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DETERMINATION OF THE OPTIMAL "GREEN" TARIFF RATE FOR REMOVING SOLAR POWER PLANTS FROM THE BALANCING GROUP OF "GUARANTEED BUYER" STATE ENTERPRISE

Abstract. The article examines the mechanism and funding of the "green" tariff in Ukraine, whose primary goal is to increase the share of electricity generated from renewable energy sources (RES) in the overall energy system balance. The functioning of the State Enterprise "Guaranteed Buyer" (GarPok), which serves as the main purchaser of electricity under the "green" tariff, is described, along with the sources of funds for the payment of this tariff, such as transmission fees, financial support from the state budget, and revenues from the sale of guarantees of origin. The current state of "green" tariff financing and its associated challenges, including the National Energy Company "Ukrenergo" debt to GarPok and the absence of revenue from the sale of guarantees of origin, are analyzed. The paper also discusses aspects of RES generation exiting GarPok's balancing group, including the opportunities for selling electricity on various markets. The results of an analysis of the efficiency of RES generation in the electricity market are presented, and the minimum green tariff level at which renewable energy generation exits the balancing group of SE "Guaranteed Buyer" is determined. The number and installed capacity of generation facilities operating on the electricity market through traders' balancing groups are also provided.

Keywords: Green tariff, renewable energy sources (RES), negative imbalances, positive imbalances, electricity market, energy supply.

1. Introduction

The main characteristics of the electricity market and the structure of generating capacities are discussed in [1, 2]. As shown in [3], according to Ukraine's commitments after signing international agreements, the country has declared its goal of achieving carbon neutrality in the economy by 2060, and carbon neutrality in the energy sector by 2050, with a significant reduction in coal usage. Achieving this goal is possible through the large-scale implementation of renewable energy sources (RES). The authors of [4–7] have studied the impact of RES generation volumes on the potential energy balances in the country's energy supply structure. Increasing the share of renewable energy generation in the overall energy system balance is achievable through the guaranteed purchase of electricity from RES generation at fixed "green" tariffs (the internationally accepted equivalent of "feed-in-tariff"). Articles [8, 9] present research on the current state of green tariff formation, aimed at identifying the most effective and acceptable tariff mechanisms under the current uncertain external conditions to stimulate the development of RES in Ukraine.

The company responsible for purchasing electricity under the green tariff is the State Enterprise "Guaranteed Buyer" (GarPok). GarPok is obliged to purchase all the electricity generated by entities granted the green tariff from facilities or project phases (launching complexes) that are part of the balancing group of the guaranteed buyer and are powered by alternative energy sources (or, for hydropower, only from micro, mini, and small hydropower plants) at the established green tariff, taking into account the premium for the entire duration of the green tariff application. The volume of electricity purchased cannot exceed the amount that can be generated by the facility or project phase (launching complex) during each settlement period (hour), based on the installed capacity of the electricity-generating equipment specified in the license for electricity production [10]. During each settlement period (month), the volume of electricity generated at the facility or

project phase (launching complex) from alternative energy sources (or from hydropower – only from micro, mini, and small hydropower plants) is determined after subtracting the energy consumed for the facility's own needs, according to the readings of the metering devices for self-consumption [10].

The flow of funds for the payment of the green tariff is regulated by the "Procedure for the Purchase by the Guaranteed Buyer of Electricity Generated from Alternative Energy Sources" [11]. However, the low level of payments for the green tariff has prompted part of the generation under the green tariff to initiate legislative changes that would allow them to sell electricity on the market and exit GarPok's balancing group. **The goal of this paper** is to determine the optimal green tariff level for solar power plants to exit the balancing group of the State Enterprise "Guaranteed Buyer," enabling these plants to be used as energy sources for energy storage systems or electrolyzers under self-production agreements.

2. Methods and Materials

Components of green tariff financing. The payment balance of GarPok is determined as follows:

$$P_t = P_r + P_{NEK} + P_p + P_b + P_{ex} - V_v - V_r - V_{nb}, \quad (1)$$

where P_r – the total payment to the Guaranteed Buyer for the sale of electricity under bilateral contracts (BC), the day-ahead market (DAM), and the intraday market (IDM) for the settlement month m , in UAH; P_{NEK} – the cost of the service for ensuring the increase in the share of electricity production from alternative sources, provided by the Guaranteed Buyer to the transmission system operator, for the settlement month m , in UAH; P_p – the revenue from the sale of guarantees of origin for electricity generated from renewable energy sources (including from foreign economic agreements/contracts), reduced by the expenses related to the sale of such guarantees of origin, for the settlement month m , in UAH; P_b – the funds received as financial support from the state budget for fulfilling special obligations to increase the share of electricity production from renewable energy sources, for the settlement month m , in UAH; P_{ex} – the revenue from the sale of electricity under electricity export contracts, reduced by the amount of expenses, including those related to obtaining access to the capacity of interstate crossings, taxes, fees, and other mandatory payments associated with the sale of electricity under electricity export contracts, for the settlement month m , in UAH; V_v – the budgeted expenditures of the Guaranteed Buyer according to the approved budget by the Regulator for the settlement month m , in UAH; V_r – the total payment of the Guaranteed Buyer for the purchase of electricity on the intraday market (IDM) to reduce electricity imbalances for the settlement month m , in UAH; V_{nb} – the actual revenues or expenses related to the settlement of the electricity imbalance of the Guaranteed Buyer, which account for the amount of funds received from sellers under the "green" tariff in accordance with the acts of acceptance and transfer of the service for reimbursing the share of the costs of settling the imbalance of the Guaranteed Buyer's balancing group and reimbursement of the cost of deviations for the settlement month m , in UAH.

Currently, the components of cash inflows – P_r , P_{NEK} – are being utilized in this formula. GarPok does not export electricity, so there are currently no inflows from this component. Guarantees of origin are still in the implementation phase as of the preparation of this material on April 25, 2024, so there are also no cash inflows from this source. Additionally, budget allocations to cover the green tariff are absent.

The share of expenses for the service of ensuring an increase in the share of electricity production from alternative sources in the total expenses of the transmission system operator (TSO) for the years 2023/2024 is 47.2 billion UAH / 52.5 billion UAH, respectively, as indicated in [12], and is presented in Table 1.

Table 1. Compensation of the Green Tariff in the Transmission Tariff of NEC "Ukrenergo"

Expenses for the service of ensuring an increase in the share of electricity production from alternative sources	Unit of measurement	In the tariff calculated for the 2023/2024 year	Share of total expenses of the TSO for the 2023/2024 year
– for private households	billion UAH	5,67 /3,93	12,01 % /7,49 %
– excluding private households	billion UAH	19,3 /12,29	40,89 % /23,42 %

In total, for the service of ensuring an increase in the share of electricity production from all alternative sources (both private households and industrial entities), NEC "Ukrenergo" allocates 52.90 % / 30.91 % of the funds received from the sale of electricity transmission services to GarPok in the 2023/2024 years.

The price on the day-ahead market and at the Ukrainian Energy Exchange (UEB) has a significant impact on covering the green tariff. During periods of maximum solar generation, GarPok reduces the price of electricity sold across all market segments. This is a component of P_r in GarPok's payment balance. Table 2 presents the values of the weighted average price of electricity sold by GarPok on the UEB, according to [13].

Table 2. Weighted Average Price of Electricity Sold by GarPok on the Ukrainian Energy Exchange (UEB) [13]

Period	Oct. 23	Nov. 23	Dec. 23	Jan. 24	Feb. 24	Mar. 24	Apr. 24
Weighted average price, UAH/MW·h	3266,73	3779,96	4320,00	3918,75	2727,30	1713,30	1648,34

According to [14], the operations for the sale of electricity generated from renewable energy sources (RES) account for about 30 % of the green tariff. The remaining portion of the tariff is funded by NEC "Ukrenergo" (Table 3). In the event of arrears for the electricity transmission service, the funds received from NEC "Ukrenergo" are insufficient to cover the green tariff, as shown in Figure 1 [15]. Currently, NEC has an outstanding debt of 22.85 billion UAH to GarPok.

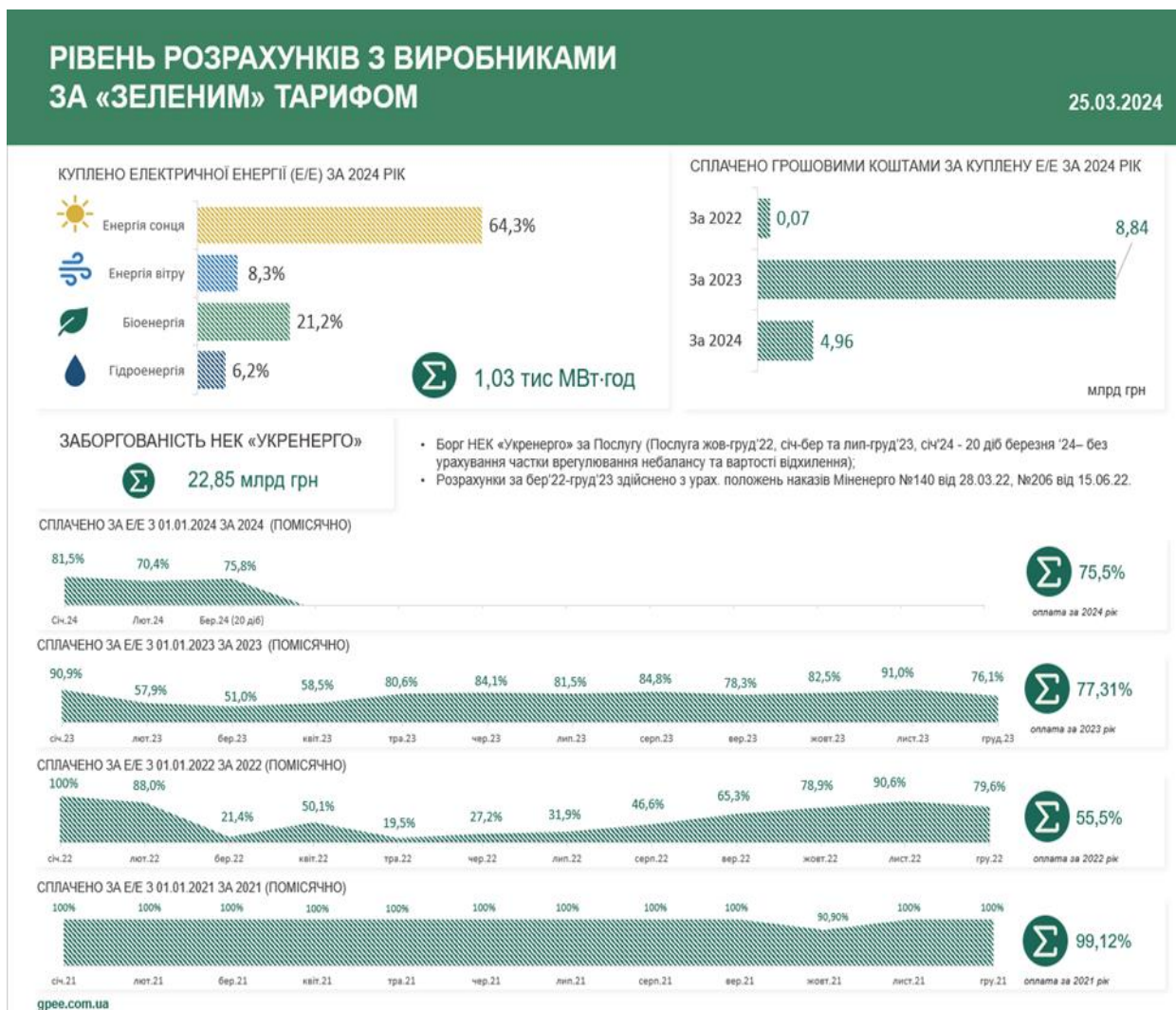


Fig. 1. Status of Settlements for the Green Tariff with RES Generation as of March 25, 2024 [15].

The average payment level of GarPok for the first half of 2024 is 65.5 %. This situation regarding settlements for the green tariff has prompted some RES generators to exit GarPok's balancing group and sell electricity on the electricity market.

Aspects of Exiting the Balancing Group of the Guaranteed Buyer. According to Part 41 of Article 71 of the Law of Ukraine on the Electricity Market [10], entities that generate electricity from alternative energy sources at electricity generation facilities or stages of their construction (commissioning complexes) and sell it at the green tariff have the right to exclude an electricity generation facility (or facilities) from the balancing group of the guaranteed buyer by suspending the contract for the purchase and sale of electricity at the green tariff for that facility and the participation agreement in the balancing group of the guaranteed buyer.

According to the Procedure for the Purchase of Electricity from Alternative Energy Sources by the Guaranteed Buyer [11], approved by the NKREKP Resolution No. 641 dated April 26, 2019 (as amended by NKREKP Resolution No. 178 dated January 24, 2024), the exclusion of a generating unit (or units) of a seller at the green tariff from the balancing group of the guaranteed buyer is effective from the first day of the calendar month, but no earlier than 20 calendar days from the date of submission of the corresponding application to the guaranteed buyer for the suspension of contracts and related supplementary agreements.

To enable the sale of electricity in the market, different requirements are established for generators of varying capacities [16]. Generating units are classified into four categories based on the voltage level at their connection point and their capacity (Table 3).

Table 3. Classification of Generating Units According to [7]

Type of Connection Point	Voltage	Capacity
A	< 110 kV	up to 1 MW inclusive
B	< 110 kV	from 1 MW to 20 MW inclusive
C	< 110 kV	from 20 MW to 75 MW inclusive
D	110 kV or above	above 75 MW*

*A generating unit also belongs to type D if its connection point has a voltage below 110 kV and a capacity above 75 MW.

Producers who have exited the Guaranteed Buyer's balancing group are obliged to submit proposals for unloading on the balancing market and have the right to submit proposals for loading according to market rules. The balancing service provider must meet the market rules for balancing service providers. To participate in the balancing market, a market participant submits an application to the transmission system operator (TSO) for joining the balancing service agreement. The TSO reviews this application and informs the applicant of the completeness and correctness of the information provided within 5 working days from the date of receipt. In the case of providing incomplete and/or inaccurate information, the TSO notifies the market participant, who must provide the necessary information within 14 calendar days from the date of receiving the notification. If the market participant does not provide the necessary information within the specified period, the application is not considered.

Additionally, for sales on the market, generating units of type C and D built after the Code of the Transmission System came into effect, as well as type C and D generating units that have undergone modernization and/or reconstruction, are required to be technically capable of providing ancillary services. To do this, they must undergo the auxiliary services provider (ASP) verification process. An ASP (potential ASP) initiates the ASP Verification process no later than 30 calendar days before the planned date for testing the ASP's electrical installations by submitting a request to the TSO. The TSO makes a decision on approving the test program for the ASP's electrical installations and notifies the ASP (potential ASP) within 10 working days from the date of receiving the request from the ASP (potential ASP). In the case of connecting the ASP's (potential ASP's) installations to the distribution system's electrical networks, the TSO must coordinate its decision with the relevant distribution system operator (DSO).

Analysis of the Operation of RES Generation in the Electricity Market. Upon exiting the balancing group of the Guaranteed Buyer, renewable energy sources (RES) generation can operate in the following markets and platforms:

- The long-term contract market with a fixed price of 1 MWh and a fixed supply volume (Ukrainian Energy Exchange platform);
- Bilateral contracts with a trader;
- Sale of electricity on the spot market (Market Operator platform).

Due to the significant dependence of renewable energy generation on climatic factors and the inability to accurately predict electricity supply over a long-term period, the long-term contract market for renewable energy generation is not attractive.

The terms of electricity sales to a trader are linked to the spot market; additionally, the trader requires a discount for their services, which depends on payment conditions, imbalance compensation, and adjustment terms. Consequently, financial guarantees must be distributed by 17:00 two days before the delivery day (D-2), and a forecast schedule for supply must be submitted to the trader by 16:00. Since the forecast on D-2 is less accurate than on D-1 (the day preceding the delivery day), this increases the producer's imbalances. Selling on the spot market allows for selling forecasted volumes a day in advance (Day-Ahead Market), with the last adjustment to the application possible until 12:00 on D-1.

The advantages of independently selling electricity in the market are as follows:

- Timely payment;
- Reduced negative impact of imbalances when participating in a balancing group.

However, the disadvantages include:

- The market tariff for electricity is lower than the "green" tariff for solar power plants (SPPs);
- The need for staff training to operate in the electricity market;
- The necessity of entering into a contract for participation in the balancing market (for generation types B, C, D) and in the ancillary services market (for generation types C, D).

3. Results

In the calculations provided below, it is assumed that the solar power plant (SPP) operates in the day-ahead market (DAM) and regulates imbalances with NEC "Ukrenergo."

To determine the feasibility criterion for exiting the Guaranteed Buyer balancing group (GB), the amount of funds received from market activity must exceed the payments to the GB, taking into account the actual percentage of payments. The study was conducted over the period from January 1, 2024, to June 30, 2024. It is assumed that the ratio of these funds should be greater than 1:

$$\frac{C^{\text{pнн}}}{C^{\text{гп}}} > 1, \quad (2)$$

where $C^{\text{пнн}}$ – funds received from the operation of the solar power plant (SPP) in the day-ahead market (DAM), million UAH; $C^{\text{гп}}$ – Funds received from the operation of the solar power plant (SPP) within the Guaranteed Buyer's balancing group, million UAH.

The revenue from the sale of electricity for the calendar month on the day-ahead market (DAM) is determined by the following formula:

$$C_{\text{м}}^{\text{пдн}} = \sum_i^k P_i^{\text{пдн}} * O_i^{\text{д}-1}, \quad (3)$$

where $P_i^{\text{пдн}}$ – the price on the day-ahead market (DAM) at hour i of the day; $O_i^{\text{д}-1}$ – forecasted generation volume of the solar power plant (SPP) one day before the supply day, MW; i – calculation hour; k – last hour of the month.

The excess of forecasted generation over actual production leads to a deficit in the energy system. In this case, the party that created the deficit purchases imbalance volumes W_i from the National Energy Company "Ukrenergo" in the corresponding hour of the day ($W_i < 0$, indicating a negative imbalance). The purchase price of the imbalance in this case is determined by the following formula [18]:

$$P_i^{\text{нер}} = \max(P_i^{\text{пдн}}; P_i^{\text{бп}}) * (1 + K^{\text{им}}), \quad (4)$$

where P_i^{6p} – the price established on the balancing market in the corresponding hour, UAH; K^{im} – the imbalance price coefficient according to the Market Rules; i – calculation period (hour of the day).

The ratio of the average cost of negative imbalances to the average price of the day-ahead market (DAM) is shown in Figure 2. It was created by Tolstov D.V. based on data from the Market Operator (MO) and NEC "Ukrenergo" [20, 21].

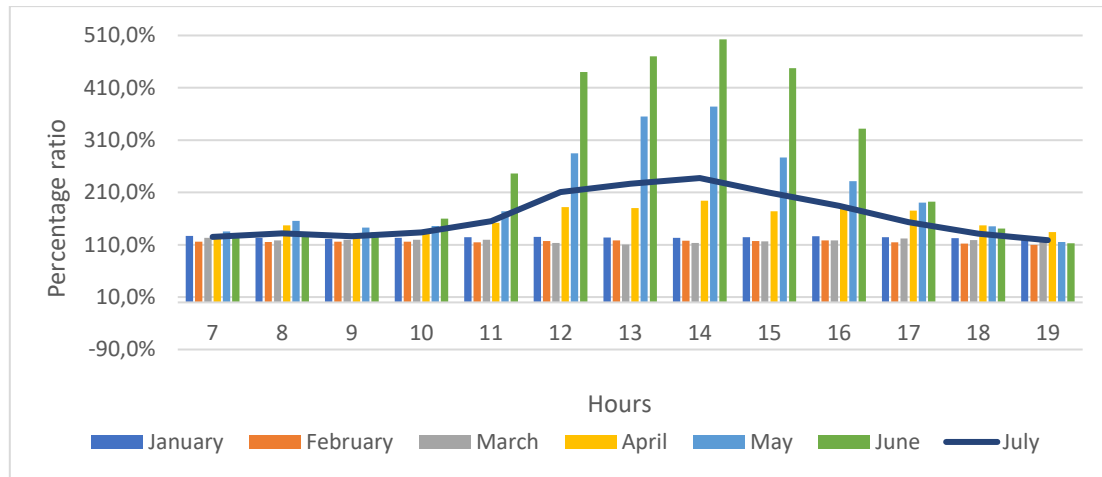


Fig. 2. The ratio of the average cost of negative imbalances to the average price of the day-ahead market (DAM)

As seen from the data in Figure 2, starting from April 2024, the difference between the cost of negative imbalances and the average price of the day-ahead market (DAM) is increasing due to changes in the order of formation of P_{6p} and the destruction of a significant portion of flexible generation. During hours of maximum solar activity, prices are sold in the range of 10–60 % of the DAM price cap, while acceptance for loading on the balancing market is at the maximum price of the balancing market. This situation leads to the case where, in the event of a negative imbalance, the generation will have to pay NEK "Ukrenergo" an amount that exceeds the revenue from the DAM for that hour by 2–4 times.

If a market participant is in surplus, i.e., selling imbalances W_i in the corresponding hour of the day ($W_i > 0$), positive imbalance), the sale price of the imbalance for that participant is determined by the formula.

$$P_i^{poz} = \min(P_i^{DAH}; P_i^{6p}) * (1 - K^{im}). \quad (5)$$

The ratio of the average cost of positive imbalances to the average price of the day-ahead market (DAM) is presented in Figure 3.

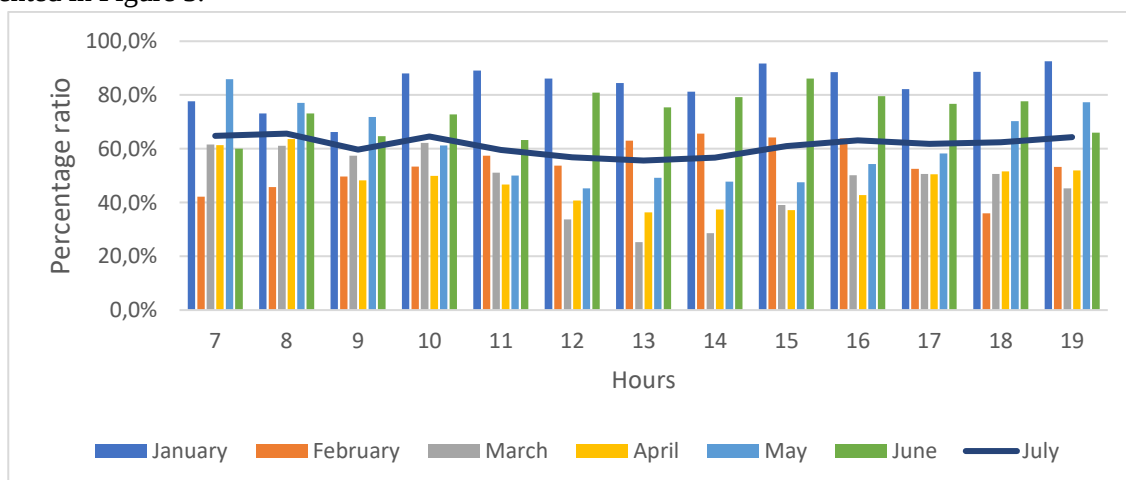


Fig. 3. The ratio of the average cost of positive imbalances to the average price of the day-ahead market (DAM)

As seen from Figure 3, the average ratio during the hours corresponding to solar power generation fluctuates between 60 % and 65 %. Due to damage to generation facilities, a rise in the ratio to 82 % is recorded in June 2024.

The income from balancing electricity imbalances for a calendar month is determined by the following formula:

$$C_M^{\text{поз}} = \sum_i^K P_i^{\text{поз}} * (O_i^{\phi} - O_i^{D-1}), \quad (6)$$

where O_i^{ϕ} – Actual generation volume, MW.

The expenditure of funds for balancing electricity imbalances over the calendar month is determined as:

$$C_M^{\text{нег}} = \sum_i^K P_i^{\text{нег}} * (O_i^{\phi} - O_i^{D-1}). \quad (7)$$

The total revenue from operating on the Day-Ahead Market (DAM) consists of:

$$C_M^{\text{рнн}} = C_M^{\text{рнн}} - C_M^{\text{нег}} + C_M^{\text{поз}}. \quad (8)$$

Since January 1, 2022, renewable energy facilities with a capacity exceeding 1 MW are required to reimburse 100 % of the imbalances to the Guaranteed Buyer. Thus, imbalances are accounted for both in the Guaranteed Buyer's balancing group and in sales on the free market. The forecast for generation volumes is provided to the Guaranteed Buyer by 09:00 on D-1, while in the market, generation can utilize forecasts made at 11:30 on D-1, which improves accuracy [23]. In the balancing group of the Guaranteed Buyer, the procedure for calculating negative imbalances is carried out according to the National Energy Regulation Commission's (NERC) resolution on the approval of market rules dated March 14, 2018, No. 307 [19], while a different calculation is used for positive imbalances. Participants in the Guaranteed Buyer's balancing group reimburse the Guaranteed Buyer for a share of the cost of balancing energy imbalances within the balancing group, and if the actual volumes of energy delivery/withdrawal of such a participant exceed their forecasted hourly delivery/withdrawal schedules, they reimburse the Guaranteed Buyer for the cost of deviation [20]. The reimbursement volumes are calculated using the following formula:

$$C_M^{\text{поз}} \Gamma \Pi = \sum_i^K (O_{\phi}^i - O_{i-3}^i) * (P_i^{\text{рнн}} - P_i^{\text{поз}}). \quad (9)$$

Currently, NEC "Ukrenergo" has debts to participants in the balancing market and for balancing settlements. As of June 27, 2024, payments are being made for the third decade of February 2023, which indicates a receivable debt with a term of 16 months [23].

For the analysis of renewable energy generation in the market, data from forecasts and actual figures for solar power plants with a capacity of 1 MW are used. This ground-mounted solar power plant is located in the Kherson region. The power plant was commissioned in 2013 and has a "green" tariff of 33.93 euro cents since 2013.

The forecast for solar energy generation was made on D-1 before 11:00. The "green" tariff in the hryvnia equivalent is 10,304.6 UAH/MWh excluding VAT [24].

The revenue from the operation of the solar power plant in the Guaranteed Buyer's balancing group is:

$$C_M^{\Gamma \Pi} = C_M^{\text{зт}} - C_M^{\text{нег}} - C_M^{\text{поз}} \Gamma \Pi, \quad (10)$$

where $C_M^{\text{зт}}$ – payments by the Guaranteed Buyer for the "green" tariff, which are defined as:

$$C_M^{\text{зт}} = \sum_i^K O_{\phi}^i * k_M^D * t^3, \quad (11)$$

where k_M^D – the actual payment percentage for the "green" tariff in the month, %; t^3 – «green» tariff, UAH/MWh.

Since the accounts receivable for the "green" tariff and positive imbalances have the same nature—being the debt of NPC "Ukrenergo" to market participants—these amounts will not be considered in the comparison of cash inflows on a monthly basis. For comparison, excluding accounts receivable, equation (1) will take the following form:

$$\frac{\sum_i^K P_i^{DAM} * O_i^{D-1} - \sum_i^K P_i^{HER} * (O_i^\phi - O_i^{D-1})}{\sum_i^K O_i^\phi * k_M^D * t^3 - \sum_i^K (O_i^\phi - O_{i-3}^\phi) * (P_i^{DAM} - P_i^{PO3}) - \sum_i^K P_i^{HER} * (O_i^\phi - O_i^{D-1})} > 1. \quad (12)$$

Prices from the Day-Ahead Market (DAM) and the Balancing Market (BM) were used for calculations for the period from January 1, 2024, to June 30, 2024. The calculation for solar power generation was conducted for the period from January 1, 2023, to June 30, 2023. The difference between the actual and forecasted values, as well as the cost of created imbalances, is presented in Table 4.

Table 4. Actual Values, Forecast, and Cost of Imbalances

Month	1	2	3	4	5	6
Forecast Volume DAM, O_i^{D-1} , MW	40,39	73,3904	110,1036	80,8798	180,102	171,0578
Actual Generation Volume, O_i^ϕ , MW	34,61	80,44	114,48	97,88	191,32	175,64
Negative Imbalances Volume, MW	-15,898	-8,953	-16,531	-6,756	-14,994	-12,784
Positive Imbalances Volume, MW	6,223	20,672	23,713	35,06	33,636	20,362
Cost of Negative Imbalances, C_M^{HER} , UAH	81 189,21	31 451,77	47 655,86	21 460,44	110 484,87	101 289,81
Cost of Positive Imbalances, C_M^{PO3} , UAH	14 565,08	35 908,03	26 871,40	70 399,12	62 422,30	52 236,21

Results of the operations in the balancing group of the guaranteed buyer and the activities under the "green" tariff, taking into account the actual payment percentage, are presented in Table 5.

Table 5. Indicators for Solar Power Plants (SPP) Operating in the Balancing Group of the Guaranteed Buyer

Month	1	2	3	4	5	6
Actual Generation Volume,, O_i^ϕ , MW	34,61	80,44	114,48	97,88	191,32	175,64
Negative Imbalances Volume, MW	-15,90	-8,95	-16,53	-6,76	-14,99	-12,78
Positive Imbalances Volume, MW	6,22	20,67	23,71	35,06	33,64	20,36
"Green" Tariff, t^3 , UAH/MW	10 304,46	10 304,46	10 304,46	10 304,46	10 304,46	10 304,46
Planned Payments from the Guaranteed Buyer, UAH	356 606,45	828 901,07	1 179 633,97	1 008 610	1 971 469,90	1 809 844,44
Guaranteed Buyer Payment Level, k_M^D	82%	70%	70%	71%	46%	54%
Cash Inflows from the Guaranteed Buyer Considering the Payment Level,, C_M^{3T} , UAH	290 634,25	583 546,35	823 384,51	717 122,31	914 762,03	970 076,62
Cost of Negative Imbalances, C_M^{HER} , UAH	81 189,21	31 451,77	47 655,86	21 460,44	110 484,87	101 289,81
Compensation for Positive Imbalances, C_M^{PO3} ГП, UAH	2 339,37	24 001,15	32 103,75	41 043,13	35 965,12	18 822,00
Total Amount, $C^{ГП}$, UAH	207 105,68	528 093,43	743 624,90	654 618,74	768 312,04	849 964,81

As shown in Table 5, despite the low payment level for the "green" tariff, cash inflows remain high due to the significant value of the "green" tariff, which for this solar power plant (SPP) amounts to 10,304.46 UAH/MW.

Table 6 presents the calculated indicators for the operation of this SPP when exiting the Guaranteed Buyer (GB) balancing group. This SPP sells the forecasted generation volume based on the forecast made on D-1 at 11:30 on the Day-Ahead Market (DAM).

Table 6. Indicators for Solar Power Plants (SPP) Operating in the Market

Month	1	2	3	4	5	6
Forecast Volume DAM, O_i^{D-1} , MW	44,282	68,722	107,296	69,577	172,68	168,059
Actual Generation Volume, O_i^{ϕ} , MW	34,607	80,441	114,478	97,881	191,322	175,637
Negative Imbalances Volume, MW	-15,898	-8,953	-16,531	-6,756	-14,994	-12,784
Positive Imbalances Volume, MW	6,223	20,672	23,713	35,06	33,636	20,362
Profit from the Day-Ahead Market, C_m^{pdm} , UAH	172 266,24	219 763,35	253 576,17	200 038,06	475 742,13	478 184,09
Cost of Negative Imbalances, C_m^{ner} , UAH	81 189,2	31 451,77	47 655,86	25 278,29	110 484,87	97 380,40
Cost of Positive Imbalances, C_m^{noz} , UAH	14 565,08	35 908,03	26 871,40	65 515,83	62 422,30	51 178,40
Monthly Inflows, C^{pm} , UAH	91 077,0	188 311,59	205 920,31	174 759,77	365 257,26	380 803,69
Accounts Receivable (16 Months), UAH	14 565,08	35 908,03	26 871,40	65 515,83	62 422,30	51 178,40
Total Amount, UAH	105 642,11	224 219,61	232 791,71	240 275,59	427 679,56	431 982,09

As shown in Tables 5 and 6, the ratio of cash inflows from market operations to cash inflows from the Guaranteed Buyer (GB), taking into account the payment level, is 0.37. Due to the high value of the "green" tariff for this solar power plant (SPP), it is not advisable to exit the GB.

To assess the number of potential participants wishing to exit the Guaranteed Buyer balancing group, an analysis of the "green" tariffs was conducted based on the current data from the National Commission for State Regulation of Energy and Public Utilities [24]. The selection criterion was that the profit from activities in the electricity market exceeds the profit from participation in the balancing group without considering accounts receivable from the Guaranteed Buyer and NPC "Ukrenergo." The results are presented in Table 7.

Table 7. Number of Solar Power Plants (SPP) Meeting the Selection Criteria

"Green" Tariff, UAH/MW	4604,9	4516,7	4450,6	4296,4	4142,2	3306,1	3195,3
Number of Solar Power Plants (Queues) with Capacity Greater than 10 MW	15	0	0	0	0	0	3
Number of Solar Power Plants (Queues) with Capacity Less than 10 MW	65	6	58	23	42	1	0
Effect from Market Operations (Criterion)	1,02	1,05	1,07	1,13	1,19	1,69	1,79
Criterion at 100 % Payments from the Guaranteed Buyer and Payment of Positive Imbalances to NPC	0,63	0,64	0,65	0,68	0,71	0,95	1,00

As shown in Table 7, only at the minimum "green" tariff of 3,195.3 UAH/MW does the profit from market operations exceed that from the Guaranteed Buyer (GB) balancing group. However, if we disregard the accounts receivable from the Guaranteed Buyer to the solar power plants (SPP), the threshold value of the "green" tariff is 4,604.9 UAH/MW. The data presented in Table 8 also includes rooftop solar power plants,

which typically operate in a mode generating electricity for local consumption and only feed excess electricity into the grid. To exclude these SPPs, Table 8 has been created.

Table 8. Information on Solar Power Plant (SPP) Operations in the Electricity Market

Number of Solar Power Plants (SPP)	Tariff, UAH/MW	Availability of Installed Capacity Data	Installed Capacity Volume, MW	Availability of Balancing Group (BG) Data	BG Trader / Guaranteed Buyer / Data Unavailable
3	3195,3	3	147,74	3	3/0/0
1	3306,1	1	5,91	1	0/1/0
19	4142,2	14	13,42	19	0/19/0
14	4296,4	13	13,3	11	7/4/3
37	4450,6	35	29,72	37	16/20/1
61	4604,9	60	375,66	61	12/49/0

Information regarding trading companies that have included solar power generation in their balancing groups has been compiled by the author based on data from NPC "Ukrenergo" [25] and is presented in Figure 4.

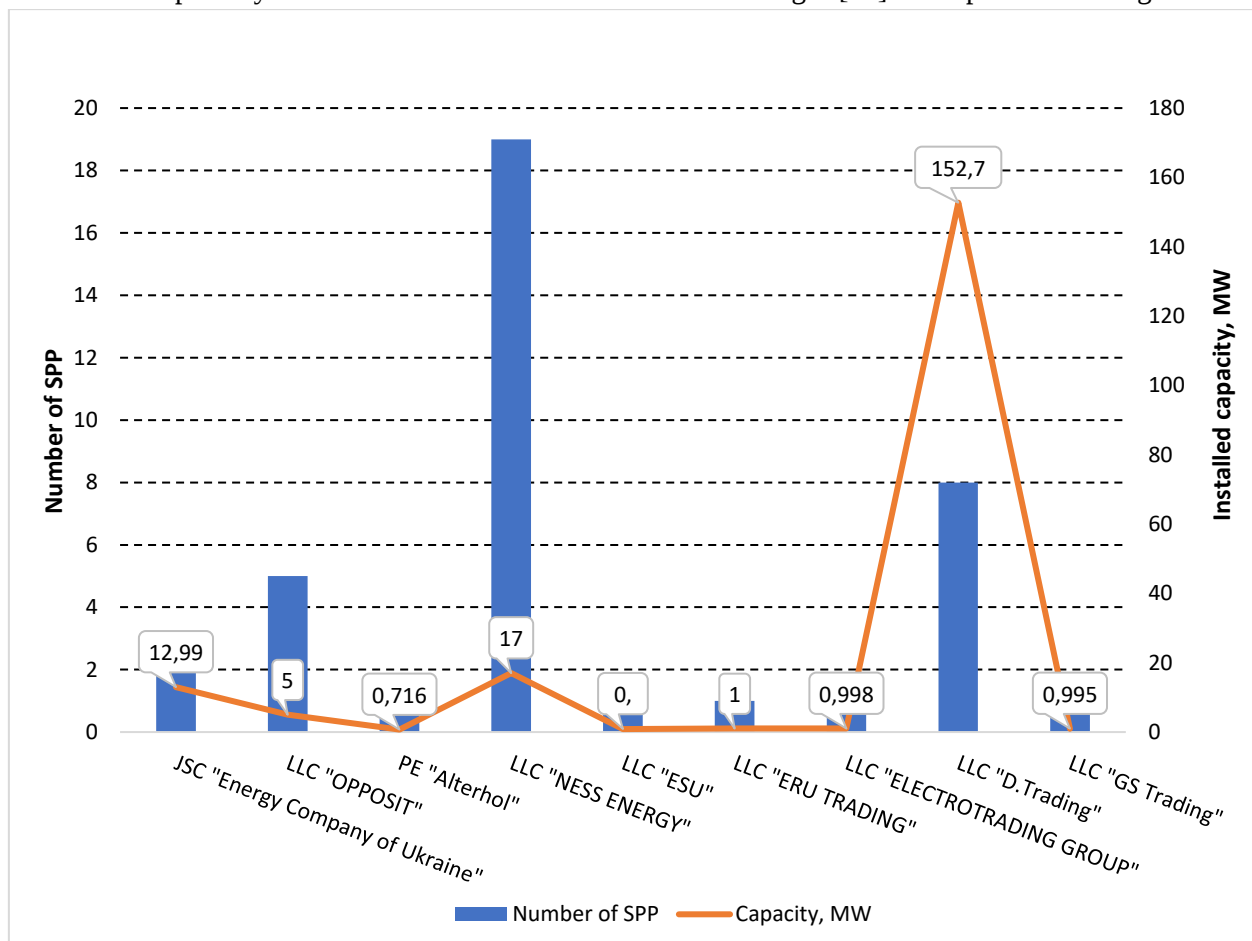


Fig. 4. Number and Installed Capacity of Solar Power Plants (SPP) in the Trader's Balancing Group

4. Discussion

The study of the optimal value of the "green" tariff was conducted using solar power plants (SPP) as an example. The obtained data can be utilized for other renewable energy generation sources to determine their economic efficiency in the electricity market. Participation of generation in the intraday and balancing segments of the market, which are segments where the forecast submission period for generation volumes for

sale is closest to the period of electricity delivery, will reduce the negative impact of imbalances on the financial performance of the system, thereby increasing the profitability of the enterprise.

The use of battery-type energy storage systems or proton exchange membrane electrolyzers [26] with a fast-acting Energy Management System (EMS) will minimize imbalances (in the case of renewable energy sources, both types of imbalances; when using electrolyzers, only positive imbalances) to the lowest possible level. Participation in the balancing group will help compensate for any remaining imbalances.

5. Conclusions

As a result of the conducted analysis, the value of the "green" tariff at which solar power plants (SPP) should opt out of state support and sell electricity in the market has been determined. A selection criterion for such SPPs has been established, specifically that the profit from market operations must exceed the profit from participation in the balancing group of the Guaranteed Buyer State Enterprise without considering accounts receivable from the Guaranteed Buyer and NPC "Ukrenergo."

The assessment revealed that the percentage of SPPs that meet the evaluation criterion and operate without state support is 30.95 %, with their share in the installed capacity of SPPs meeting the criterion being 32.83 %.

The calculations confirmed that at a "green" tariff of 4,604.9 UAH/MW, SPPs exit the balancing group of the Guaranteed Buyer State Enterprise, which aligns with the data from NPC "Ukrenergo."

It has been shown that the majority of SPP generation that has exited the balancing group of the Guaranteed Buyer State Enterprise has joined the balancing group of LLC "NESS ENERGY," while the balancing group of LLC "D.Trading" has the largest installed capacity.

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ВИЗНАЧЕННЯ ОПТИМАЛЬНОЇ ВЕЛИЧИНИ «ЗЕЛЕНОГО» ТАРИФУ ДЛЯ ВИХОДУ СОНЯЧНИХ ЕЛЕКТРОСТАНЦІЙ З БАЛАНСУЮЧОЇ ГРУПИ ДП «ГАРАНТОВАНІЙ ПОКУПЕЦЬ»

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Анотація. У статті розглянуто механізм та фінансування «зеленого» тарифу в Україні, основним завданням якого є збільшення частки електроенергії, що виробляється з відновлюваних джерел енергії (ВДЕ), у загальному балансі енергосистеми. Описано функціонування ДП «Гарантований покупець» (ГарПок) як основного покупця електроенергії за «зеленим» тарифом, а також джерела надходження коштів для виплати цього тарифу, такі як плата за передачу, фінансова підтримка

з державного бюджету і доходи від продажу гарантій походження електроенергії. Проаналізовано сучасний стан фінансування «зеленого» тарифу та його проблеми, включаючи заборгованість НЕК «Укренерго» перед ГарПоком та відсутність надходжень від продажу гарантій походження. Розглянуто аспекти виходу ВДЕ-генерації з балансуючої групи ГарПока, включаючи можливості продажу електричної енергії на різних ринках. Представлено результати аналізу ефективності роботи ВДЕ-генерації на ринку електричної енергії, визначено мінімальне значення «зеленого» тарифу, при якому генерація з відновлюваних джерел виходить з балансуючої групи ДП «Гарантований покупець». Показана кількість та встановлена потужність об'єктів генерації, що працюють на ринку електричної енергії через балансуючі групи трейдерів.

Ключові слова: «зелений» тариф, відновлювані джерела енергії (ВДЕ), негативні небаланси, позитивні небаланси, ринок електричної енергії, енергозабезпечення.

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