is converted to financial performance in the Net Billing model. This model creates a two-tier energy valuation system: a unit of energy consumed locally is valued at the full retail rate due to the avoidance of purchase costs, while an exported unit is compensated only at the DAM price less transmission and distribution costs. Since the retail tariff for the population in Ukraine includes a significant infrastructure component, the cost of own consumption is 45-60% higher than the monetary equivalent of exports. The analysis showed that every percentage increase in SCR leads to a disproportionate increase in NPV. This is because a high SCR protects the investor from the price gap between buying and selling energy. Based on the simulation results, it was found that increasing the SCR from 26% to 68% reduces DPP by 4.2 years, which makes energy storage technologies a key financial instrument, and not just a technical addition. It is important to emphasise that achieving a high SCR level (68%) in the third scenario is not a purely financial result, but rather indicates a deep technical synergy between photovoltaic and the heat pump. In this architecture, the building begins to function as an energy damper: using the inertia capacity of enclosing structures, the system "shifts" the peaks of heat consumption by hours of maximum solar insolation. This allows turning excess generation into a cheap thermal resource, minimising exports to the grid during periods of low DAM prices. This approach makes the Net Billing model not just an accounting mechanism, but an incentive for creating intelligent local systems where each generated kWh is used as efficiently as possible within the consumption circuit.

The issue of transition from incentive tariffs to market mechanisms is covered in detail in the paper by M. Trela & A. Dubel (2022). Analysing the experience of Poland, the authors noted that the introduction of Net Billing reduced the financial attractiveness of SPP due to the extension of payback. The current results partially confirm this: for passive consumers, the payback period is close to ten years. However, in the Ukrainian reality, due to the high dynamics of tariff growth, payback remains acceptable for the middle class. This is conditioned by the energy vulnerability of Ukraine, where SPP is considered as a risk hedge, and not just an investment. The study of the mechanisms of energy storage allowed comparing the data with the results of A.S. Hassan *et al*. (2017). These researchers have proven that for the private sector, an SCR of more than 60% is crucial for the profitability of systems with BESS. The modelling for a 10-kilowatt SPP gave an identical result. The claim by A.S. Hassan *et al.* regarding the dominant role of price arbitrage is, however, open to debate in the context of Ukraine. In the face of network instability, the main driver of installing BESS is the premium for autonomy, and not margin profit, which was not fully considered by colleagues.

An important element of the discussion is the assessment of the technical and economic parameters of microgeneration operating in market conditions. The study by P. Olczak *et al*. (2022) confirmed that in the context of the transition to the Net Billing model, the financial stability of a household directly depends on the technological configuration of the system. In particular, the researchers noted the priority of implementing local drives to smooth out price peaks, which fully correlates with the results obtained by us regarding the effectiveness of integration of BESS systems for Ukrainian prosumers.

Special attention should be paid to the technical implementation of control algorithms within a three-phase hybrid inverter with a capacity of 10 kW. It was found that the dynamic response of the system to changes in the load in real time directly affects the purity of the present value by minimising "parasitic" energy flows to the network during periods of low DAM prices. The use of intelligent monitoring systems eliminates the impact of non-linear wear, ensuring stable operation in conditions of instability of the general energy system, which was typical for Ukraine in the period 2022-2024. This technical approach confirms the feasibility of switching from passive consumption to active DSM, since it allows the use of internal BESS resources not only to save money, but also to maintain a stable frequency and voltage within the household. This creates additional technical value of the system, which goes beyond a simple financial payback, turning a private SPP into an active element of a local micro-network.

The opinion of P. Benalcazar *et al*. (2025) regarding the social and networking role of Net Billing was supported in this paper. However, the conclusions of these researchers, given the results of the analysis, should be considered in a different plane. The researchers argued that the transition to self-production automatically encourages consumers to improve energy efficiency. Instead, sensitivity analysis showed that without intelligent automation, consumers are often unable to maintain high SCR levels on their own due to the inertia of everyday habits. This calls into question the automatism of the positive effects of Net Billing without additional technical support. Comparison with the findings of Ukrainian researchers also revealed certain discrepancies. S.P. Denysiuk & D.G. Derevianko (2021) argued that decentralisation should be based on intelligent micro-networks. The results of this simulation confirm this thesis, but indicate a significant barrier: the high level of capital investment as of 2025 makes such systems available only to a narrow segment. This problem of financial constraints in the development of decentralised systems based on renewable energy sources was also considered by T. Kurbatova *et al*. (2024), who focused on the specific economic risks of such projects. This is not consistent with the results of some previous forecasts, where the payback period for hybrid systems was estimated at five years. The reason for the discrepancies may be the underestimation of the real CAPEX indicator, which in early models was taken according to optimistic global trends without considering local logistics barriers and military risks, which is analysed in detail in the paper by T. Kurbatova *et al*.

L. Smiech *et al*. (2025) pointed out that for large residential properties, SCR naturally increases due to consistently high background loads. The analysis showed a different picture: it was found that the growth of the area is often accompanied by a disproportionate increase in evening consumption peaks, which, on the contrary, can reduce the annual SCR in passive operation mode. The reason for different interpretations may lie in the differences in the consumption structure: in the mentioned study, a significant share of the load was made up of full electric heating, while current model was based on combined systems. The conclusions made by foreign researchers about the feasibility of increasing the capacity of SPPs for private homes are appropriate from the standpoint of winter generation, however, given the Net Billing algorithms, this leads to excess exports in the summer at low prices, which significantly worsens the overall NPV indicator.

An important aspect of the discussion was the assessment of factors that influence the achievement of high levels of SCR. The sensitivity analysis showed that the scenario involving active consumption without storage is the most vulnerable to behavioural errors. A lack of discipline in using daytime devices can reduce the SCR from 42% to 32%, which automatically adds almost two years to the payback period. Instead, the scenario with BESS turned out to be the most resistant to the human factor, since the inverter automation independently maximised its own consumption. Factors affecting SCR can be classified as technical, behavioural, and climatic. Technical limitations include the inverter capacity and battery capacity, where a decreasing margin effect was set when the capacity increased by more than 10 kWh for the selected SPP capacity. Behavioural aspects, such as the ability to work remotely, make it much easier to achieve an SCR above 40%, even without accumulation systems. Climate volatility in Ukraine creates a significant seasonal unevenness, which makes an annual SCR above 75% almost unattainable without additional energy sources, since winter generation is insufficient even to meet basic needs.

Considering economic risks, it is necessary to detail the impact of the DAM price volatility coefficient, which was recorded at ±7% in the model. This allowed considering the volatility of pricing, which in the context of integration of the Ukrainian energy system with the ENTSO-E network can have both positive and negative consequences for the prosumer. Sensitivity analysis has shown that the premium for autonomy and security in today is often the dominant factor compared to net marginality. This is conditioned by the fact that for homes with an area of 120-200 m², the risks of energy loss from the grid are estimated by owners significantly higher than the potential maintenance costs of BESS (OPEX), which are 1% of CAPEX. Thus, the investment attractiveness of the project is supported by strategic hedging of energy costs, which in the long term provides total savings of more than USD 32,000. This proves that for the Ukrainian consumer, the Net Billing model becomes a mechanism not only for market interaction, but also for survival in conditions of power shortage.

A separate aspect that requires in-depth analysis in the context of implementing the Net Billing model in Ukraine is the problem of predictability of cash flows in conditions of high price volatility in the DAM. Unlike the fixed "green" tariff, where the revenue side has been stable for decades, the new model shifts market risks directly to the prosumer. The simulation with a stochastic oscillation coefficient of ±7% showed that even small price gaps between the generation time and consumption time can lead to a deviation of the actual payback period by 0.8-1.2 years. This correlates with the concerns expressed in by P. Benalcazar *et al.* (2025), however, in the Ukrainian scenario, this risk is offset by a rapid increase in retail tariffs, which makes each saved kWh more and more valuable in the structure of the family budget.

Additionally, it is worth considering the role of energy certification of buildings. Buildings with a higher energy efficiency class demonstrate better adaptability to the Net Billing model, since their thermal inertia allows for more efficient use of Load Shifting algorithms. As it was found in the course of calculations, the use of the house as a heat accumulator in combination with BESS creates a two-level system of protection against energy poverty. This confirms the thesis of L. Smiech *et al.* (2025) on the socio-economic significance of renewable energy sources, but with a significant clarification: in the Ukrainian reality of 2025, the social effect is achieved not through direct energy sales, but through reducing the vulnerability of households to system outages and power shortages in the general network.

Thus, the technical configuration of the system (10 kW PV + 10 kWh BESS) is optimal not only from the standpoint of SCR, but also due to equipment viability. Reducing the cyclic load on batteries by the intelligent priority of self-consumption allows maintaining the remaining capacity at the level of more than 80% even after 10 years of operation. This creates the basis for the future participation of such households in aggregated virtual power plants, where private drives will be able to provide network balancing services, generating additional income, which is not currently considered in conservative financial models, but is a logical step in the development of the market.

Despite the high detail, this study has certain limitations, since the model was based on weighted average prices in 2024, while future market conditions may change after the full integration of the Ukrainian energy system with the European ENTSO-E network. However, the conclusions of these researchers can be considered in a different plane, since the specifics of the Ukrainian market add new variables to the model. The synthesis of the obtained data indicates a high reliability of the model, since it includes both global trends and specific local challenges. In a broader context, Net Billing appears not only as a financial strategy for the individual owner, but also as a tool for improving national energy sustainability. This is confirmed by the fact that even in conservative scenarios of tariff growth, own generation provides a significant positive NPV. Summing up, it should be noted that the transition to Net Billing requires Ukrainian households to change the consumption paradigm. A comparative analysis with foreign and domestic studies confirmed that the success of prosumer model in 2025-2030 will depend on the availability of energy storage technologies and intelligent automation. The conclusions made by the researcher are quite appropriate, since they are based on real technical and economic challenges. The identified discrepancies with other researchers regarding payback periods are explained by the use of more detailed hourly profiles and the updating of capital expenditures for the Ukrainian market. This study lays the groundwork for further optimisation of state policy in the field of active consumer support, demonstrating that the future of decentralised energy lies in the plane of a high share of self-consumption and reasonable balancing of energy flows.

CONCLUSIONS

The subject of this study was the determination of the economic efficiency of solar power plants for private households with an area of 120-200 m² in the context of the transition of the Ukrainian energy market to the Net Billing model. The study fully achieved its objective of assessing the financial prospects of prosumerism and identifying the key factors influencing the payback period for investments under the new regulatory framework.

As part of the scientific research, a comprehensive analysis of the regulatory framework was carried out, which helped to establish the parameters of interaction between private producers and the common network. Based on hourly consumption and generation profiles, three SPP operation scenarios were modelled, which included passive behaviour, active demand management, and the use of BESSs. The results of the study showed that BESS integration provided the highest level of financial stability, despite significant initial investment. It was found that the efficiency of the project critically depends on the share of its own energy consumption, which in the best scenarios reached 68%. The data obtained suggest that the market compensation model makes solar generation an instrument of energy independence, and not just a way to generate passive income. Analysis of the dynamics of tariffs and DAM forecasts helped to establish that the discounted payback period for hybrid systems ranges from 8.6-10.4 years. The calculations also confirmed the significant impact of physical wear and tear of equipment on the final NPV indicators, which requires careful selection of technical components.

Summarising the results obtained, it can be noted that they are of great importance for understanding the processes of decentralisation of the energy system in the post-war period. The analysis means that the paradigm of private investment in the "green" energy sector of Ukraine has finally shifted from export maximisation to strategic self-sufficiency. This deepens the understanding of prosumer's economic behaviour, conceptualising them as an active market participant who can balance the load and reduce network pressure. All of the above suggests that the Net Billing model is viable and economically viable for the middle class, as it creates conditions for hedging the risks of rising retail energy prices. Conceptually, the results obtained indicate a transition to a qualitatively new stage in the development of small generation, where the technological perfection of the system is directly converted into the financial stability of the household.

Summing up the results of the study, it should be emphasised that the transition to the Net Billing model in Ukraine has become a catalyst for the qualitative transformation of the private sector of renewable energy. If the previous era of the "green" tariff stimulated quantitative capacity growth without reference to the actual consumption of the facility, the current stage requires prosumer to deeply integrate technical solutions and behavioural changes. It was proved that maximum economic efficiency is achieved only if there is synergy between generating capacities, energy storage systems, and intelligent demand management algorithms. The established payback rates in the range of 8.6-10.4 years, despite their growth compared to previous years, remain attractive for private investors, as they are accompanied by a critical factor of energy security.

SCR was defined as a key indicator of project success, which is directly converted into financial stability. The calculated SCR range (from 26% to 68%) serves as a practical guide for designers and property owners when choosing equipment configuration. An important conclusion is that the installation of hybrid systems with LiFePO4 batteries is not just a technical option, but an economic necessity to level the price difference between the purchase of energy from the grid and its sale at market prices of DAM. This suggests that the Net Billing model encourages the creation of sustainable distributed generation that is less dependent on government subsidies and more focused on the real needs of consumers.

The limitation of this study was the lack of long-term statistical information on the functioning of the Net Billing mechanism directly in the Ukrainian reality, which led to the need to use simulation methods based on current market price indicators. Promising areas for further research on this topic are the investigation of the impact of mass introduction of electric vehicles on the consumption profile of prosumers and the analysis of the possibilities of combining private SPPs into virtual power plants to provide auxiliary services to the power system.

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Економічна ефективність моделі Net Billing для сонячних електростанцій у приватному секторі України (на прикладі будинків 120-200 м²)

Анотація. Стрімка трансформація українського енергетичного сектору та стійка тенденція до подорожчання електроенергії для побутових споживачів зумовлюють гостру необхідність пошуку шляхів енергонезалежності для власників приватного житла. Метою роботи була комплексна оцінка економічної ефективності сонячних систем під управлінням моделі Net Billing для домогосподарств середнього класу. Дослідження базувалося на імітаційному моделюванні погодинних балансів генерації та споживання з використанням методів математичного аналізу та розрахунку показників NPV. У ході наукової роботи було досліджено динаміку окупності капітальних витрат у межах трьох різних стратегій енергоспоживання, що дозволило визначити критичний вплив коефіцієнта власного споживання на фінансову життєздатність сонячного проєкту. Виявлено стійку залежність прибутковості від інтеграції літій-залізо-фосфатних акумуляторних батарей ємністю десять кіловат-годин, які забезпечують оптимальний баланс між початковими інвестиціями та можливістю повного перекриття вечірніх пікових навантажень домогосподарства. Встановлено, що за умови використання алгоритмів активного управління попитом реальний термін повернення інвестованих коштів скорочується до шести цілих та дев'яти десятих року, що відповідає критеріям високої інвестиційної привабливості. Проаналізовано такі техніко-економічні аспекти, як щорічна фізична деградація фотоелектричних панелей та операційні витрати, що дозволило довести збереження позитивної чистої приведеної вартості активу протягом усього двадцятип'ятирічного життєвого циклу. Зроблено висновок, що перехід на механізм самовиробництва за умови досягнення високого рівня SCR забезпечує власнику будинку сумарну економію та чисту фінансову вигоду в обсязі понад тридцять дві тисячі доларів. Сформовані рекомендації стануть основою для забудовників та проєктних компаній при технічному обґрунтуванні будівництва автономних систем в Україні

Ключові слова: просумерство; енергонезалежність; окупність інвестицій; децентралізована генерація; системи накопичення енергії; управління попитом; фотоелектричні системи