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Support for Household Prosumers in the Early Stages of Power Market Decentralization in Ukraine

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Abstract: This paper aims to reconsider prosumers' role in the power markets in the early stages of their decentralization, accounting for rising self-supply trends, security threats, and economic and regulatory barriers. The development of prosumerism envisages finding the ratio between retail market sales under the feed-in tariff and the net billing mechanism. Within the methodology section, the indicator of prosumer efficiency for electricity generation (EUR/kWh) is proposed based on average consumption/production ratios and consumption/delivery incentives. To support household prosumers, the mentioned incentives on the renewable energy market consider the self-supply cost of electricity, the levelized cost of electricity for small-scale green energy facilities (solar photovoltaic and wind), and transaction costs. This paper evaluates prosumer efficiency under three consumption/production ratio scenarios for Ukrainian households (self-consumption of 40%, 20%, and 100% of green electricity annually generated by a household and selling the leftovers via the feed-in tariff) for 2023. The gradual movement from fixed tariffs for households toward market-based prices promotes the emergence of new related market players and their consolidation in the market. Participation in the organized power market segments is relevant for day-ahead market prices above 130 EUR/MWh, disregarding the households' tariff rate. The low price caps inhibit the prosumer's participation in the market, while the transition from the feed-in tariff to net billing significantly promotes their development only under high price caps.

Keywords: prosumers; incentives; net billing; externalities; day-ahead market; local flexibility markets



Citation: Zhou, M.; Pysmenna, U.; Kubatko, O.; Voloshchuk, V.; Sotnyk, I.; Trypolska, G. Support for Household Prosumers in the Early Stages of Power Market Decentralization in Ukraine. *Energies* **2023**, *16*, 6365. <https://doi.org/10.3390/en16176365>

Academic Editor: Marco Merlo

Received: 28 July 2023

Revised: 26 August 2023

Accepted: 28 August 2023

Published: 2 September 2023



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1. Introduction

Households have been interested in installing and using solar power installations for a long time [1]. Despite the almost tenfold increase in the installed capacity of household solar power plants (SPPs) in Ukraine from 2018 to 2022, the share of households that have embarked on the path of energy prosumerism is still insignificant—about one percent of all households. Since 24 February 2022, the state of war slowed down and, in some regions, inhibited the development of low-carbon and energy-efficient technologies and stagnated a significant part of the generation of large renewable energy sources (RESs) in the country; whole regions fell under hostilities, populated areas were captured and occupied, some citizens experienced internal displacement and migrated abroad, and there was a general destabilizing effect of the war on the state's economy, including a drop in income, an increase in the exchange rate, the shutdown of enterprises, job loss [2], and

a decrease in social responsibility [3]. The installation rate of SPPs operating under the feed-in tariff (FIT) has been reduced tenfold since the beginning of martial law [4]. The main conditions maintaining the profitability of green power businesses have changed drastically. Suppliers have suspended payments to households for electricity produced by alternative sources, and the prospects of the fulfillment of long-term obligations by the state by 2030 have become unclear.

At the same time, numerous attacks on critical infrastructure facilities, especially centralized energy structures; the need to restore the system after accidents (blackouts); and frequent emergency and planned power limitations of a large number of consumers in different regions of Ukraine have become significant and necessitate fostering the decentralization of energy supply in both industrial and household sectors. Together with these factors, as noted in [5], for transition economies that are not even under martial law, prosumerism is a new efficient way to ensure energy independence and security and even tackle energy poverty due to green power's higher availability and affordability [6]. However, the power markets in the early stages of decentralization, which is the case in Ukraine, face difficulties entering the wholesale market's organized segments, so forms of market participation and efficacies differ [7–9]. Due to this phenomenon, it is necessary to know how important it is for prosumers to access organized segments or whether it is enough to expand their presence in the retail market.

This paper aims to consider the ways of enhancing the possibilities of prosumer development and the following gains (security of energy supply, transition to climate-friendly technologies, and reduction in energy poverty) at the beginning of the path to power-market maturity. The objectives of this paper are to analyze the economic incentives of household prosumers in the early stages of power market decentralization and to reveal the existing and possible external effects coming along with the development of prosumerism, as negative externalities can slow down or suspend their development, whether or not their operation influences the system stability. For this purpose, this paper aims to study the institutional and technical constraints to the rapid deployment of prosumers and the establishment of their notable impact and appreciable market role. The assessment of economic feasibility is recognized as the main instrument to understand the speed of an energy technology transition and the success or failure of the technology's development. However, the paper's novelty is to consider the economic assessment of household prosumers' activity and the institutional prerequisites of their evolution beyond the economic criteria of a single installation project. These prerequisites include the removal of regulatory constraints and market barriers, the expansion of market possibilities for stakeholders by introducing aggregating agents, virtual plants, technological upgrades to the power grid, the synergy of adjacent markets (e.g., electric vehicles (EVs) and prosumers), the launch of performance contracting, green bonds, state loans, and other financial support mechanisms.

The remainder of this article is organized as follows: Section 2 presents a review of studies on the economic issues associated with prosumerism and market-participation models. Section 3 describes the research methodology and stages. Section 4 outlines the technical and institutional constraints for prosumers, their possible role in the market, and their externalities. In addition, prosumer efficiency is estimated as the aggregate of the comparative efficiency of the consumption side and the absolute efficiency of the production side under three scenarios of the self-consumption/production ratio, taking into account market conditions and regulatory impacts. Section 5 provides the conclusions and further provisions for using the study results.

2. Literature Review

As a result of the rapid development of RESs around the world and the trend to decentralization of the energy supply, researchers' focus has shifted to local decentralized power systems and self-sufficiency in energy. Scholars pay attention to prosumers as the specific group of energy producers with their capability for onsite production, flexible consumption, and the ability to reformat power systems and markets.

The economic issues of RES utilization, the role of FIT application, the consequences of its misapplication, the advantages of the net billing model, and the experience of the variety of financial support mechanisms implemented for prosumers are studied by Perujo A. et al. [10], Kurbatova T. et al. [11], Trypolska G. and Rosner A. [12], Sotnyk I. et al. [13], Tuerk M. [14], and others. For example, Sotnyk I. et al. [15] focused on industrial prosumer fostering. Recognizing the insufficiency of FIT as stimuli for the further expansion of RESs, the authors identified the following prosumerism drivers: power market prices, green energy taxation, investment support, state guarantees, national decarbonization goals, responsibility for imbalances, European energy legislation adoption, etc.

The studies related to the countries in the early stages of power market decentralization conclude that small solar household installations (operating on FIT) have an unreasonably high period of payback even if households sell their electricity through aggregators. Kuzior A. et al. [8] envisaged the application of green energy taxation for RES boost. Adverse external effects that can influence the economic feasibility and sustainability of RESs were investigated by Unruh G. [16], Owen A. [17], Pysmenna U., Trypolska G. [18], and Bardy R. and Rubens A. [19].

The role of prosumers in energy security and the green transition are discussed by Sotnyk I. et al. [20], Galvin R. [21], Lir V. [22], and Paravantis J. [23]. Galvin R. [21] argued that prosumers face ‘geo-sociotechnical’ issues when optimizing energy management and reducing CO₂ emissions. The researcher interviewed households with solar photovoltaic (PV) or solar thermal (ST) collectors and learned how these installations influenced their everyday lives and the way they use energy. In addition, Galvin R. [21] studied the impact of weather, diurnal and annual rhythms, grid technologies, and political regimes on installed SPPs. Lir V. [22] investigated the global transition trends to smart grid technologies and RES development to enhance energy security.

Sotnyk I. et al. [15] considered the prosumerism transition, i.e., the pathway to increase the number of green power self-consumers. The authors stated that only 5–20% of the companies need to use large-scale nonrenewable power, while 80–95% of firms can meet their energy demand with up to 1 MW capacity of green power facilities. Prokopenko O. et al. [24] emphasized that power system decentralization based on RES transition induces a shift in the energy policy from the obsolete model of the fossil fuel dominance of large producers to a new competitive model where the supremacy of a single type of power technology or fuel is minimized.

Grzanic et al. [25] and Gopinathan N. et al. [26] analyzed models and opportunities for prosumers with PV installations, EVs, power storage, and other flexible devices. Several studies [25,27–30] have examined different types of aggregation of individual prosumers: energy communities or microgrids, combined market participation, and decentralization models to stimulate internal energy exchange and solve local grid problems. Market participation models for prosumers relying on smart grid technologies through peer-to-peer (p2p) trading, self-dispatching zones, virtual power plants, EV demand response, etc., were investigated by Grzanic M. et al. [25], Junlakarn S. et al. [31], 2022, and Kelm P. et al. [32].

Prosumers as the ancillary service providers and their role in the enhancement of power system flexibility were studied in [33–36]. Fazoranti M. et al. [37] and Rücker F. et al. [35] discussed the standards of the smart grid and its features, such as the sufficiency of demand response, distributed automation, the promotion of household e-vehicle charging, the obligation for energy storage, and smart metering systems. These researchers conclude that grid development is crucial for prosumerism fostering. By optimizing demand and providing a flexible output, most prosumers are capable of significantly reducing the need for large-scale power grid control capacity.

To summarize, recent studies mainly consider prosumers’ problems in mature power markets, bypassing the nascent prosumerism, and the initial stages of power system decentralization. Also, economic evaluation is available in relation to individual projects’ profitability and payback period. However, external factors need to be considered to determine the possibilities for the implementation of RESs.

3. Materials and Methods

Although prosumerism is very promising in some countries due to their favorable geographic location and incentive tools, numerous technological and institutional constraints can significantly slow its expansion. Nonstandard connections, restrictions on capacity/equipment installation, limitations, imbalances, the lack of flexibility, and storage obligations all may affect the economic acceptability of prosumer models. Therefore, in the first stage, we will identify technical barriers and adverse external effects of a technical nature that accompany prosumer development and require adjustments to the technical energy policy. Next, using the policy analysis method, we will analyze the features of regulatory policy for prosumers to determine what regulatory constraints may exist on their appearance. Then, applying the institutional analysis method, we will consider the market conditions to assess the obstacles to prosumers' participation in the market (e.g., market barriers, transaction costs, price regulation, vulnerability, etc.). In the next step, prosumer efficiency is determined as the sum of all the incentives to autonomize consumption and deliver surpluses. J. Kals's theory regarding the typical strategies for implementing energy efficiency measures [38] is used to study policy compliance to establish energy prosumerism. The transition from a "passive" strategy through the "strategy of implementing all investment-attractive measures" to a "maximum" strategy in the case of prosumerism is reflected in the transition from individual projects' profitability assessment to the analysis of system costs and economic effects of newly installed systems as a whole. However, in the early stages of prosumerism promotion, with a small share of prosumers in the market, the incentives of individual projects are extremely important. Therefore, we will assess their sufficiency to estimate the obstacles to the rapid development of RESs and the realization of sustainable transition.

Compared with self-supply or net production, in prosumerism, both of these activities are combined, and thus, this approach offers both incentives and disincentives. Assuming that electricity tariffs for households are so low on the consumption side that they are equal to the levelized cost of electricity (LCOE) in prosumer power plants, the regulatory policy of cross-subsidizing household consumers or the mechanism of public service obligations for the availability of electricity to the population is also the policy of curbing prosumerism. Likewise, on the production side, the parity of the day-ahead market (DAM) prices with the LCOE as a result of the application of price-caps in organized market segments is a significant factor in favor of the continuation of FIT use in case the state pursues the goals of the development of decentralized energy sources.

Following the experience of the European Union (EU) in introducing investment grants for households and energy cooperatives with a capacity of up to 50 kW [12,28,39–42], it is apparent that prosumer efficiency in the early stages of market decentralization is not sufficient enough for the rapid launch of prosumer investment projects. Investment grants of more than EUR 200/kW are required to ensure a payback period of six years.

The difference between total and comparative efficiency methods is that the total efficiency is based on profit assessment (the difference between the sales price and the cost) regardless of the sales volume. In contrast, comparative efficiency is based on achieving a reduction in the costs of the product at a comparable amount and price level. The method of comparative efficiency on the consumption side involves the determination of the ratio of savings on the current costs of providing renewable energy to the difference in capital investments by capital investment options (incremented and depreciated in the LCOE) or to a single investment. In general, the comparative efficiency on the consumption side in prosumerism is similar to the evaluation of the efficiency of energy-efficient projects [13,43]. Here, the value of the saved unit of energy and the cost of the expenses to achieve this saving are compared.

We will highlight a set of factors that, in many countries in the early stages of decentralization of the energy market, affect the feasibility of prosumer projects along with the profitability of technology use. In addition, we will assess the presence and influence of negative externalities that affect the existing form of prosumers. For example, such exter-

nalties do not allow for the formation of energy cooperatives instead of many separate households with autonomous or partially autonomous energy supply. Only after these stages is the assessment of the economic efficiency of a particular project comprehensive.

The efficiency of renewable energy production usually characterizes the economic efficiency of any energy production technology and is determined by a number of indicators, including the change in the unit efficiency, a reduction in specific fuel consumption, income, and sales profit in the electricity market. Accordingly, prosumer efficiency is the aggregate of the comparative efficiency of the consumption side and the absolute efficiency of the production side, which can be expressed as the sum of savings in costs for consumed energy and the gained profit from the electricity delivery to the grid:

$$I_{CD} = I_C * R_{C/P} + I_D * (1 - R_{C/P}), \quad (1)$$

where I_{CD} is the prosumer efficiency (incentive) per kilowatt hour of generated electric energy, EUR/kWh; $R_{C/P}$ is the yearly averaged consumption/production ratio (volumes consumed by a prosumer divided by volumes of produced electricity in a period); and I_C and I_D are the consumption and delivery incentives, respectively, EUR/kWh:

$$I_C = T - LCOE, \quad (2)$$

where T is the self-supply cost of electricity, EUR/kWh; $T = \{T_h, T_m\}$, where T_h and T_m are the regulated tariff rate for households and the market electricity price for small nonresidential consumers, EUR/kWh; and $LCOE$ is the levelized cost of electricity for small-scale RESs (PVs, wind, etc.), EUR/kWh.

$$I_D = T - LCOE - C_t, \quad (3)$$

where C_t indicates the transaction costs (aggregator fee and/or DAM entry fee), EUR/kWh; $T = \left\{ FIT; \frac{\sum(P_{DAMh} * V_{DAMh})}{V_{DAM}} \right\}$, where P_{DAMh} is the hourly DAM price, EUR/kWh; and V_{DAMh} and V_{DAM} are the hourly and daily electricity volumes delivered to the grid, kWh.

4. Results and Discussion

4.1. Prosumers: Technical Constraints

A prosumer household is a household that both produces and consumes energy in different ratios. It could refer to homes with rooftop solar PV panels, wind turbines producing electricity, and rooftop ST collectors for water heating. Toffler A. coined the term ‘prosumer’ [44]. Micropower plant technologies for prosumers range from photovoltaics, wind power, and geothermal energy to small hydroelectric power plants and microcombined heat and power plants [45]. Galvin R. [21] indicates that a key feature of geo-sociotechnical interconnections and influences for prosumers is that they are neither the central concern in policy making nor powerful political decision makers. However, PV and ST panels are in focus because they are the only energy sources in which performance is directly determined by meteorological conditions. They also transmit this energy to prosumers and the grid.

Micropower plant installations are low-voltage systems and may be grid-connected. These systems can operate with local power generators (e.g., PV panels or wind turbines) and local storage units, monitors, and controllers of energy, from the connected sources delivering it to consuming equipment or batteries as well as to the grid, operated by a distribution system operator (DSO) [46]. The analysis of the benefits of prosumer flexibility and the issues related to grid operation and optimization is presented in [34]. The obtained results show that, when all consumers are prosumers, the total network costs decrease by 16.45%. The grid flexibility also increases since prosumers can trade energy between each other and the grid. In addition, local generation reduces energy losses by 27.5%. However, poorly managed grid operation can lead to local overload problems due to bidirectional power flows.

The mismatch between power generation and consumption is a challenge for DSOs and prosumers, who must accept that some of the energy generated may be lost if not immediately consumed without sufficient storage capacity [32]. Therefore, the electrical energy management system becomes one of the key components in the late stages of power market decentralization within smart grid development. Its task is to control the connection of prosumers' installations to the grid and the local dispatch of energy with balanced power production–consumption via smart metering and power flow aggregation [47]. Rücker F. et al. [35] evaluated the impact of smart charging strategies and EV charging constraints on the self-sufficiency of prosumer households. Three exemplary mobility profile scenarios were proposed and simulated, differing in their distribution of departure and arrival times. It was found that smart charging strategies, the use of bidirectional chargers, the relaxation of charging power constraints, and the use of forecasting algorithms increase the self-sufficiency of prosumer households with PV and EV systems.

Research involving prosumers with ST collectors has received less attention in the literature. Nevertheless, the value of these types of prosumers in the energy and electricity balances can be significant due to lower electricity consumption thanks to self-sufficiency in water heating. Lickleder T. et al. [48] showed that the technical execution of thermal energy trading has several challenges. Previously used procedures for the design of district heating networks cannot be adopted directly.

4.2. Prosumers: Regulatory Constraints

The long-term application of FIT to support RESs in Ukraine certainly played an essential role in the rapid growth of their installed capacity, particularly domestic SPPs and wind turbines. However, the shortcomings of this system and the need to transition to alternative pricing systems and support methods are discussed in [11,12,29,49,50]. In addition to the general regulatory barriers for producers of RESs in Ukraine, such as the impossibility of independent participation in the market for bilateral contracts outside the balancing group of the state enterprise “Guaranteed Buyer”, the introduction of contracts for difference, market barriers to participation in any segment of the electricity market, responsibility for imbalances, etc., there are barriers specifically for small and household RESs, as well as prosumers.

Thus, to overcome such obstacles and implement the relevant features of the EU Winter Energy Package, specific legislative innovations were recently initialized with the recent adoption of the Law of Ukraine “On Amendments to Certain Laws of Ukraine Regarding the Restoration and Green Transformation of the Energy System of Ukraine” (Reg. No. 9011-d). This law allows for the implementation of the provisions of European legislation, which is extremely important for the EU integration of Ukraine [51,52]. The law establishes a mechanism for issuing, using, and terminating guarantees of the origin of electric energy generated from RESs. It will expand producers' possibilities for electricity sales and increase the economic attractiveness of new RES projects. To introduce new support pricing mechanisms, the auction model for the distribution of support quotas for green energy generators is improved based on the ‘contracts for difference’ model [53]. Among other general issues for RES producers, there is a possibility of exporting electricity surplus during off-peak hours. For this, producers will be given the right to leave the balancing group of the “Guaranteed buyer” and to sell the electricity on the market, receiving compensation under FIT. The right to export green electricity is given to both RES producers and the “Guaranteed buyer” in general.

Concerning the market alternatives of small-scale and household RES producers and prosumers, the concept of the active consumer (prosumer) was introduced. The concept of a new market participant—the “aggregator”—was defined, as well as the possibility of connecting third-party generation facilities to the internal grids of active consumers. Prosumers have been given the right to install RES generation facilities and energy storage to meet their consumption needs and sell the remaining electricity under the net billing model. For this, self-production contracts will be negotiated between consumers and

electricity suppliers. The principle of these contracts is that suppliers will purchase leftovers on a market basis (hourly), credit the funds to consumers' accounts, and automatically pay for the electricity consumed by prosumers from the grid at the retail supply price. Until the introduction of the competitive power market system in 2019, Ukraine did not have a sustainable RES financing model. This resulted in the accumulation of significant debt with FIT payments [54]. To transit from the FIT scheme and, at the same time, keep incentives for RESs, bilateral trade schedules for the purchase and sale of electricity should be adjusted for prosumers.

4.3. *The Role of Power Market, Market Integration, and Barriers*

The decentralization of the electricity market provides opportunities for generators to go beyond their self-commitments, including the freedom to choose the ways of contractual power delivery to an agreed location and interact with other producers (aggregation, the exchange of power through bilateral trade, etc.) [55]. Institutionally, this means the arrangement of short-term intraday markets, real-time markets, self-dispatching zones, microlevel means of peak shaving, p2p trading, and the involvement of market participants with as low capacities and annual consumption volumes as possible [31,56]. The early phase of decentralization of the electricity market could also mean the introduction of the first smart grid standards (SMART Grid 1.0–2.0—demand response, distributed automation, IP protocol; e-vehicles; energy storage, smart metering) [37,56].

The decentralization of the power grid due to the sufficient technological level of the network allows for the possibility of the integration of prosumers into the market outside the limits of the self-sufficiency model and the release of surpluses into the DSO grid. As an example of early decentralization and smart grid introduction, the Hawaiian Electric and Honeywell pilot project (2012) demonstrated how demand response technologies could help to integrate prosumers with RESs into the grid [57]. The system of “fast demand response” (Fast DR) was introduced for commercial and industrial consumers, who had the option of reducing electricity demand within 10 min of receiving a notification of an imbalance between demand and generation.

Similar cases in the early stages of EU SMART power are the project ADDRESS (active distribution network with full integration of demand and distributed energy resources), implemented in 2008–2013 [58] to manage distribution networks for “active consumer” integration and FENIX (flexible electricity networks to integrate the expected energy evolution), implemented in 2005–2009 [59] and aimed to construct a flexible electrical network. The main objectives of the latter were to elaborate the functioning mechanisms of the pan-European energy system, in particular, to develop the concept of virtual power plants and generate algorithms for including decentralized generation sources and RESs into the general energy system.

Using the EURELECTRIC classification [60], we can define the early stages of power market decentralization as the introduction of the early standards of smart grid. This corresponds to the first two stages of the technological development of the grid: (1) the development of conventional grids, including the rapid identification of damage and self-healing capability through network automation; the expansion of grid operation and management; and intelligent measurements; and (2) intelligent integrated generation through the balancing of the energy system with a large share of various RESs, including decentralized generation; the integration of EVs and heating and cooling systems; and intelligent energy storage solutions.

If focusing on the opening phases of the competitive market, defined by the possibilities of market participation, and on the means of feeding the grid for participants with a small connected load of less than 1 MW, the first stages then entail the admission of participants with a connected capacity of more than 1 MW. British power market underwent its early stages in 1990–1994 [61]. Initially, only large electricity consumers with a connected capacity of more than 1 MW were allowed to enter the electricity market. This group of consumers originally included only a small number of relatively large industrial companies.

Since 1994, consumers with a connected power of more than 100 kW have been admitted to the electricity market, while consumers with a connected power of up to 100 kW have only been allowed to enter since 1998.

Therefore, the early phases of the decentralization of the electricity market overlap with the beginning of the technological development of smart grids and correlate with the initial stages of market opening. Indeed, grid technological development can promote or inhibit the development of prosumerism [33]. For instance, Latvia's net-metering model hinders solar energy development in households because it does not render SPPs attractive investments [62,63].

It should be noted that the above-mentioned stages are primarily characterized by the underdevelopment of auxiliary market and financial institutions that would accompany the activities of prosumers, as well as nongovernmental financial institutions providing investment support, market aggregator agents, and market flexibility tools for greater prosumer participation in the market. Development companies and aggregator firms are among the market agents that follow the emergence of prosumers and contribute to enhancing their presence on the market. More than twenty companies in Ukraine are engaged in the development and implementation of turnkey projects for home power plants. They are SunsayNRG, Tolk, Unisolar, Ecosphera, OngSolar, Campus-bild, Megawatt, Xolar, Gener, Sunlarix, and Solarsystem. Some startups, such as Joule, help potential prosumers find appropriate subcontractors and experts in a particular region and perform comparative characteristics of available equipment and technologies. Despite the development of prosumer-related institutions, which is a specific evolution to the green transition and power system decentralization, prosumerism could have a significant impact not only on the increase in its share but also on the condition of prosumers' power market integration. To this end, in many developed energy markets, flexibility mechanisms are introduced in both the retail (aggregators at the local flexibility markets) and wholesale (organized) sectors through market-based platforms, in particular, the day-ahead flexibility market mechanism [36]. Sufficient price incentives and diminishing barriers are the keys to participating in such sectors for aggregated prosumers.

Grzanic M. et al. [25] reviewed the pricing evolution and strategies providing different opportunities for prosumers. They noted the lack of investigations concerning prosumers' producer-side pricing and envisaged three models for prosumer-grid interaction. They include single prosumer flexibility, aggregated multiple flexible prosumers, and energy community with the possibility of p2p trading and two different types of aggregation: microgrids and energy communities. In the early stages of prosumerism, single flexibility usually dominates with some presence of energy communities but without p2p mechanism implementation because of the modest rate of smart grid development. The incentives for passive consumers to become active market participants are as follows: dynamic market prices, a reduction in network charges, pricing mechanisms for new balancing groups, and direct trading.

4.4. Externalities' Point of View

The development of decentralized generation and the significant growth in prosumers' share in the energy mix can have both positive and negative external effects (externalities). As studied in [18], sustainable transitions are slowed down, suspended, and even postponed because of the need to avoid negative externalities that threaten the stability of the system. In contrast, positive externalities can accelerate energy transitions and foster sustainable economies [19,64].

Thus, the positive externalities of prosumer expansion, which have a tangible impact on power systems, energy security, and other main socioeconomic parameters, are primarily considered as follows:

- Fostering sustainable energy transitions due to ownership diversification and the distributed generation approach, which is called the "key to a successful energy transition" [64];

- The decentralization of power systems and bringing energy sources closer to places of their consumption to provide energy for regions, as well as reducing the daily irregularity of consumption, which increases energy security and reduces losses of energy carriers during transportation;
- The development of horizontal (p2p) power markets, including numerous smart grid and microgrid projects, to demonstrate the synergetic effect of combining distributed energy sources with new grid design and technologies in power self-supply, creating prerequisites for more competitive markets.

The negative externalities that follow a significant number of prosumers entering the power market and inhibit the progress of decentralized power systems toward the transition to green technology have a systemic nature and are mostly evident when the development of power technologies is heterogeneous, and regulation is sporadic. The externalities related to technology include the effects on the operating modes of DSOs and the need for nonstandard connections in some places in case of interactions with the public network, energy storage, designing for the flexibility of load and generators, and EV charging. Some distribution system operators and utilities are skeptical of such new connections because injecting excess prosumer generation into the grid during surplus periods is subject to technical and regulatory complications and leads to greater imbalances. However, externalities in the form of increased daily irregularity and the increased need for backup capacities and/or power limitations are not expressed as much as in large-scale RES generation. In [20], it is emphasized that the unsustainable operation of RESs can worsen the level of energy security, so the need for supporting RES equipment with backup capacities (flexible generating facilities and energy storage capacities) should be taken into account when assessing the integrated indicator of energy security.

Among the negative externalities related to the economy are the difficulties of purchasing electricity surpluses by DSOs, namely, peculiarities concerning obligations and FIT. The situation with the ban on the ground household SPPs and the entrepreneurs' "loophole" to avoid such a ban (for example, installing household SPP "garlands" on abandoned buildings) led to a negative impact on the household SPP sector as a whole. This externality must be regulated in a different way than by prohibiting all households from installing on-the-ground solar panels.

In [18], it is highlighted that negative externalities might be minimized by an adequately tailored policy. In the case of small-scale RESs and prosumers, it should be externality market arrangement, supplementary market arrangement, market redesign, and broader economic assessment and reassessment (e.g., RES system value assessment, which embraces environmental, social, and economic efficacy, includes power system flexibility impact; reduction in water use; employment impact, as discussed in previous studies [10,65,66]; and net billing model application concerning the externalities of FIT misuse).

4.5. Estimation of Prosumer Incentives

With a relatively high level of FIT and open opportunities for market participation, estimating prosumer efficiency allows us to understand why the rate of new prosumers' emergence is unsatisfactory. This assessment takes into account existing regulatory and institutional constraints reducing the attractiveness of prosumerism under three scenarios of self-consumption/production ratio: 0.4 (a prosumer consumes 40% of electricity and 60% is fed into the grid yearly), 0.2 (20% is consumed) and 1 (all the electricity generated is consumed for the household's own needs). Several factors are considered for the evaluation of the comparative production efficiency. First of all, it is the parity or nonparity between the FIT (price of sale to the grid) and the weighted average daily DAM price. The values of the factors relevant to the Ukrainian power market, which influence the prosumer efficiency (equipped with PV), are presented in Table 1.

Table 1. Values of the factors that impact the overall prosumer efficiency in Ukraine.

Factor	Unit	Values		
Tariff for households	EUR/kWh	0.042	0.066	0.160
FIT rate	EUR/kWh	0.163	0.146	0.146
DAM base price	EUR/kWh	0.070	0.088	0.140
DAM off-peak/base rate		0.930	0.800	0.800
DAM entry fee	EUR/month	100	100	100
DAM aggregator fee	EUR/kWh	0.0100	0.0100	0.0100
LCOE PV	EUR/kWh	0.050	0.040	0.030
Consumption/production rate		1	0.4	0.2

Sources: authors' assumptions based on [67–70].

Today, the household consumer tariff compensates only less than half of the actual electricity production, transmission, distribution, and supply cost. This underpayment is the cause of cross-subsidization and price distortions in the market. Under the previous market model (single buyer), this burden was distributed among all other consumer categories. As a result, the cost of electricity for the country's economy became more expensive. Under the current market model (full-scale competitive market), price distortions are compensated at the expense of the most important power producers and market entities, which are determined as entities that participate in public services' obligation mechanism (the imposition of special obligations to protect public interests). From 1 June 2023, the Government of Ukraine has once again increased the fixed tariff, but it still does not compensate even half of the market cost of electricity [67].

FIT is established until the end of 2029; its amount is EUR 0.163/kWh until 2025 and will be EUR 0.146/kWh from 2025 [68]. The Ukrainian government has recognized that the FIT system is obsolete for the continued support of RESs and is in the process of introducing the system of net billing in relation to the electricity price of the DAM market. The level of DAM prices varies greatly due to regulations on price caps. In June 2023, it was EUR 0.070/kWh, and after the increase in price caps on 30 June 2023, it reached 0.100/kWh and has the prerequisites to rise higher [69]. Additionally, the law will oblige households to purchase batteries to store electricity for at least four hours of consumption.

The base/off-peak or peak/base price ratios determine the extent of DAM price fluctuations for the Ukrainian power market. Prosumers' surpluses that are fed into the grid correspond to the time of day with maximum solar irradiation in the case of PV plants and mainly to night hours in the case of wind power plants. The use of batteries makes it possible to accumulate surpluses and use them under the net billing system at the maximum prices corresponding to peak values. The less the DAM off-peak/base rate is, the more incentives a prosumer has to exploit generating units together with power storage units, apart from the expected regulatory obligations introduced in legislation.

High entry barriers for prosumers to participate in the market, namely, aggregator fees and DAM market participation fees, can reduce the incentives to participate in the market directly or through an aggregator. The fixed rate introduced for prosumers to participate in the market at the level of EUR 100/month can be significant for small prosumers but acceptable for the aggregator. In the case of introduction for small DAM participants, the specific fee rate per amount of electricity accepted and sold should not create additional barriers to their participation.

The results of the prosumer efficiency (equipped with PV) evaluation as the integral consumption and delivery incentive are shown in Table 2.

Table 2. Prosumer efficiency (consumption (C) + delivery (D) incentive) under three scenarios of self-consumption/production ratio.

Parameter	Unit	Tariff for Households		
		0.042 EUR/kWh	0.066 EUR/kWh	0.160 EUR/kWh
C/P rate 0.4				
C+D incentive FIT	EUR/kWh	0.0586	0.0682	0.1058
C+D incentive NB * low price caps	EUR/kWh	0.0028	0.0124	0.0500
C+D incentive NB medium price caps	EUR/kWh	0.0136	0.0232	0.0608
C+D incentive NB high price caps	EUR/kWh	0.0448	0.0544	0.0920
C/P rate 0.2				
C+D incentive FIT	EUR/kWh	0.0808	0.0856	0.1044
C+D incentive NB low price caps	EUR/kWh	0.0064	0.0112	0.0300
C+D incentive NB medium price caps	EUR/kWh	0.0208	0.0256	0.0444
C+D incentive NB high price caps	EUR/kWh	0.0624	0.0672	0.0860
C/P rate 1				
C+D incentive	EUR/kWh	−0.008	0.016	0.1058

Source: authors' estimations. * NB—net billing.

Table 2 reveals several findings:

- Participation in the market is relevant only for DAM prices above 5400 UAH/MWh for any tariff for households.
- The incentive for prosumerism doubles at the tariff for households close to the market value, more than twice higher than the fixed value.
- The incentive to deliver a larger share to the grid than to consume (0.2 vs. 0.4) increases with high DAM price caps and decreases when the household tariff rates are brought up to the market level.

5. Conclusions

In the early stages of electricity market decentralization, which overlaps with the technological evolution of electricity grids toward smart grids and is correlated with the initial stages of market opening, the development of prosumerism is based on the incentives of individual projects. The state's regulatory role is enhancing such incentives as well as diminishing constraints, namely, market barriers, institutional costs, and barriers to technology transfer. The comparative efficiency of consumption and the absolute efficiency of production are aggregated and estimated as the sum of energy cost savings on the consumption side and the profit from sales to the grid/to the power market.

The analysis presented in this article has certain limitations regarding regulatory energy policy. The limitations include the application of price caps, fixed electricity tariffs for vulnerable consumers, and restrictions on the ratio of electricity self-consumption/delivery to the grid for households. These restrictions may vary from country to country, but for the most part, they apply similarly in the early stages of market decentralization.

The minimum value of the prosumer efficiency for the Ukrainian power market in the early stages of its decentralization and smart grid development is −0.008 EUR/kWh, assuming a low fixed household tariff and that the consumption/production rate is equal to unity. Thus, the above-mentioned factors are the least favorable conditions for increasing the number of prosumers. The maximum level is equivalent to 0.1058 EUR/kWh,

corresponding to market-based household tariffs regardless of how much electricity the prosumer can supply to the grid.

This paper shows that the possibility of reducing the cost of own electricity consumption is of primary importance to fostering prosumerism. The gradual movement from fixed tariffs for households toward market-based prices promotes new prosumers' emergence and their consolidation in the market as new stakeholders. We could double the incentive for prosumers by raising the tariff for households twice as high as the current fixed value so that it approaches the market-based value. Incentives to feed a larger amount to the grid than the amount consumed (0.2 vs. 0.4) increase with high DAM price caps but slightly decrease when the residential tariff is raised above the market-based level.

Low price ceilings hinder prosumers' participation in the organized wholesale market. Therefore, the transition from FIT to net billing is recognized as progressive, given greater competitiveness and market orientation, flexibility, and compliance with daily market price dynamics. However, like FIT, it will significantly promote the increase in the number of prosumers only under relatively high upper price caps or their absence during peak and off-peak hours.

Although FIT has been the most effective tool to promote prosumerism. Current regulatory policies should focus on facilitating the participation of new entrants, namely aggregators and developers, who are also essential contributors to the development of prosumerism. Additionally, investment grants/subsidies are needed for both individual prosumers and energy cooperatives to overcome capital cost barriers and encourage prosumers.

Author Contributions: U.P., O.K. and V.V. conceptualized and prepared the methodology for the project. U.P. and G.T. performed the formal analysis. V.V. contributed to software analysis. I.S., O.K. and M.Z. guaranteed the resources and data curation. M.Z. and U.P. wrote the original version of the manuscript. I.S., G.T. and V.V. participated in the writing of the article by reviewing and editing the manuscript. M.Z., I.S. and O.K. supervised the study and contributed to visualization. I.S. and O.K. were responsible for project administration. M.Z. and I.S. secured the funding. All authors have read and agreed to the published version of the manuscript.

Funding: This publication was prepared in the framework of the research project: Formation of Economic Mechanisms to Increase Energy Efficiency and Provide Sustainable Development of Renewable Energy in Ukraine's Households" (No. 0122U001233), funded by the National Research Foundation of Ukraine.

Data Availability Statement: This study analyzed publicly available datasets.

Conflicts of Interest: The authors declare no conflict of interest. The funders had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript; or in the decision to publish the results.

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