

Research Paper

Development of energy cooperatives in Ukraine: scale, energy mix and business models



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ABSTRACT

The paper explores the prerequisites for the expansion of energy cooperatives as a market-based form evolving from self-sufficiency of electricity supply to the wide range of models of the energy and energy-related business activity, basing on the international and Ukrainian experience. We assume that a cooperative size and energy technologies combination are important parameters that determine their efficiency. The insufficient per capita household income as the barrier of the energy cooperatives development hinders the development of sustainable energy and market transitions. To provide the investments that are able to cover the cost of purchasing and installing of generating units for self-sufficiency and active consumption, it is needed to align the share contribution and the needed installed generation capacity sufficient for the number of participants united with the appropriate amount of the share contribution and to define the optimal cooperative size. Maintaining the individual interest for each participant creates a driving force for increasing the number of energy cooperatives.

1. Introduction

Modern challenges in the field of energy security and decarbonization are prompting countries and communities to look for new approaches to energy production and consumption (Ostapenko et al., 2023; Sotnyk et al., 2022, 2023). One of these solutions is energy cooperatives, a form of collective management of local energy sources based on the principles of voluntariness, openness, and economic participation.

For Ukrainian communities, especially during the war and post-war period, this model is not only a tool for cutting expenses and earning profit, but also a means of strengthening energy independence, creating jobs, and developing the local economy.

Environmental problems related to fossil fuel extraction, depletion of fossil fuels, overloading of low voltage electrical grids and deterioration of their performance are the reasons for integrating sources (small generating capacities) of distributed generation (DGS) and converting the existing power system into a restructuring one. So, that is a question

of creation of local electric systems and micro electric grids which would promote the increase of energy efficiency of RES during their operation, namely – the creation of energy cooperatives.

The rapid pace of the new RES facilities construction can also boost employment in the amalgamated territorial communities (ATCs) in Ukraine by creating jobs in new green technologies (Trypolska et al., 2021). Since energy cooperatives are mostly focused on the implementation of local projects to ensure energy independence from district heating and electricity, the installation of distributed generation facilities is appropriate, of course, taking into account the priority of environmental friendliness. Therefore, the projects of using RES in DGS and creation of energy cooperatives are promising.

Thus, this study aims to substantiate the role of energy cooperatives for establishing optimized self-sufficient energy systems with a high degree of decentralization with the participation of household consumers and territorial communities. The research examines the efficiency of energy cooperatives and their parameters: number of participants, share contribution (funds, equipment, property rights, land

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plots contribution, made by a member for a cooperative creation and development), cooperative size, installed capacity, self-sufficiency share, individual interest. The offered approach can be proposed for the evaluation of an energy community of versatile type and business model.

The remainder of this article is organized as follows: [Section 2](#) presents a review of studies on the economic issues associated with energy cooperatives, their business models, their role in the power system decentralization. [Section 3](#) describes the research methodology and calculation stages. [Section 4](#) presents the results of the versatile energy cooperatives parameters estimation and the comparative analysis of bioenergy cooperatives and outlines the role of energy cooperatives in the sustainable energy transitions. [Section 5](#) provides the conclusions and further provisions for using the study results.

2. Material and methods

Energy cooperatives have been around for decades and have proven to be effective. In the United States, energy cooperatives are widespread and operate in a different format: mostly owing power grids and supplying energy to consumers. In the 1930s, electricity was already being actively used in cities, but not in rural areas: it was not profitable for companies to build networks in sparsely populated regions of the country. That's why energy cooperatives began to emerge after the passage of the Rural Electrification Act of 1936. It made it possible to receive federal loans for the construction of power grids, and such funding went to cooperatives created by local residents.

Most of these organizations are still operating today. Cooperatives own 42 % of the power grids in the United States and serve 12 % of the population ([NRECA, 2024](#)). At the same time, they also produce 5 % of the country's electricity and are gradually increasing the share of renewable energy. While in 2010, solar power plants in cooperatives had an installed capacity of only 35 MW, in 2018 it was 916 MW ([Wierling et al., 2018](#)).

Energy cooperatives are currently most widespread in Germany. The active development of renewable energy projects was stimulated by the "feed-in tariff" introduced in 2000, and in the next few years, organizational requirements for cooperatives were also simplified. The number of new associations peaked in 2011. After the abolition of the fixed tariff in 2012, this trend began to decline. At the same time, the public energy sector is considered to be one of the drivers of the country's transition to renewable energy, especially in the early stages. In 2012, 46 % of the country's "green" capacities belonged to citizens and cooperatives. In 2016, this number dropped to 42 %. There are still about a thousand energy cooperatives in Germany. About 60 % of them use solar power plants, 30 % use wood, 20 % use wind power plants, and 9 % use biogas (one cooperative can have several areas of operation) ([Wierling et al., 2018](#)). However, the regulatory and infrastructural complexities remain, impacting the full enablement of RECs and CECs trading, such as complications in permitting, grid access bottlenecks and insufficient incentives to stabilize costs ([Addleshaw Goddard, 2025](#)).

An energy cooperative as an institutional form could be the part of the energy community institution. The least includes also eco-villages, citizen renewable initiatives, small-scale heating projects etc. ([Caramizaru, Uihlein, 2020](#)). The energy communities' models were examined by [Orlando et al. \(2023\)](#), in which a combination of local cooperation and financial incentives can promote the wider adoption of green technologies in households. The need to strengthen policy coordination and communication with end users and the key trends in the development of renewable energy sources were discussed by ([Kuzior et al., 2021](#)), ([Sabishchenko et al., 2020](#)), ([Zaitseva-Chipak et al., 2024](#)). They emphasize the importance of developing and applying flexible financial models, engaging the citizens and businesses in energy transition. Some researchers argue that the citizen-led energy communities could conclude waste share of EU energy balance (half of EU citizens could be producing their own energy by 2050 ([Kampman et al., 2016](#)).

However, the deeper research of energy cooperatives optimum parameters and their efficiency in the different market conditions under the regulation is needed. The further development of methodology for the energy cooperatives parameter assessment is necessary, taking into account the different energy technologies deployment combination.

Commissioning of new generating units from traditional or renewable energy sources is capital-intensive. The level of individual per capita household income in the country does not provide sufficient investment to cover the cost of purchasing and installing individual generating units for self-sufficiency and active consumption, even taking into account the rapid movement of energy technologies along the learning curve and the significant reduction in levelized cost of electricity (LCOE) ([Sotnyk et al., 2022, 2023](#)). This is a key factor in bringing together community members and businesses to co-finance various local projects for decentralized, reliable and environmentally friendly energy supply. Therefore, energy cooperatives are becoming an effective public and socio-economic model as part of the local government (community) development policy. As such, an energy cooperative uses its social leverage to implement energy projects by jointly overcoming administrative and political barriers, and with the help of economic leverage, economic barriers: lack of or inadequate state support systems, high financial risks, lack of expertise and engineering expertise, conflicts of interest with other stakeholders, suppliers of fossil fuel and energy resources, and representatives of centralized energy systems.

The advantages of decentralization in peacetime are that the operation of energy sources as close as possible to the places of consumption reduces the technological costs of its transportation, which ultimately reduces the cost of energy due to the removal of the "transmission and distribution" component of the cost, as it allows electricity to be supplied to the end consumer without transmission and distribution fees in accordance with the amount of electricity consumed, and during martial law - greater autonomy and independence from centralized energy sources. Thus, the cost advantages of decentralization combined with security benefits form the basis for a sustainable energy transition ([Sotnyk et al., 2024](#)). Energy cooperatives are able to bring together a wide range of actors from civil society, agriculture, and business to meet energy needs at different levels. Proven is the importance of the creation of cooperatives based on the various business models: active consumption (prosumers), heat supply models (cogeneration), system service providers, electric mobility services, energy storage, energy-efficient contracting, and businesses involved in the production and sale of bio-fuels, with the maximum use of the opportunities offered by local energy balances instead of the mono-business model (increasing the number of sources of self-sufficient demand based on solar energy systems). In this regard, the transition from the currently most widespread mono-model based on photovoltaics to the models that combine energy technologies is important.

3. Theory and calculation

3.1. The evolution of business models of energy cooperatives

Energy cooperatives are created around a wide range of economically available and technically feasible technologies for the use of alternative energy sources, as well as in combination of these technologies with highly efficient traditional ones (gas turbine, gas piston, and electric storage technologies). However, it is not only technology that determines the type of energy cooperative, but mainly the function of the cooperative in providing energy to the community: energy production, energy supply and efficient procurement, energy service as a type of activity in the energy sector. D. Oliynyk identifies such activities of energy cooperatives as the sale of energy to end users, provision of energy supply and energy efficiency services, which aims to reduce energy poverty and develop local energy infrastructure ([Oliynyk, 2017](#)). At the same time, energy cooperatives, while valuable for mobilizing finance and involving citizens, can be less optimal for immediate support to

vulnerable populations because of the share purchase hurdle. Structuring supportive frameworks, such as lending shares or incorporating subsidies, could help mitigate this limitation in cooperatives but RECs and CECs inherently offer lower barriers to entry for socially vulnerable members. This flexibility of functions and types is a significant advantage of the cooperative organizational and legal form. Based on these functions, the following are formed:

- production cooperatives specializing in the production of energy resources and/or the cultivation and processing of energy raw materials, and the use of secondary energy resources;
- consumer cooperatives that act as trading entities in the energy markets to ensure the interests of their members - their activities include participation in the segments of the electricity market, aggregation, trading, wholesale purchase of energy resources (joint purchase of energy raw materials (firewood, pellets, briquettes/pellets made of straw and wood), wholesale purchase of energy efficiency services (energy audit services, thermal modernization of residential and industrial or office facilities); organization of the purchase of energy installations (boilers, batteries, solar panels (Kuzmina, 2019) by cooperative members for further individual operation (which distinguishes them from production cooperatives).
- energy service cooperatives that can operate as ESCO companies under the performance contracting mechanism, as well as provide engineering and technical support services. The possibility of such activities is ensured by the regulatory framework (Laws of Ukraine “On Cooperation”, “On Consumer Cooperation”, “On the Electricity Market of Ukraine”, “On Alternative Energy Sources”), according to which energy cooperatives, in addition to the production, transportation and supply of energy resources, have the right to provide services related to the energy needs of cooperative members and the community.

While the purpose of production and energy service cooperatives, in addition to stable and reliable self-sufficiency in energy resources at minimal cost, may be to make a profit from the sale of surplus energy to third parties, as well as to ensure the interests of third parties, the purpose of consumer cooperatives is to optimize their own energy supply costs and increase the reliability of fuel and energy supplies.

The decentralized model of energy involves expanding the participation of non-core stakeholders from the non-energy business and individuals in the investment and management of energy facilities. Thus, as for the non-energy Ukrainian business entities, Metinvest, Myronivsky Hliboproduct, Dnipro Metallurgical Plant, Nova Poshta (Nova Energy), Epicenter K (Epicenter Energy), Myrhorod Mineral Water Plant, AgroVista Holding and other enterprises commissioned new distributed generation facilities in a short time in the face of the full-scale invasion of Russia. For individuals and communities, the process is slower, as investment opportunities are much smaller. Therefore, the dynamics of creating energy cooperatives lags behind the dynamics of developing the energy business of non-energy enterprises.

The model of an energy cooperative as a set of active consumers requires RES and/or energy storage facilities connected to the consumer’s internal networks (in order to participate in the ancillary services market, provide balancing services and purchase and sale of electricity) and provides for participation in organized market segments independently or as part of aggregated groups. The status of an active consumer provides the cooperative with advantages in the electricity market, namely: no connection fee when connecting to the networks of other consumers, electricity supply to the DSO and TSO networks within the permitted capacity (no more than 50 % of the consumption capacity), operation in the market under the net metering mechanism, easier access to bank guarantees, capacity tenders and co-financing projects to expand existing capacities.

The model of an energy cooperative as a member of a balancing group (e.g., as part of the balancing group of the State Enterprise

“Guaranteed Buyer”) provides for the sale of surplus electricity to this enterprise, which is also the party responsible for the balance, at feed-in tariff rates. The Group’s electricity is sold by the company at auctions of the Ukrainian Energy Exchange (bilateral contracts segment) or on the DAM. The limiting factor is the company’s untimely payments to the group members and accumulated debt for electricity. Therefore, there is a tendency to leave the group under the scheme of temporary suspension of the contract, which allows rejoining the balancing group in case of more favorable conditions within it.

The global experience of forming various business models of energy cooperatives as an institution indicates common principles of their functioning with enterprises (profit), and at the same time, with a self-governing community - democratic governance, social orientation and adherence to the principles of sustainable development. The principle of “one member, one vote” allows members of local communities to influence their development and determine its strategic directions.

The study (Energy Cooperatives, 2022) presents the division of energy cooperative business models inherent in Western Europe (formal division into REC and CEC due to differences in the definition of the latter (Trypolska et al., 2023)): energy centers (energy hubs), bioenergy villages, and energy cooperatives of different directions depending on the energy technology (type of energy resource), in particular, a cooperative based on biomass processing, biogas, and heat recovery (heat pump cooperative). A generalization of business models and types of cooperatives depending on the energy technology is given in the Table 1:

Energy centers (energy hubs) generate and/or sell electricity to cover the electricity needs of local consumers, including energy cooperatives, districts, settlements, industrial and non-industrial enterprises, including in the form of power supply and balancing of microgrids of small enterprises or local organizations. Energy centers promote the use of electricity from RES for industrial and domestic needs both practically and educationally, playing the role of educational hubs and technology centers for RES and energy efficiency.

On the basis of energy cooperatives, bioenergy villages can be created, with electricity produced for the needs of the community. For example, one of the first bioenergy villages, Junde (Germany), is a photovoltaic + wind energy cooperative. The community of Junde operates a 500 kW biomass boiler (wood chips), a photovoltaic solar power plant, a 700 kW biogas CHP plant that consumes 17 thousand tons of biomass (agricultural waste) per year, and a 5.5 km heating main (Zhelezna, 2021).

Types of energy cooperatives based on a combination of energy technologies. Although the construction and operation of an energy cooperative based on a single energy technology is organizationally and economically simpler, the advantages of basing an energy cooperative on a combination of energy technologies over a mono-technology are:

Table 1
Business models of energy cooperatives.

By combination of energy technologies	By scale and “industrial / domestic / industrial-domestic” feature
<ul style="list-style-type: none"> - Industrial and domestic with a gas piston / gas turbine unit - Photovoltaic + cogeneration - With heat storage - “Optimal Wartsila configuration” - With local networks (USA) - With thermal insulation of buildings (energy efficiency cooperatives) - Photovoltaic - Photovoltaic + wind - Photovoltaic + biogas - Biogas / biomass - Heat pump - Electric storage 	<ul style="list-style-type: none"> - Energy centers (energy hubs) - Bioenergy villages - Cooperatives for heat supply - Cooperatives around the source of renewable energy - Cooperatives with an industrial enterprise as a part By main function - Production - Consumer - Energy service Participation in the energy market - Participant in spot energy market segments (DAM and IDM) - Active consumer - Member of the balancing group

Source: developed by the authors

- (1) minimization of RES limitations, optimization of schedules of power output by generation types;
- (2) the ability to offer a competitive level of electricity prices for transmission to the grid due to the combination of RES and highly maneuverable technologies, since in power systems with a high share of RES, the equilibrium price depends mainly on the balance of supply and demand rather than the cost;
- (3) diversification of energy sources, which increases the reliability of energy supply in the event of equipment failure or reduced availability of fuel (e.g., shortages or logistical disruptions in biomass supply).

The most common model is based on photovoltaic mono-technology (solar panels) - the model of a photovoltaic cooperative, which mainly takes the form of consumer cooperatives for self-sufficiency and sale of surplus electricity under feed-in tariff and net billing scheme (Trypolska and Rosner, 2022; Trypolska et al., 2024).

The formation of energy cooperatives using biomass is usually localized in communities that develop the cultivation of energy raw materials for biofuel production and/or have sources of biomass production as waste from woodworking industrial processes. For example, in Austria and Poland, biomass processing cooperatives are a very common type of energy cooperative (Caramizaru, Uihlein, 2020). The cooperative is formed on the basis of a farm, wood harvesting, forestry, or furniture company. Other common cooperative options are biomass farms, CHP/mini-CHP/biomass boiler house with district heating systems. Such facilities can be jointly owned by the community, farmers, and forest land owners and can bring together a large number of farmers. Cooperatives based on biomass district heating and electricity systems are a type of consumer cooperative where citizens unite to purchase and distribute electricity and heat from a cogeneration source.

The “Wartsila Optimal Configuration” is a combination of energy technologies that could be the basis for an energy cooperative, developed by Wartsila as a result of modeling the cheapest configuration of electricity and heat generation capacity in post-war Ukraine. The configuration is a highly maneuverable gas-fired capacity with electrified heat sources to balance the renewable energy plants and could form the basis for large-scale decentralization of Ukraine’s energy system (Petryk, 2025).

The predominant business model of energy cooperatives in Ukraine and the world at the stage of their formation is the following: the

cooperatives based on decentralized renewable energy projects using solar energy and biomass, which performed the function of self-sufficiency in energy resources and sometimes expanded to active consumption.

The evolution of business models of energy cooperatives takes place from the initial model of self-sufficient demand (self-consumption) to six main models (Fig. 1), which are essentially self-sufficient demand models with the provision of energy and non-energy services to third parties:

- active consumption (prosumers);
 - models with heat supply (cogeneration);
 - system services (provision of services to the system operator from the primary, secondary, and tertiary reserves);
- The concepts of decentralization of the energy system are based on self-sufficiency of demand of local systems, which can be energy cooperatives, as well as on ensuring maneuverability in the electricity market, smoothing fluctuations in generation and load. Technologically, it is realized through the operation of electricity storage and heat storage facilities, cogeneration units, their combination with photovoltaic systems, and the operation of bio CHP (mini-CHP). Digitalization and the participation of aggregators provide an opportunity to integrate real energy sources with a virtual power plant and/or aggregator for an effective presence in the electricity market and local heat supply. Furthermore, (DGRV, 2007) points out the crucial role of energy cooperatives and their local structures in the decentralization of energy systems;
- electric mobility (providing charging services for electric vehicles to their owners). In particular, a proposal from an energy cooperative to share electric vehicles in partnership with local utilities or other companies that can provide equipment and engineering that goes beyond the knowledge and capabilities of cooperative members. Electromobility as a business can empower communities through sharing concepts, especially in rural and tourist areas where the need for mobility is prevalent and alternative transportation is lacking;
 - energy efficiency contracting (provision of energy efficient services to third parties): energy efficiency and energy saving measures that increase economic efficiency through more rational use of resources, as well as building financial and operational models for renewable energy installations;

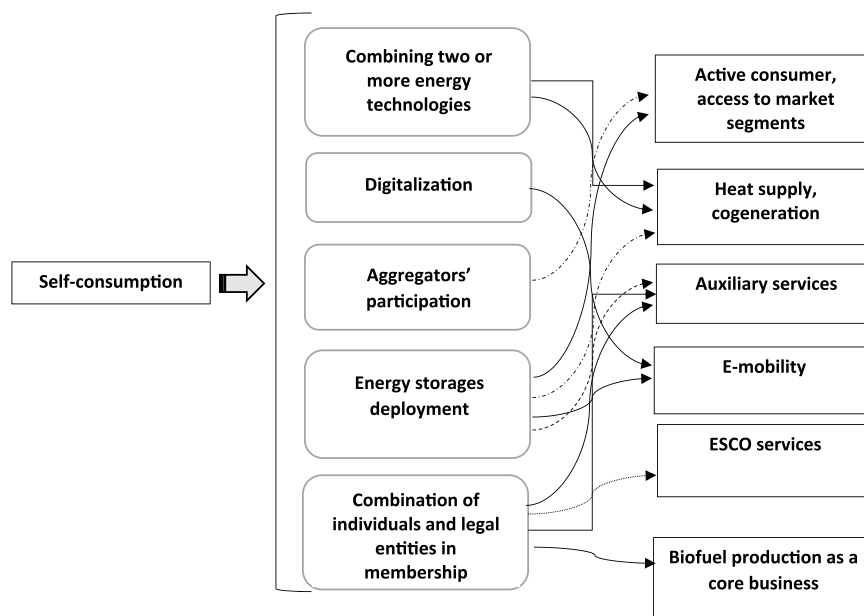


Fig. 1. Evolution of business models of energy cooperatives Source: developed by the authors.

- biofuel production businesses: there are energy cooperatives in Ukraine that grow energy willow and sylvan (e.g., Severinivka village, Vinnytsia region).

The prerequisites for the emergence of new business models were the following factors: the emergence of new market agents - aggregators - on the market and legislative consolidation, increased flexibility by combining several energy technologies, including cogeneration, electric storage, coverage of the district heating sector in the territory of the cooperative, including the use of heat storage to optimize the load of power generating equipment. A separate factor was the awareness of cooperative members and the regulatory and legal support from the state for the creation of energy cooperatives with mixed participation of individuals and legal entities. Legal entities that are members of the cooperative are industrial enterprises as

- owners of decentralized generation of small and medium capacity - gas piston, gas turbine, industrial heat pump, etc;
- Sources of fuel and raw materials and secondary energy resources for the cooperative (farms, logging enterprises, food processing enterprises (oil extraction plants, fruit and vegetable processing).
- The legal form of the businesses that the cooperative is engaged in as its core business, such as growing raw materials and producing biofuels, providing energy efficiency services, engineering and manufacturing energy efficient equipment, and providing energy storage services to other communities.

3.2. The scale of the energy cooperative and its efficiency

The scale threshold of an energy cooperative is the total installed capacity of energy facilities operated by a single cooperative, which can be expressed in terms of the amount of individual share contribution of cooperative members, beyond which the efficiency of cooperative management decreases due to the peculiarities of local community self-government mechanisms and the requirements for the operation of an energy facility of a certain technology in the power system and work in the energy market. We will call it the “effective range of scale”. Increasing the scale within the effective range allows to increase the opportunities for representation of the cooperative in different market segments and expand its activities (change the type of cooperative).

The more types of activities a cooperative combines (the more branched the type), the more flexible and efficient the cooperative is. Efficiency increases especially when several types of primary energy sources are combined (e.g., sun + wind, sun + biogas), several types of final energy sources (electricity + heat), and goods are combined with services (electricity generation + system services). In turn, branching out requires more capital, which does not necessarily lead to an increase in the size of the share contribution, as well as changes in the cooperative’s management system.

The best practices of building an extensive energy cooperative that combines several types of activities and energy technologies are concentrated mainly in Germany. For example, the Oberrospfe cooperative combines the operation of a biomass boiler (wood chips from the county’s forestry pruning plus purchased wood chips) with a capacity of 850 kW, 2 rooftop photovoltaic installations with a total capacity of 155 kW, a biogas CHP plant, and a 7 km district heating pipeline (Zhelezna, 2021), (Shelenko et al., 2024). All the plants, except for the biogas CHP, were commissioned earlier (2008), and the biogas CHP started operating 4 years later. The energy cooperative, which united several bioenergy villages, required about EUR 4 million in investments at the beginning of its operations, of which 82 % were raised through government grants, EU grants, and loans. Grant and loan support in the amount of at least 80 % of the investment need is the most important factor in the successful construction of an energy cooperative with substantial initial investments.

A prerequisite for the successful functioning of a cooperative is also

the combination of several functional purposes of the cooperative for the community, which allows solving two or more goals simultaneously (energy supply together with waste management, electricity and heat supply), as well as the use of available community resources that can reduce the cost of using the technology (use of renewable energy sources, waste, savings on waste removal, joint land use, use of previously abandoned sites unsuitable for other uses, etc.) At the same time, the efficiency of the cooperative takes into account the opportunity costs of other, more expensive or unavailable energy supply options. Also, the role of the community in the creation and operation of the cooperative is to overcome barriers that depend on the community, such as approval of the use of space for wind turbines or solar panels (obtaining permission is much easier if the result of the facility is used by the community itself, as opposed to community approval of land use for commercial industrial SPPs and WPPs), so community participation in the planning and establishment of the energy cooperative is crucial.

The significant amount of investment in the start-up of the energy cooperative has led to the effectiveness of the public-private partnership mechanism, which has been previously tested in projects for the development of housing and communal services, especially in France.

Thus, according to (Zaitseva-Chipak et al., 2024), the most profitable projects for energy communities in Ukraine are:

- Solar power plants on the roof of apartment buildings;
- Solar collectors for water heating at public utilities;
- Solar power plants to provide energy to utilities;
- Wind generation;
- Heat pumps for heating;
- Electricity from solid waste processing;
- Joint energy storage in settlements where a large number of households have their own solar power plants;
- Stand-alone power plants in isolated areas with difficult electricity supply;
- Biomass CHP and mini-CHP plants;
- Low-potential heat utilization plants.

Energy cooperative efficiency is the efficiency of the promoter expressed per member of the cooperative. The efficiency of the promoter, as studied in (Zhou et al., 2023), is a combination of the comparative efficiency of the consumption side and the absolute efficiency of the production side, which can be expressed as the sum of the savings in energy costs and the profit received from supplying energy to the grid or selling it on the market for each investment option (technology), since the sale of the produced energy resource to the grid or to a trader is a means of generating profit. For an energy cooperative, this expression can be applied as follows:

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

where I_{CD} is the efficiency of the energy cooperative (incentive) per unit of energy produced and consumed, EUR/kg of oil equivalent;

$R_{C/P}$ is the average annual consumption/production ratio or self-sufficiency ratio (volumes consumed by the energy cooperative correlated with the volumes of energy produced per year);

I_C and I_D are incentives for consumption and supply to the grid, respectively, EUR/kg of oil equivalent, which are defined as the difference between the price of an energy resource on the market (from the grid) and the cost of its production by the energy cooperative’s facilities.

Accordingly, the incentives for consumption and grid supply, distributed in proportion to the number of cooperative members, form the individual interest of a cooperative member (additional income over and above the benefit of cheaper energy resources for own consumption) in his or her share contribution.

Let us formalize the share contribution and individual interest of an energy cooperative. The aggregate of share contributions of energy cooperative members forms a share fund – the aggregate of share and

additional share contributions of energy cooperative members (property refundable contributions of energy cooperative members in the form of money, property rights, land plots in the monetary equivalent). Additional share contributions from energy cooperative members in excess of the share, as well as targeted contributions, are also allowed (Vostryakova, 2023).

The amount of a cooperative member's share contribution can be a significant barrier to community involvement due to low household income. Reducing the amount of the contribution to increase participation requires a higher installed capacity of the energy cooperative's equipment to maintain the percentage of self-sufficiency of its members, which in turn requires a higher installed capacity of equipment and limits the possibility of reducing the contribution. This can also lead to a reduction in the capacity available for generation and supply of electricity to the grid, and therefore reduces the profitability (interest) of participation for the cooperative member.

The required amount of the share contribution C is determined by the specific capital cost CAPEX of putting into operation 1 kW of installed capacity of the selected energy technology or their combination, the required value of the installed capacity of the cooperative's equipment N_{inst} and the number of participants involved n :

$$C = \frac{N_{inst} \bullet CAPEX}{n} \quad (2)$$

or

$$N_{inst} = \frac{C \bullet n}{CAPEX} \quad (3)$$

The required scale of the cooperative in terms of installed power generation capacity can be expressed as follows:

$$N_{inst} = \frac{CONS_i \bullet n}{R_{c/p}} \quad (4)$$

where

$CONS_i$ is the consumption capacity of the i -th member of the cooperative.

Capacity of energy production for sale to the market (to ensure individual interest) N_m :

$$N_m = (1 - R_{c/p}) \bullet N_{inst} \quad (5)$$

Accordingly, the individual interest of a cooperative member is the ratio of the member's annual individual income to the value of his or her share:

$$I = \frac{I_D N_m \bullet 8760 \bullet ICUF}{n \bullet C} \quad (6)$$

where ICUF – Installed Capacity Utilization Factor of a cooperative.

Substituting expression (5) into formula (6), we obtain:

$$I = \frac{I_D (1 - R_{c/p}) \bullet N_{inst} \bullet ICUF \bullet 8760}{n \bullet C} \quad (7)$$

Where an individual contribution (share) is defined as:

$$C = \frac{I_D (1 - R_{c/p}) \bullet N_{inst} \bullet ICUF \bullet 8760}{n \bullet I} \quad (8)$$

If we substitute expression (3) into (8), we get an expression for calculating the individual interest of a member of an energy cooperative:

$$I = \frac{I_D (1 - R_{c/p}) \bullet ICUF \bullet 8760}{CAPEX} \quad (9)$$

3.3. The regulatory policy impact on the interest of participants

From the above formalization of the parameters of an energy cooperative, the prerequisites for attracting participants in the energy cooperative and ways to implement these prerequisites, as well as

technological, economic (market) and financial ways to find guarantees of breakeven and financial stability of energy cooperatives follow. Thus, ensuring an attractive value of I for participants requires competitive energy prices formed by the market environment, reducing the need for specific investment costs through a) selection of energy equipment at the best price, optimization of capital expenditures; b) participation of third-party capital in initial investments; c) preferential customs clearance and taxation.

Providing guarantees of break-even and financial stability of energy cooperatives is a task not only for governments but also for non-governmental institutions. For example, the mechanism of bankruptcy protection of energy cooperatives in Germany results in insolvency resistance and a high level of financial security due to regular monitoring through the federation of cooperatives (DGRV, 2007).

At the same time, the state regulatory policy imposes certain restrictions on the activities of energy cooperatives, which can, if not discourage participants from joining cooperatives, but affect the attractiveness of participation in them. The following regulatory levers have an indirect impact on the individual interest of a member:

- capacity limitations and self-sufficiency requirements;
- territorial restrictions;
- restrictions on types of activities and licensing;
- responsibility for the balance;
- rules for energy sharing.

Let us consider each lever separately. The capacity limit and self-sufficiency requirements relate to the restriction on the ratio of production to own consumption ($R_{c/p}$). Thus, in Poland, production may not exceed 80 % of the energy cooperative's consumption, and at least 50 % of the total supply must be consumed by end users (NRECA, 2024). At the same time, the energy cooperative must cover at least 40 % of the energy needs of its members. Production must cover at least 70 % of the cooperative's own consumption needs, or 40 % if the cooperative has been operating for less than a year (Transposition Tracker. Rescoop).

In addition, territorial restrictions can make it impossible for facilities and/or members to join the cooperative, whose participation can expand the cooperative's scale and increase its revenues. For example, in Sweden, there is a regulatory requirement for an energy cooperative to operate within a clearly defined territory with limited geographical distribution (the types of activities and the geographical area in which they are carried out must be specified in the cooperative's charter) (Palm, 2021). Only residents or those who work or are permanently connected with the territory are eligible for membership in the cooperative, provided that their membership is not their main commercial or professional activity.

Removing restrictions on the combination of energy cooperative activities (energy production, distribution, supply, trading, aggregation, storage, participation in balancing, provision of ancillary services to the energy system, energy efficiency services, electric vehicle charging services, as well as production, consumption, storage and sale of biogas and biomass fuel) can increase the individual interest of cooperative members. For example, in Poland, cooperatives can be traders, although they are limited to trading with and on behalf of their members (Caramizaru, Uihlein, 2020). Energy cooperatives may engage in the production of electricity or biogas, agricultural biogas, biomethane, or heat from renewable energy sources, trade in them, or store them, which is carried out as part of activities carried out exclusively in the interests of such cooperatives and their members.

Regulatory restrictions on the capacity of RES generating facilities operated by a cooperative are intended to regulate the impact of cooperatives as promoters on the operation of the power system in terms of the adequacy of regulatory capacities, system modes and restrictions, as well as to establish rules for operating in a competitive market environment. For example, energy cooperatives in many countries are required to limit the maximum installed capacity. For the most part, this

limit is 5–10 MW for electricity production and 40–50 million cubic meters per year for biogas (Uabio, 2019).

Responsibility for balance in the electricity market is a common requirement for energy cooperatives. The cooperative, like any other electricity market participant, is responsible for the balance, i.e. for minimizing the deviation between the amount of electricity consumed and produced. It has to inform the distribution system operator (transmission system operator) of its consumption and production schedules and is responsible for imbalances that arise due to deviations from these schedules. At the same time, there is an option: to be responsible for the balance independently, or to delegate responsibility to a third party (to become a member of a balancing group). For example, in Ukraine, the State Enterprise “Guaranteed Buyer”, which is obliged to purchase electricity from energy cooperatives with an installed capacity of less than 150 kW at a feed-in tariff in excess of their monthly consumption, is the party responsible for the balance for both cooperatives and other RES producers that are part of its balancing group (Procedure, 2019).

Facilitating community energy sharing as equal users of the grid, as well as as a set of consumers and sub-consumers, imposes obligations and restrictions on both energy cooperatives and distribution system operators. For example, in the Czech Republic, energy cooperatives are allowed to participate in energy sharing, but they are subject to a number of restrictions: the number of connection points within an energy cooperative may include no more than 1000 registered transmission/consumption/production points located on the adjacent territory of administrative districts of no more than 3 municipalities. The joint use of electricity outside the cooperative may be carried out only by active consumers, who may be organized into groups consisting of a maximum of 11 points, not limited geographically (Energy Cooperatives, 2022). At the same time, no tax or tariff preferences (e.g., distribution fees, balancing fees) are provided.

3.4. Focus on agro-bio-cooperatives in Ukraine

One of the main obstacles to the emergence of energy communities in Ukraine is the lack of awareness of and knowledge about them. However, Ukraine has a strong and historic cooperative movement, which predates the Soviet era. It has also demonstrated the strength, resilience and mobilisation of its communities and other civil society organisations during the war Nowadays. While the development of energy communities in Ukraine holds great potential, the movement is just beginning to emerge. Energy communities first developed as a by-product of agriculture. Ukraine has a strong agricultural sector and a large, untapped potential to develop biomass (Kurbatova, Hyrchenko 2018a; Kurbatova 2018b, Kurbatova et al., 2023). Many agricultural cooperatives are also energy communities in that they recycle their biomass waste to produce energy for the cooperative or for others, often in the form of heating fuels (WECF, 2017).

The total energy potential of biomass in Ukraine reaches 23 million tons of oil equivalent (toe), with approximately 44 % coming from plant waste and 32 % from energy crops. Agricultural biomass (agricultural residues) accounts for 11 million toe per year, while promising energy crops add another 7.45 million toe, offering broad opportunities (Uabio, 2019).

The creation of energy supply cooperatives for the production of straw pellets is considered promising. Fuel can be sourced from the residues of grain and oilseed crops. The available potential of straw and crop residues reaches 25–35 million tons of conventional fuel per year (around 13–18 % of primary fuel consumption), but only about 1 % – 77,000 tons per year is actually used (Saf.org, 2024). The potential straw production in Ukraine for energy purposes could replace 16 million tons of coal. This demonstrates that the energy use of straw could be a strategic element in replacing imported energy sources (Hontaruk, 2019).

The technically available biogas production potential is 7.8 billion cubic meters annually (approximately 40 % of natural gas consumption in 2018), from the following sources:

- 50 % – crop residues (wheat and corn straw),
- 35 % – silage corn,
- 11 % – manure and poultry litter,
- 4.7 % – other waste (Was et al., 2020).

Biogas production from manure can reach 2.9 billion cubic meters, though only about 1.3 billion cubic meters are practically realized on farms. The bioenergy feedstock potential from crop harvests is 3.6 million toe in value from corn residues alone, with an equivalent potential in total.

As of early 2024, there are 68 biogas plants in operation with a total capacity of 135 MW and 24 biomass power stations (wood chips, husks) with a capacity of 178 MW (Tryboi et al., (2024). In 2023, biogas plants produced about 580 million kWh of electricity, with an average capacity utilization of 49 %. The total installed capacity of biogas cogeneration exceeds 300 MW, but up to 80 % of facilities are owned by large agro-holdings. Small farms and households with their own bioenergy facilities are very few. The main reason is the high cost of equipment and the fragmented structure of farms.

Many waste resources remain unused – there is enough straw, wood residues, manure, and silage. Cooperation enables the accumulation of biomass in volumes sufficient to install bioenergy production facilities. The cost of building and operating bioplants with a capacity of 20–50 kW amounts to hundreds of thousands of hryvnias. For small farming enterprises, financing this is extremely difficult, so forming a cooperative helps distribute the risks. Thus, forming bioenergy cooperatives allows small enterprises to save on large installations, cover expenses, organize logistics, and access financial support. Cooperation enables gathering sufficient biomass resources.

By replacing expensive gas or diesel fuel with biogas from their own biomass, communities can reduce energy costs and increase energy independence. Modern tariffs on the green energy market make production profitable - although government debt on feed-in tariffs remains an issue. Ukraine has access to 8.7 GW of renewable energy capacity, and bioenergy is a vital part of the green transition strategy in response to wartime risks and the need for energy autonomy (Ecopolitic, 2024). Using manure, crop residues, and straw helps reduce greenhouse gas emissions, avoids open-air burning, and provides organic fertilizer without losing valuable nutrients.

The creation of agro-bio cooperatives may be relevant not only for countries with a large rural population. Local bio-waste collection centers can be part of multi-fuel energy cooperatives. Therefore, the development of bioenergy cooperatives is not only an opportunity to realize agricultural potential and ensure community energy independence, but also a driver of the country’s green economy.

4. Results and discussion

4.1. Calculation of the versatile energy cooperative parameters

As an example, here are the following values for an energy cooperative with an installed capacity of 2000 kW of power generating units and a number of 1000 members (Table 2):

The proposed method allows to estimate the amount of individual contribution of a member of an energy cooperative and his/her individual interest in participating in the cooperative. The involvement of individuals in energy cooperatives is driven by incentives consisting in energy supply reliability and an individual interest which is the income generated by cooperative’s business activity. This interest is a significant incentive, while the amount of a member’s share contribution is a significant barrier to attracting community residents. Reducing the contribution aiming to attract more individuals leads to greater obligations for self-sufficiency, simultaneously reducing the possibility to supply electricity to the grid, which, in turn, reduces profitability (interest). Therefore, it is important to find the balance between the size (installed capacity) of a cooperative and the amount of share

Table 2
Data for calculating the parameters of the energy cooperative.

Parameter	Unit	Value
The data:		
I_D	UAH	4
$R_{c/p}$	-	0,7
N_{inst}	kW	2000
ICUF	%	30
N	persons	1000
CAPEX	EUR/кВт	1600
Exchange rate (EUR UAH)	UAH	45
The results:		
I	%	4,38
C	UAH	144 000
	EUR	3 200

Source: developed by the authors

contribution for its members using the formulaic tool proposed above.

4.2. Comparative analysis of bioenergy cooperatives using straw for biogas production

Minimum effective power of the equipment – 20 kW is often considered the minimum for a small boiler or biogas plant that can be operated profitably. The average cost of installation is 45,000 UAH/kW, with an assumed annual operation of 8000 h. The cost of energy production from straw is estimated at 0.25 UAH/kWh, while the substitution value of commercial electricity is 1.50 UAH/kWh. The boundary conditions of the model assume full grid accessibility during the operating period, stable and sufficient feedstock availability to ensure continuous plant performance, and timely full payments based on the substitution of commercial electricity. The calculation does not include profit tax, depreciation, or the cost of borrowed capital, which should be considered in extended financial modeling.

Let’s conduct a comparative economic analysis of bioenergy cooperatives that use straw for biogas production, using three power options as an example: 20 kW, 30 kW, and 50 kW. The calculation is based on typical parameters for Ukraine (Table 3).

As seen from the Table 3, for all options, the payback period is ~4.5 years, which is an economically attractive indicator for a public project. Although there are several critical assumptions and variables that could significantly influence the accuracy and real-world applicability of the results.

The model uses average values for key economic indicators such as investment cost per kW, biogas yield from straw, operational hours, and replacement electricity tariffs. However, these figures may vary depending on technology supplier and localization (domestic vs. imported equipment); straw quality and biogas yield (which can depend on moisture and pretreatment); operation regime, as small plants often work intermittently due to logistic and personnel constraints. A more precise analysis would require region-specific cost assessments, pilot data from operational cooperatives and detailed logistic modeling. Storage, and transport of straw can represent up to 30–40 % of total operating costs. There is currently no established market for straw as fuel in most Ukrainian regions.

While straw is a widely available and underutilized agricultural

Table 3
Data for calculating the parameters of agro-bio-cooperatives.

Capacity (kW)	Investment (UAH)	Annual production (kWh)	Raw material costs (UAH)	Grid electricity, replaced (UAH)	Annual income (UAH)	Payback period * (years)
20	900 000	160 000	40 000	240 000	200 000	4.5
30	1 350 000	240 000	60 000	360 000	300 000	4.5
50	2 250 000	400 000	100 000	600 000	500 000	4.5

* simple payback formula: investment / annual return)

Source: developed by the authors

residue in Ukraine, it is not the only viable feedstock for small-scale biogas cooperatives. Replacing or supplementing straw with other biomass types could offer several advantages:

- Silage maize or energy crops (e.g., miscanthus, sorghum) offer higher biogas yields per ton and are easier to digest due to lower lignin content. However, they require dedicated land and higher production costs.
- Animal manure, particularly from medium-sized livestock farms, is a low-cost substrate with consistent availability. Its use improves process stability, though biogas yield per ton is lower. It is ideal for co-digestion with straw.
- Food waste or agro-industrial residues (e.g., potato peels, brewery waste) have high methane potential but require careful hygienic control and may be seasonal.
- Grass and green cuttings from communal areas are also accessible and renewable, though they demand careful moisture control.

Each of these feedstocks has its own logistic, regulatory, and processing considerations. Future analysis should include scenario comparisons to assess which combinations are most effective in terms of yield, cost, and availability in specific regions.

Also the analysis suggests an investment of 900,000–2250,000 UAH for small-scale systems, but it does not include design, permitting, and grid connection costs; not account for loan servicing, insurance, or interest rates; not reflect the difficulty small cooperatives face in securing financing due to lack of credit history or assets. This suggests a need for financial modeling under different funding scenarios (e.g., grants, soft loans, crowdfunding).

All these limitations emphasize the need for further detailed research and the creation of an individual approach to the model with the subsequent implementation of agro-bio-cooperatives.

5. Conclusion and policy recommendations

The recognized crucial role of energy cooperatives and their local structures in the decentralization of energy systems - from the dominance of large energy companies to thousands of small and medium-sized enterprises, many of which are formed on the basis of the pooling of finance and management participation of millions of active and informed citizens - constitutes the democratization of the energy sector. The evolution of the organizational and legal forms of energy cooperatives as business types is based on a combination of activities, combining types of energy technologies, entering new markets, synergy of communities and public partnerships, individuals and enterprises, responsibility of local governments for promoting the development of energy independent territorial units, against the background of delegation of socially important functions of energy supply and social welfare.

The expansion of energy cooperatives as an institutional form capable of implementing the sustainable energy transition requires symbiotic interaction with another institution in the energy market – aggregators, a combination of energy technologies for greater flexibility and optimization of the load of power generating equipment, promotion of the creation of energy cooperatives with mixed participation of individuals and legal entities (owners of decentralized generation units, of

fuel and raw materials and secondary energy resources for the cooperative needs, also the enterprises as businesses that run cooperatives as their main activity), as well as with the participation of the state (public-private partnership).

It is important to promote not only the horizon-wide development of energy cooperatives within the same business model (increasing the number of sources of self-sufficient demand based on solar power plants), but also the creation of cooperatives based on the following business models: active consumption (promoters), models with heat supply (cogeneration), system service providers, electric mobility services, energy storage, energy efficient contracting, and biofuel production and sales businesses, with full use of local energy resources.

The prerequisites for the successful energy cooperatives are the combination of several functional purposes of a cooperative for a community, which allows solving two or more goals simultaneously, as well as the use of available community resources, which can reduce the cost of using technology. Also, the role of a community in the creation and operation of a cooperative is to overcome barriers that depend on it.

Regarding the combination of energy technologies used by an energy cooperative, it is necessary to move from the most common model based on photovoltaic mono-technology to models that include cogeneration, heat pumps, biogas, electricity and heat storage equipment, industrial and domestic with gas piston/gas turbine units, biomass CHP, etc.

The experience of energy cooperatives around the world shows that attracting grant and loan support in amounts that guarantee the majority (50–80 %) of the investment needs is the most important factor in the successful construction of an energy cooperative. It is important that government regulatory policy does not discourage participants from joining cooperatives by reducing their individual interest through capacity limits and self-sufficiency requirements, territorial restrictions, restrictions on activities and licensing, financial consequences of balance sheet responsibility, and rules for energy sharing.

The creation of energy cooperatives in Ukraine is a prospective area that follows the best international practices. However, today there are only a few such cooperatives. Given the fact that Ukraine is an energy-dependent country, increasing the share of energy from RES in total consumption is one of the main ways to reach energy security. According to international practice, energy cooperatives can become a new effective mechanism for reorienting Ukraine's economy towards the sustainability. This, in turn, requires an appropriate legal framework, political environment and favorable conditions, including state support measures.

To date, there is no single universal model for creation and promotion of energy cooperatives. However, in the majority of countries, regardless of the type of energy cooperative, the preference is given to the cooperative form of production and distribution of renewable energy. With increasing attention to environmental issues around the world, the competitive advantage of decentralized renewable energy technologies, decentralization, and the growing interest in community control over infrastructure, this trend will increase. Therefore, the developing of institutional environment for energy cooperatives establishment should be a priority, as it can make energy more accessible and increase the energy security.

Abbreviations

Acronym	Definition
ATC	Amalgamated territorial communities
CAPEX	Capital expense
CEC	Citizen energy communities
CHP	Combined heat and power
DAM	Day-Ahead Market
DGS	Distributed generation sources
DSO	Distribution system operator
ESCO	Energy Service Company
ICUF	Installed Capacity Utilization Factor

LCOE	Levelized cost of energy
RES	Renewable energy communities
TSO	Transmission system operator
Symbol	Description
I_{CD}	efficiency of the energy cooperative (incentive) per unit of energy produced and consumed, EUR/kg of oil equivalent
$R_{C/P}$	average annual consumption/production ratio or self-sufficiency ratio (volumes consumed by the energy cooperative correlated with the volumes of energy produced per year)
I_C, I_D	incentives for consumption and supply to the grid, respectively, EUR/kg of oil equivalent, which are defined as the difference between the price of an energy resource on the market (from the grid) and the cost of its production by the energy cooperative's facilities
N_{inst}	value of the installed capacity of the cooperative's equipment
C	share contribution
$CONS_i$	consumption capacity of the i-th member of the cooperative
N_m	capacity of energy production for sale to the market
I	individual interest of a cooperative member

Author Agreement Statement

We the undersigned declare that this manuscript is original, has not been published before and is not currently being considered for publication elsewhere.

We confirm that the manuscript has been read and approved by all named authors and that there are no other persons who satisfied the criteria for authorship but are not listed. We further confirm that the order of authors listed in the manuscript has been approved by all of us.

We understand that the Corresponding Author is the sole contact for the Editorial process.

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Uliana Pysmenna: Writing – review & editing, Writing – original draft, Methodology, Investigation, Formal analysis, Conceptualization. **Sviatoslav Petrovets:** Writing – original draft, Investigation, Data curation. **Iryna Sotnyk:** Supervision, Resources, Project administration, Funding acquisition, Conceptualization. **Tetiana Kurbatova:** Writing – review & editing, Formal analysis.

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