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Organizational and Economic Mechanisms for Promoting Residential Battery Energy Storage Systems in Ukraine

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ABSTRACT

Energy storage technologies are one of the ways to decrease the intermittency of renewable energy such as sun or wind. The article aims to consider the organizational and economic mechanisms of promoting residential battery energy storage systems (R-BESS) in Ukraine, as households have ensured the significant growth of installed capacities of residential PV installations, reaching 1.4 GW by 2024. The energy system of Ukraine faces balancing challenges, and partial covering of the demand for energy by households with the help of R-BESS should be beneficial for the energy system. Using methods of levelized cost of electricity and cost of storing electricity, and based on the projected electricity demand and the number of R-BESS, measures were suggested to stimulate the R-BESS installation. Significant investments are required to employ R-BESS, reaching EUR_{2024} 2.9-3.6 billion by 2050. If the interest rates for loans are subsidized, the expenditures on subsidies will reach only EUR_{2024} 35-44 million, and the households themselves must allocate the remainder of the funds.

Keywords: Residential Battery Energy Storage System, Renewables, Solar Photovoltaics, Ukraine
JEL Classifications: O2, O5, Q28, Q42, Q47

1. INTRODUCTION

Ukraine has been an Energy Community party since 2011, and in 2023, the country received the candidate status to join the EU. It means that gradually, Ukraine needs to harmonize its legislation in basically all spheres, which is also the case for energy and respective energy legislation. Ukraine is deploying progressively renewable energy, with the highest progress achieved in electricity from renewable energy sources (RES), moderate success in sectors of heating and cooling from RES, and a severe lag in the use of renewable energy in the transport sector. The share of RES in the energy balance is estimated at 9% in 2022 (the official statistical data is collected but not published due to martial law) (Ukrainvest, 2022). On the other hand, a similar situation with difficulties in spreading RES in the transport sector is observed globally, and transport faces the slightest penetration of RES among the main end-use sectors, reaching only 4.1% in 2020 (REN21 2023).

From Soviet Union times, Ukraine gained a heavily centralized energy supply system, especially with electricity output. Some energy-generating facilities' installed capacity reaches as much as 6 GW (Zaporizhzhya Nuclear Power Plant, temporarily occupied by the Russian Federation in 2022). Renewable energy generation was the generation that managed to attract more investments than conventional energy: out of USD 38.7 billion attracted in 2013-2017, RES attracted 12%, and conventional energy-10% (OECD, 2019). Until 2022, the capital investments into renewable energy in Ukraine exceeded USD 12 billion (Ukrainvest, 2022), and in 2020, the country was open for investments, and Ukraine's FDI index was considerably higher than the OECD average FDI Index (OECD, 2021).

The unprecedented hostilities brought by Russian bombing and shellings with the full-scale invasion of the Russian federation in 2022, coupled with the targeted destruction of energy generating, transmitting, and distribution infrastructure, exacerbated the issue not only of physical protection of infrastructure but also of decentralization of energy supply. The trend of energy system decentralization is entirely in line with the European aspirations of Ukraine, as anticipated by the 2050 Energy Strategy of Ukraine (CMU, 2023a). In 2022, the Minister of Energy of Ukraine claimed that until 2032, Ukraine plans to build 7.1 GW of new installed capacities of RES and at least 750 MW of energy storage (UA Energy, 2022); the latter would require EUR 0.7 billion. Energy system decentralization also anticipates lower risks for energy generating facilities, making them less attractive military targets for the hostile neighbors, as they usually have lower installed capacities than those available in Ukraine of the centralized energy generation, and their cost is significantly lower than that of the missiles. For Ukraine, in the current conditions, decentralization of the energy system is one of the ways to enhance energy security. The "lowest" level of decentralized energy, such as generating facilities, is residential or household energy generation. As of early 2024, the households had 1.4 GW of installed generating capacities. They mainly comprised solar PV, whereas there were four wind installations with a cumulative capacity of 31 kW and six combined solar and wind installations with a cumulative capacity of 245 kW. Wind installations didn't gain popularity, as people in the residential sector were having difficulties maintaining them. The households' relatively large-scale solar PV installations gained momentum due to the favorable support scheme (the feed-in tariff [FIT]) in the past (Sotnyk et al., 2020; 2022; Kurbatova et al., 2020). Due to the necessity of ensuring the increased prosumption of the energy produced, there is a need to assess the possibilities of Ukraine using residential battery energy storage (R-BESS) systems. This paper aims to consider the organizational and economic (financial) mechanisms of stimulating residential energy storage systems (batteries) in Ukraine and estimate the cost of such mechanisms.

2. LITERATURE REVIEW

Beliak (2023) compared international studies on organizational and economic mechanisms and concluded that, in a broad sense, it is a combination of elements and processes that are used to coordinate and regulate the operation, resources, and behavior of organization members.

Pysmenna et al. (2021) studied the organizational and economic mechanism of (large) energy accumulation systems in Ukraine. The authors assessed the need for energy storage in Ukraine and defined the types of energy storage used, such as I. Energy storage systems (ESS) used to reduce the limitation of renewable energy capacity; II. ESS for smoothing peaks in demand on the daily load curve; III. ESS is used to provide reserve services in the power system. Based on calculations, authors conclude that the first type of ESS is economically unfeasible in Ukraine; the second type has slightly higher economic feasibility, whereas the third type has the highest economic feasibility with a payback period for investments of about 4-6 years. However, auctions of high volumes are required to purchase primary regulation services (more than 100 MW each), which precludes the involvement of smaller capacities in this segment of the electricity market. As the degree of decentralization of the power system increases, the role of smaller local capacities becomes more significant in providing primary reserve. The conducted sensitivity analysis indicates that the first type of ESS use highly depends on the availability of the feed-in tariffs. Once they are gone or substituted with the auction price, the internal rate of return becomes negative.

The growth of retail electricity prices coupled with the declining costs of R-BESS led to the increasing capacities of R-BESS. However, national policies strongly influence residential battery adoption. While many countries lack specific battery storage promotion, general support for renewables positively impacts energy storage. Countries with weak interconnection, like the UK, need storage for supply-demand variations. Conversely, well-connected countries like the Netherlands face less pressure (Potau et al., 2018).

In Europe, Germany and the UK led in storage deployment until 2018 (Potau et al., 2018); in terms of R-BESS capacity installed, Germany remained the leader in 2022, followed by Italy, Austria, and the UK. R-BESS in Europe is seen as a tool to decrease household electricity bills. 2021 the demand for R-BESS significantly exceeded the supply (Estebanez, 2023a). In 2022, in Europe, the capacities of R-BESS increased by 9.3 GWh; by 2026, the capacity of R-BESS is projected to reach 32.2 GWh (SPU, 2023). For instance, 1-h batteries were profitable in the Netherlands and Italy in 2022 without additional revenue streams and are projected to remain profitable due to high electricity prices (Estebanez, 2023b). Bloomberg projects 508 GW of battery installed capacity globally by the end of 2030 (Bloomberg, 2023). Favorable conditions, including renewable support and market rules, boost EU competitiveness. Regulatory barriers and poorly designed renewable support schemes hinder battery deployment. Innovative schemes, like Germany's low-interest loans, incentivize residential battery installation. Some countries stop preferential tariffs, making storage appealing. Grid integration is crucial, especially in smart grids (Potau et al., 2018). Heymans et al. (2014) proved that Li-Ion batteries require financial incentives should they be reused in energy storage systems, such as lower energy rates and reduced auxiliary fees.

Countries incorporating storage in capacity auctions accelerate deployment, yet de-rating short-term capacity hampers progress. Some nations invest in R and D, like the UK's Faraday Challenge and Germany's Battery 2020 program, fostering battery technology advancement.

Concrete regulatory issues hinder battery storage adoption, like liability, ownership problems, and business model uncertainties. Discriminatory grid tariffs, counting battery storage twice, increase costs, though Germany and the UK address this through legislation. Renewable energy support, including priority dispatch rules and subsidies during negative prices, negatively impacts battery deployment. Net metering makes residential storage redundant, hindering uptake. National support for non-renewable energy forms like coal or nuclear power also impedes energy storage adoption (Potau et al., 2018).

Schwarz et al. (2019) explored the challenges posed by integrating growing shares of residential solar photovoltaics in many countries. The study highlights the impact on electricity systems, including sharp system-wide load changes and the need for fast-ramping generation capacity. The authors propose a policy reorientation, emphasizing a system integration perspective to avoid potential risks to electricity affordability, climate change mitigation, and the reliability of the electricity supply system. The authors conclude that given that renewables are becoming more affordable, even countries with no public support schemes may need to introduce support schemes to integrate the renewables.

Kuleshov et al. (2019) studied the economic performance and benefits of R-BESS in Finland and concluded that the application of batteries is not feasible under the existing electricity rates. However, declining investment costs to purchase batteries and growing electricity prices could make the R-BESS feasible.

Nousdilis et al. (2020) studied the techno-economic mode of PV installations coupled with batteries. They stated that the decision to charge/discharge household battery systems is based on electricity price signals. The authors conclude that the high capital cost is one of the most significant factors limiting the widespread use of integrated PV and battery systems. The profitability of integrated PV and BES systems depends on the battery cost. With the price level of 2020, the integrated PV-BES systems are less profitable than the standalone PV system, but the projected decrease in battery price will likely change the situation in favor of batteries.

Brennenstuhl et al. (2024) studied the experience of prosumers in cases of vehicle-to-home integration in Germany and stated that the latter provides flexible load and supply potential, as well as helps better coupling of transport with other sectors, provided that bidirectional charging (Vehicle-to-Grid and Vehicle-to-Home) is available. Vehicle-to-grid may increase the efficiency and cost-effectiveness of electricity grids and save CO_2 emissions. Incomprehensive standardization, faster battery deterioration, and uncertainties with inverter efficiencies are the main factors preventing owners from wider use of batteries. Authors prove that despite battery faster degradation, financial benefits are attainable.

Elshurafa (2020) studied the monetary value of storage in electricity generation and concluded that storage finds the most value in providing ancillary services. He stated that if energy storage operates on-grid in the distributed scale, it has to have a capacity of 10-20 kW to give energy and/or arbitrage, and it has to be 10-200 kW to ensure peak-demand cost reduction and/or to eliminate/minimize renewable energy curtailment. Suppose the storage operates off-grid on the scale of a single household. In that case, it may have a capacity of 1-20 kW, and the services may include energy supply, enhancement of diesel generator efficiency, and elimination/minimization of renewable energy curtailment.

Mohammadi (2024) studied the RES markets of prosumers and stated that the latter is an essential element of peer-to-peer energy trading in general. Yet, it requires regulation, especially in addressing the security vulnerability issue, which is yet to be developed.

In addition to the mentioned research of the referred scholars an important complementing aspect of battery recycling has to be highlighted related with the fact that old batteries have to be handled as dangerous good. Therefore, the European Parliament and the European Council approved the Regulation (EU) 2023/1542 on 12 July 2023 concerning batteries and waste batteries, amending Directive 2008/98/EC and Regulation (EU) 2019/1020 and repealing Directive 2006/66/EC (EC, 2023). The new regulation aims to promote a circular economy for batteries throughout their life cycle by formulating sustainability rules for end-of-life requirements, including collection targets and obligations for recycling and recovery of materials and extended producer responsibility. Consequently, this EU regulation also impacts all aspects of battery logistics including transport, storage and handling, which have to be considered in in the legal and organizational frameworks. Schröder and Prause (2015; 2016) investigated risk management concepts for green logistics of dangerous goods that are compliant with sustainability regulations. In recent research Gerasimova et al. (2023) showcased how blockchain and NFT-technology can be applied to create sustainable business models for circular economy in high tech sector.

Sotnyk et al. (2022) highlight the strategic economic considerations necessary for optimal investment in renewable energy, emphasizing the allocation of resources to maximize sustainability and effectiveness of energy projects, including BESS. The balancing of Ukraine's energy system amidst high renewable penetration, particularly during disruptions such as the COVID-19 pandemic, is critically examined by Kurbatova et al. (2021), who underscore the need for robust, flexible energy policies to ensure system stability-an essential factor for the integration of BESS.

Further exploring policy mechanisms, Kurbatova et al. (2023) advocate for improvements in feed-in tariffs to foster greater adoption of renewable technologies in households, directly supporting the deployment of BESS. From a sustainability and supply chain perspective, Koval et al. (2023) discuss the recycling of electric vehicle batteries, a key component of the circular economy, which is vital for managing the lifecycle of BESS and ensuring environmental sustainability.

The adoption of BESS can also learn from international experiences, as Pimonenko et al. (2017) provide insights into the implementation of net zero houses in the EU, which include the use of BESS to achieve energy independence. State support mechanisms are another crucial element examined by Prokopenko et al. (2021), who evaluate and suggest enhancements to governmental programs aimed at renewable energy development, which could facilitate the broader uptake of BESS.

Considering the broader socio-economic context, Bashynska et al. (2023) analyzed the labor market experiences in Europe, offering a backdrop for understanding the organizational frameworks that can support the deployment of technologies like BESS. The energy sector's social responsibility is also crucial, as explored by Dudek et al. (2023), who develop a methodology for assessing the social responsibilities of energy enterprises, an approach that could be adapted to include considerations for BESS adoption.

Investment dynamics within the renewable sector are further explored by Sala et al. (2023), who study the investment and innovation activities in Ukraine's electric power industry, providing a context for how such investments can encourage technological adoption including BESS. Governance and institutional effectiveness in promoting sustainable development are critically analyzed by Masyk et al. (2023), emphasizing the importance of effective governance structures in facilitating the adoption of sustainable technologies like BESS.

The integration of environmental protection and sustainable management practices is essential. Kovshun et al. (2021a) discuss the importance of information support for environmental management, which is pertinent for the successful implementation of BESS initiatives. Simionescu et al. (2020) highlight how social media can be used to enhance sustainability education, potentially increasing public support and understanding of BESS technologies. Additionally, Kovshun et al. (2021b) explore the administration of environmentally safe natural resource use, providing a framework for managing BESS in a manner that respects environmental integrity and sustainability.

This comprehensive examination of economic, policy, social, and environmental dimensions, as discussed in the aforementioned studies, provides a robust foundation for promoting the implementation of residential BESS in Ukraine, ensuring that these systems are integrated effectively into the national energy landscape.

3. THEORY AND METHODS

3.1. Legislative Framework for Households' Energy Generation and Energy Storage in Ukraine

The main impetus for the implementation of renewable energy by households in Ukraine was the feed-in tariff, which was much higher compared to the electricity tariff from the grid. The FIT is defined as a multiplication of the respective coefficient and the retail tariff for consumers of the second voltage class in January 2009.

The sizes of FIT for households are indicated in Table 1 below.

The consumer has the right to install generating units intended for the production of electricity for exclusive self-consumption without obtaining a license if such a consumer does not supply the generated energy to the Wholesale Electricity Market of Ukraine or to the networks of other economic entities. The consumer has the right to install and use energy storage systems for meeting their own needs without obtaining a license for conducting economic activities in energy storage if such a consumer does not release previously stored energy into the Wholesale Electricity Market of Ukraine or into the networks of other economic entities.

Private households that were granted the feed-in tariff, sell the generated electricity to the universal service provider. Other consumers, including energy cooperatives with the feed-in tariff, sell the generated electricity to the offtaker (The Guaranteed Buyer) (SCU, 2017). In 2023, there were significant debts accumulated for the electricity of households sold against the feed-in tariff. This is a significant demotivating factor for the upcoming investments in solar installations.

In June 2023, a Law of Ukraine "On the Amendments to Certain Laws of Ukraine Regarding the Renewal and "Green" Transformation of Ukraine's Energy System" No 3220 was adopted, which introduced the concept of active consumer[1] (i.e. prosumer), and enabled the latter to qualify for the net billing support scheme. Even if the household chooses the option of the net-billing, commercial banks are reluctant to provide loans to purchase the equipment, even at the market rate (22+%) with the collateral.

A consumer acquires the status of an active consumer if signs electricity purchase and sale agreement under the self-generation mechanism, or signs an agreement with a guaranteed buyer or a universal service provider for the sale of electricity at a feed-in tariff. A consumer also acquires the status of an active consumer if installs an energy storage system for participation in the market of ancillary services, provision of balancing services, and purchase/sale of electricity used for energy storage in energy storage systems on organized market segments, either independently or as part of aggregated groups. If a household operating under a net-billing mechanism, uses an energy storage system, the sale of electricity by it is carried out at the market price of DAM (SCU, 2023) (for instance, it was 0.083 EUR/kWh in Jan 2024 [OREE, 2024]).

The Law 3220 states that the stimulation of the installation of generating units that produce electricity from RES through self-generation mechanisms by private households is expected by means of adoption a State target economic program to promote the development of small distributed generation from RES. CMU has to adopt the program, which hasn't happened as of April 2024. The program should encourage private households

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[1] An active consumer is a consumer, including private households, energy cooperatives, and a consumer who is the customer who consumes, generates energy and/or engages in energy storage activities, and/or sells excess generated and/or stored electrical energy, or participates in energy efficiency and demand management activities in accordance with the requirements of the law, provided that these activities are not professional and/or economic activities.

Table 1: FIT rates for different installations of households

Coefficient	Size (EUR/kWh)	Coefficient	Size (EUR/kWh)	Source of info
Granted until the end 2024		Granted in 2025-2029		
Installations under 30 kW				
3.02	0.1626	2.69	0.1449	SCU (2017)
Installations on the roofs and/or facades of buildings and structures, with the capacity under 30 kW				
2.74	0.1476	2.43	0.1448	SCU (2017)
Combined wind-solar installations with the capacity of under 50 kW				
2.28	0.1228	1.98	0.1066	SCU (2023)

to install generating units with a capacity of up to 10 kW, along with energy storage systems, with a ratio of 1 kW of installed capacity of the generating unit to at least 0.5 kWh of energy storage capacity. If the stimulation is extended to other categories of consumers, the state target program can specify the ratios of installed generating unit capacity to energy storage capacity and other requirements for such generating units, energy storage systems, and additional equipment to be installed with these generating units. The program for stimulating the development of small distributed generation from renewable energy sources may include measures such full or partial compensation of interest rate on the amount of a loan for the implementation of the project for the purchase and installation of a generating unit and/or an energy storage system (SCU, 2023).

The consumer has the right to join aggregators and provide ancillary services and balancing services using their own electrical installations intended for consumption and/or generation, and/or energy storage systems. As of Feb 2024, there are no aggregators yet.

Stimulation of the electricity output from RES through the net-billing is established for generating installations of private households, designed to produce electricity from solar radiation and/or wind energy, connected to electrical installations intended for the consumption of electricity directly or through the consumer's networks, provided that the installed capacity of such electrical installations does not exceed 30 kW (SCU, 2023).

In Ukraine, there is a law enabling the existence and operation of batteries (SCU, 2022). It defined the concept of energy storage activity and introduced requirements for licensing such activity. In 2023, the first energy storage license was issued to one of the Ukrainian companies. The first launched industrial lithium-ion battery energy storage system (BESS) in Ukraine with a capacity of 1 MW (and 2.25 MWh) was launched by a vertically integrated energy holding DTEK, and located in the territory that is currently occupied (in the city of Energodar, at the site of the Zaporizhzhya TPP). There is another pilot project that is close to being developed (as the developed has obtained the respective license), in particular by a company KNESS in Vinnytsya.

3.2. Technical Challenges with the Balancing of the Energy System of Ukraine

Energy system of Ukraine has low flexibility. The situation deteriorated with the destruction of Kakhovka dam and hydroelectric power plant by the Russian army in 2023. The function of balancing of energy system was predominantly commenced by the coal power plants. Over the course of war, over 1000 MW of thermal power plants were destroyed, damaged or lost. Of the 21.5 GW of balancing capacity, about 13.3 GW remained. The possibility of rebuilding or reconstruction of such stations remain in question due to many factors. For instance, Ukraine has an emission reduction plan that appears from the use of large (above 50 MW) combustion units; the prospects and feasibility of reconstruction of Kakhovka dam and hydroelectric power plant also remains unclear, as the estimates indicate that it would require about USD 1 billion (Oliynyk, 2023).

Before the full-scale invasion in early 2022, the share of RES in the energy balance of Ukraine was more than 8%. However, the significant network restrictions take place, which is especially the case with solar energy. According to the legislation in Ukraine, the producers are supposed to be paid even if they do not produce electricity. For instance, during January 1-October 22, 2022, the RES load reduction service or limitation was applied 172 times (within 172 days). The load shedding service was provided for 1.3 million kWh (Oliynyk, 2023). Yet, the most suitable economic mechanism in this case would be the economic responsibility for imbalances, which would be the main incentive for the implementation of energy storage systems as part of RES projects (Pysmenna et al., 2021). It is worth to note that such mechanism exists in Ukraine, but it is not fully functioning.

According to TSO "Ukrenergo", even before the full-scale war, the Energy system of Ukraine faced challenges due to the rapid growth of the installed capacities of intermittent renewables without the parallel installation of balancing (regulating) capacities. To solve the problem, commissioning of 2 GW of high maneuverability generation capacity with quick start and 2 GW of fast-acting reserves based on storage systems are needed to provide the Energy system of Ukraine with the necessary reserves regulation to meet compliance requirements until 2030 (Ukrenergo, 2019). According to the REDII, the technically feasible amount of regulating capacities (including energy storage systems) for ensuring the integration of intermittent generation from RES into the power system is 900 kW for every 1 MW of RES capacity (EC, 2018).

3.3. Measures to Promote R-BESS

The development of energy storage technologies is becoming increasingly important as the share of renewable energy sources in the energy balance of countries grows. Many countries around the world actively promote the implementation and dissemination of energy storage devices in households. For instance, it was growth of the solar market that spurred the growth of R-BESS in Europe, having the average attachment rate between BESS and

PV of 27% in 2021 (SPU, 2023). Several types of government support measures are used for this purpose, including:

3.3.1. Incentives and financial support

Several countries develop and implement programs of incentives and financial support for households that install energy storage systems. This may include tax credits, subsidies for the purchase and installation of equipment, as well as low or zero import rates for such technologies. For example, in Germany, there was the KfW program that provided financial assistance for the installation of solar panels and energy storage systems in households (2013-2015; 2016-2018) (KfW, 2013). The name of this program comes from the German banking group known as KfW (Kreditanstalt für Wiederaufbau), which is focused on economic and social development. One of KfW's initiatives was a financing program for the installation of solar panels and energy storage systems in households. KfW provided financial assistance in the form of loans and subsidies to households installing solar panels and energy storage systems. This could include covering the costs of purchasing and installing equipment. KfW could offer loans with low-interest rates, flexible repayment terms, and other financial incentives to make the use of solar technologies more accessible to the population. The program also supported energy storage systems.

3.3.2. Framework for green energy transformation

Many countries, especially in the EU, opted for green energy. Energy storage is an important element of this transition, because it allows for more successful and effective integration of RES into the energy system (Beckford et al., 2023), and overcome the problem of intermittency of such renewable sources as the sun and wind. In a broad sense, an encouraging regulatory framework for RES may promote the spread of batteries, but more observation and research are needed on the impact of different RES support measures on the spread of energy storage devices. For example, a net-metering RES support system, which allows consumers to use a portion of the energy produced at any given time, can make R-BESS solutions redundant and may hinder the adoption of R-BESS. State support for fossil fuels can also seriously slow down the transition to RES, and energy saving measures (Potau at al., 2018). Network integration, especially smart grids, is essential. Countries that include storage in capacity auctions are accelerating implementation, but declining short-term storage capacity is holding back progress.

3.3.3. Establishing the regulatory base and standards

Some countries are actively developing and implementing regulatory measures to encourage the use of energy storage systems in households. It can be requirements for building codes that provide for the installation of storage systems, or the creation of standards to regulate the quality and efficiency of such technologies. For example, Japan has defined specific standards for energy storage systems in buildings to ensure their efficiency and safety. Some countries stop paying feed-in tariffs or feed-in premiums for electricity from RES, and in some cases energy storage becomes economically feasible (Potau et al., 2018). Due to the limited service life of batteries, the issue of handling used batteries, which in the EU is regulated by the 2012/19/EU Directive (EC, 2012), is an actual issue that requires ongoing attention.

3.3.4. Research and innovation

Many countries allocate significant resources to research and development of new technologies for energy storage, including the R-BESS. This may involve efforts to create more efficient batteries, intelligent energy management systems, and other innovative solutions. Collaboration between the government, industry, and research institutions helps to develop cutting-edge technologies and facilitates their faster implementation. For instance, in the United Kingdom, there is the Faraday Battery Challenge (Faraday, 2024) initiative aimed at the development and support of innovations in the field of batteries and electric energy storage systems. The program's budget is GBP541 million for the years 2017-2025. The primary goal of the Faraday Challenge is to provide the UK with high-efficiency, affordable, and sustainable battery technologies for use in transportation and other sectors. The program emphasizes the development of new materials, battery design, manufacturing technologies, and energy storage systems. The Faraday Challenge consists of three key phases. The first phase, "Early-Stream," focuses on research and development, the second phase, "Research," involves more detailed scientific research, and the third phase, "Innovation," aims to introduce new technologies into production and commercial use. Financial support includes funding for research and development, the establishment of innovative laboratories and centers, as well as support for startups and industrial partnerships. The program promotes collaboration between higher education institutions, research institutions, and industry for the joint development and implementation of new energy storage technologies.

3.4. Methods

To calculate the levelized cost of electricity LCOE, the following formula was used:

$$LCOE = \frac{\Sigma^{t}\left(Inv^{t} + O\,\&\,M^{t} + F^{t} + Decom^{t}\right) * (1+r)^{-t}}{\sum (El^{t} * (1+r)^{-t}} \tag{1}$$

Where:

t = year of electricity production and sale year of electricity production and sale

Inv^t = investments made in year t investments made in year t (EUR)

$O\&M^t$ = operation and maintenance in year t operation and maintenance in year t (EUR)

F^t = fuel cost in year t fuel cost in year t (EUR)

$Decom^t$ = decommissioning cost in year t decommission cost in year t (EUR)

El^t = electricity output in year t electricity output in year t (kWh)

r = discounting rate discount rate (%).

Additionally, the following assumptions were used:

- The decommissioning cost is 5% of construction cost, the expected lifespan of solar power installation is 25 years
- The construction time of a generating unit is overnight. It may take several weeks (DEA and MEU, 2024)
- Loans to households are provided only in UAH. In other words, as of 2024, obtaining a loan in EUR or USD is

impossible. The interest rate in UAH as of 4Q 2023 was 27.3% (NBU, 2024). The NBU discount rate is 14.5% as of March 2024 (NBU, 2024)
- Availability factor is 14% (Trypolska and Rosner, 2022).

To assess the expenses for the household batteries and to ensure the partial or full reimbursement of interest rates for those taking loans to purchase batteries, the following assumptions were used:

- The interest rate for consumer loans in Ukraine as of Feb 2024 is 22% in UAH
- The exchange rates of Mar 2024 are 1 EUR = 40.5 UAH; 1 USD = 38.6 UAH
- We assume using the classical scheme (versus the annuity) as a loan form, as the final payments are lower than in the annuity form
- The loan is provided for 7 years, as it is a common practice for commercial financial institutions in Ukraine (in other words, cheap "long" money is hardly available). Seven years is the extended assumption. In 2024, the loans for additionally, the seller provides a 7-year warranty.

To assess the value of stored "green" electricity and the effects of R-BESS for the electricity system, the following parameters were calculated: The cost of storing green electricity Csto,

$$Csto = \frac{\left((IC * CRF + Com)/T\right) + Ce}{\eta sto} \tag{2}$$

Where:
IC = investment cost of R-BESS investment cost of R-BESS (EUR)
CRF = capital recovery factor capital recovery factor (year^{-1})
Com = O&M of R-BESS Operation and Maintenance of R-BESS (EUR/kW/year)
T = Full load hours full load hours (hours)
Ce = Cost of stored electricity cost of stored electricity (EUR/kWh)
Hsto = Efficiency of R-BESS (%) efficiency of R-BESS (%)
(Haas et al., 2022).

$$CRF = \frac{r(1+r)^n}{(1+r)^n - 1} \tag{3}$$

Where:
a interest rate (%)
n=service life service life (years)
(Haas et al., 2022).

According to the existing legislation, all the green electricity needs to be purchased in Ukraine. In other words, even if there is a RES curtailment, the producer has to obtain the money for such electricity. Thus, we compare the Csto with the feed-in tariff for solar installations. If Csto is higher, then during RES curtailments, it is cheaper for the energy system to operate with batteries; if Csto is higher, then the curtailment is preferable. To make the assessments, the following assumptions were used:

- The expected service life of R-BESS is 8 years (Haas et al., 2022);
- The efficiency of R-BESS is 88% (Haas et al., 2022);
- The full load hours varying from 500 h/year (Haas et al., 2022) to 1460 h/year (to ensure 4-h operation);
- The investment cost for R-BESS is 480 EUR/kWh (UTEM, 2024);
- The O and M is 20 EUR/kW/year (Haas et al., 2022);
- We use the NBU discount rate (15%) for the calculation.

4. RESULTS

Below, we calculate the LCOE for electricity of household's solar PV with a capacity of 10-30 kW (Table 2).

Table 2 indicates that with the borrowed capital, the LCOE of electricity from residential solar PV is higher than the grid's electricity price. In the absence of the feed-in tariff, installing solar PV makes no economic sense, and the net-billing mechanism will not improve the situation, as confirmed by (Dixi, 2023; and Trypolska et al., 2023). The LCOE obtained is more or less comparable with the size of the FIT for larger installations (30 kW). However, the grid electricity price for households is steadily growing (with the last spike in 2023), so there might be volunteers to install solar panels; their number may grow in the view of the idea of willingness to self-supply electricity during electricity disruptions times, which are possible due to the hostile neighbor. Table 3 below illustrates the various costs of storing "green" electricity depending on the number of full load hours.

Table 3 illustrates that the higher the number of full load hours, the lower the cost of "green" electricity storage. Within the analyzed range of full load hours (500-1460 h/year), the cost of electricity storage remains much higher than the size of the FIT. Therefore, during RES curtailment, the FIT or net-billing price payment is much lower than the cost of storing "green" electricity per kWh.

In Ukraine, the following economic (financial) stimulation mechanisms to help households install R-BESS could be applied:

1. Partial or full reimbursement of interest rates for those taking loans to purchase batteries (as anticipated by the draft of the government program);
2. Partial reimbursement of the principal loans taken to purchase batteries.

The intention of the government to reimburse the interest rates applies to households that have installed solar panels with an installed capacity of up to 10 kW. The idea of equipping solar panels with batteries makes sense, as this measure aims to increase self-supply and electricity consumption. Additionally, such small installations have not gained popularity-as of May 2023, their number only exceeded 3% of the households' PV installations (Figure 1).

Given that a 10 kW installation would not yield a very high electricity output, the presence of abundant electricity sufficient for balancing services is doubtful, even through aggregators. Besides, as of early 2024, the aggregators do not yet exist in Ukraine. Therefore, participation in the balancing market for households with installation below 10 kW is hardly possible and cannot be

Table 2: The LCOE of residential solar PV installations in Ukraine (10-30 kW)

Indicator	10 kW	20 kW	30 kW	Source of information
Capex[2], EUR/kW	923	712	674	UTEM (2024)
Opex, EUR/kW	21	21	21	
Current FIT (granted not later than 2024), EUR/kWh		0.163		SCU (2017)
Grid el. price, EUR/kWh		0.063		CMU (2023b)
LCOE borrowed capital, EUR/kWh	0.184	0.133	0.127	-
LCOE own capital, EUR/kWh	0.109	0.090	0.087	-

Source: Own calculations

Table 3: The cost of storing "green" energy, EUR/kWh

Indicator	Full load hours		
Full load hours, h/year	500	1000	1460
Csto, EUR/kWh	1.46	0.88	0.62
FIT, EUR/kWh	0.163	0.163	0.163

Source: Own calculations

considered a support measure or even a market mechanism. As of 2023, the effect of the low economic attractiveness of R-BESS was observed in many countries globally (Bloomberg, 2023).

If the installed capacity of the PV system is up to 10 kW and the household purchases an R-BESS, the government promises to reimburse the interest on the loan for the battery. However, the battery must be sufficient to cover the household's own consumption for 4 h.

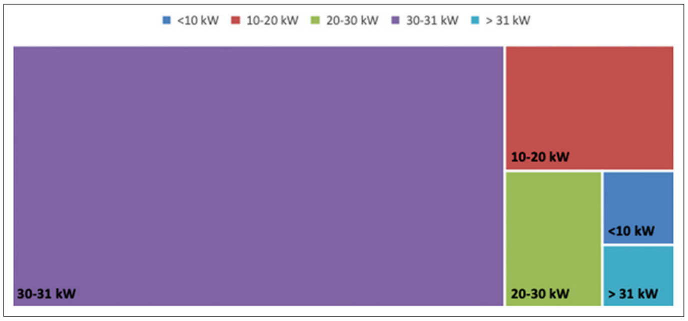
Below, we calculate the optimal capacity of a household battery. To do so, we used the data that the household's monthly average electricity consumption is 165 kWh or 5.5 kWh daily. This translates into a capacity of 0.229 kW/h. Knowing that batteries are to store at least 4 h of electricity consumption, it translates into 0.996 kWh.

The forecast of the demand for R-BESS and the projections of the installed capacities of households' batteries were used based on the data from the draft of the National Energy and Climate Plan (NECP) of Ukraine (2024) and presented in Figures 2 and 3. The projections were made using the TIMES-Ukraine model, which was developed at and is available at the Institute for Economics and Forecasting of the National Academy of Sciences of Ukraine (Diachuk et al., 2019). The NECP anticipates the use of network 4-h batteries (4-h in terms of being able to store enough energy to supply it at its maximum capacity for 4 h).

Figure 3 depicts the potential deployment of households' batteries based on two scenarios: WEM (Without additional measures) anticipates the current level of support in the industry, reflecting the Business-as-Usual case. WAM (With additional measures) depicts the adoption and implementation of the additional policy measures. WAM presumes a more optimistic and holistic development than WEM.

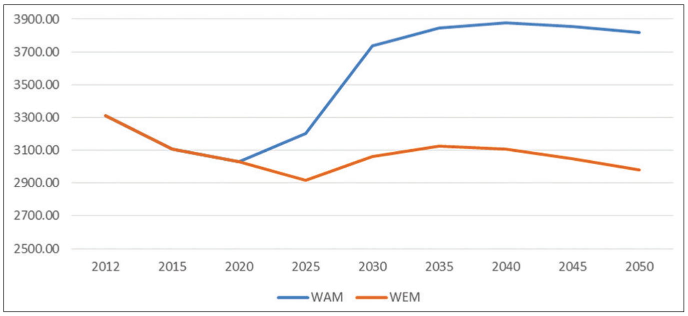
Knowing that the batteries ensure 4 h of energy storage and provision of their capacity, it corresponds to the number of batteries depicted in Table 4.

Figure 1: Distribution of solar PV installations of households by their capacity



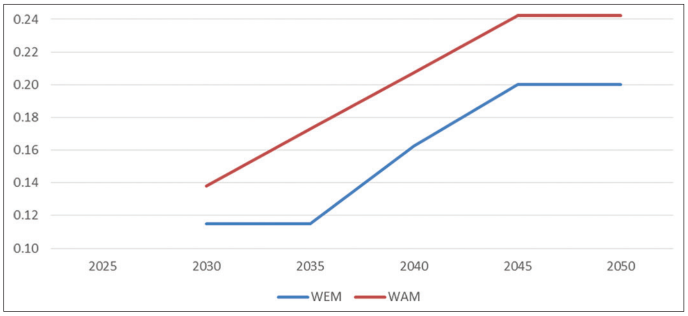
Source: Own calculations based on the data Ministry of Energy of Ukraine (personal communication)

Figure 2: The projected demand for electricity in residential sector, ktoe



Source: NECP (2024)

Figure 3: The projected installed capacities of households' batteries, GW



Source: NECP (2024)

At the prices of 2024, and exchange rates of 2024, the expenditures for the R-BESS are listed in Table 5.

Figure 4a and b below illustrate the level of expenditures needed for the deployment of R-BESS under WEM and WAM scenarios, respectively.

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[2] Consists of the network inverter, batteries, fastening system, and protection automatic equipment.

Table 4: The estimated amount of household batteries, thousand units

Scenario	2025	2030	2035	2040	2045	2050
WEM	0	57.6	57.6	81.2	100.2	100.2
WAM	0	69.1	86.4	103.7	121.1	121.1

Source: Own calculations

Table 5: The expenditures on the 2.4 kWh batteries, EUR$_{2024}$ million

Scenario	2025	2030	2035	2040	2045	2050
WEM	0	69	69	69	69	69
WAM	0	82	103	82	103	82

Source: Own calculations

Figure 4a and b indicate that the WAM scenario, which requires more policy measures, anticipates higher installed capacities of R-BESS, thus resulting in higher expenditures for them. The overall amount of debt under the WAM scenario will be only EUR 499 million higher than under the WEM scenario. The main burden of loan principal repayments will be imposed on households (Figure 5), who must pay EUR 125 million more under the WAM scenario in 2030-2056. In the meantime, the government will need to pay only EUR 9 million more under the WAM scenario over 2030-2056 compared to the WEM scenario.

The expenditures on R-BESS deployment are hardly feasible under the current grid electricity rates. However, monetizing balancing possibilities and smothering peak-hour consumption by households is essential, but it has yet to be assessed.

The conducted calculation has its limitations, in particular:

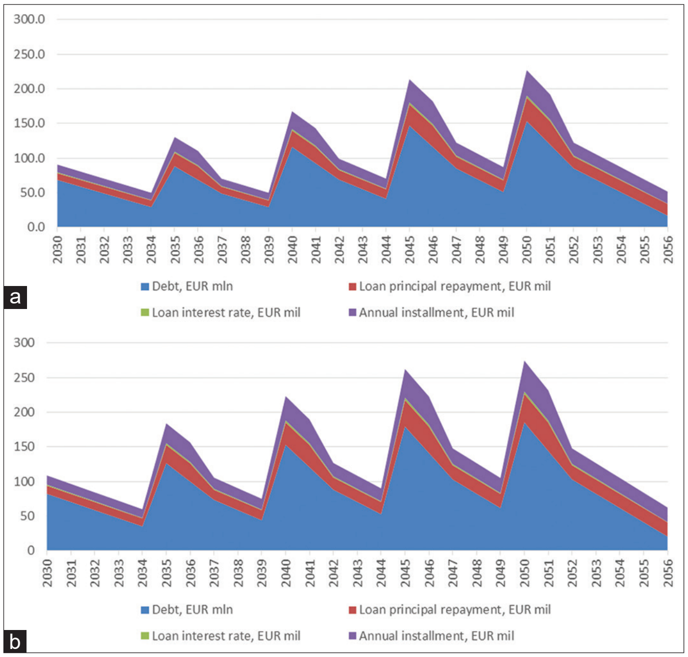
- The economy of scale and the invention of new materials for battery output will definitely change the cost of the batteries (expectedly decreasing it); therefore, the calculation listed above is a very simplified foresight into the future
- Ukraine is a country at war; its duration is not known as of 2024. During the war, the structure of energy-generating facilities and the number of households have changed
- The interest rate may increase to compensate for the high risks for the banking institutions, or it may decrease with the inflow of foreign capital and developed war warranties for potential investors.

5. CONCLUSIONS AND POLICY RECOMMENDATIONS

National policies strongly influence the adoption of R-BESS. Favorable conditions, including support for renewable sources and market rules, enhance the competitiveness of countries. Regulatory barriers and poorly developed support schemes for renewables hinder the adoption of R-BESS.

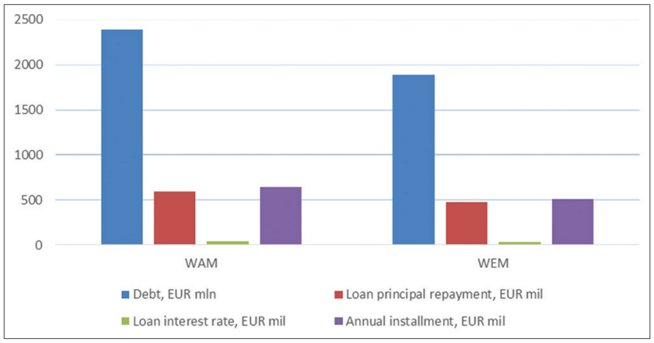
Ukraine is only at the beginning of the path aimed at coupling RES facilities with R-BESS, even though the primary legislation for battery spread is available in Ukraine. General policy recommendations for Ukraine may include but are not limited to establishing the particular, measurable targets of R-BESS installation in Ukraine. Building codes need to be amended to ensure the possibility of establishing R-BESS. However, at this stage of the market development, it is still premature to suggest the mandatory use of R-BESS. Wider adoption and implementation of the European Legislation should consider the adoption of electronic waste legislation, as well as studies and particular measures needed to ensure electronic waste management.

Figure 4: (a) Expenditures on R-BESS under WEM scenario, EUR million. (b) Expenditures on R-BESS under WAM scenario, EUR million



Source: Own calculations

Figure 5: The distribution of expenditures for R-BESS deployment under WAM and WEM scenarios, EUR$_{2024}$ million



Source: Own calculations

The relatively low grid electricity price in Ukraine makes renewable energy installations unfeasible without the feed-in tariff. This, in turn, means that R-BESS projects have very low feasibility. As of 2024, Ukraine is a country at war, the duration of which is unknown, and purely economic factors may not always be the dominant factor when deciding on the R-BESS installation; having a hostile neighbor, people may be willing to back up their electricity supply and decrease their dependence on the grid and potential disruptions of electricity supply.

Thus, should the government be willing to deploy R-BESS, significant investments are required, reaching EUR_{2024} 2.9-3.6 billion. Should the government pursue the current idea of subsidizing the loan interest rates, these expenditures could reach only EUR_{2024} 35-44 million. The remainder of the funds need to be allocated by the households themselves.

During RES curtailment, the payment for the FIT or the net-billing price is much lower than the cost of storing "green" electricity per kWh; however, it is only the case when, legislatively, the suppliers of universal services and the offtaker are obliged to pay for all the green electricity produced. If/when this provision is abolished, comparing the cost of stored electricity with the grid's electricity price would become even less attractive, as it is incomparably lower than the FIT or the net-billing price. To make renewables more appealing, the cost of the grid electricity needs to be steadily increased to become market-based.

There is a need to establish a body or a program disbursing the funds to provide soft loans because very few banks are interested in providing micro loans to households. The funds that need to be provided most likely have to originate from development or recovery loans supplied to Ukraine by IFO or development banks. In 2024, Ukraine established its own Green Fund; the subject of its fulfillment is the incoming funds from the CO_2 tax. Yet, these funds are estimated to be only EUR 16 million as of 2024 and are insufficient for Ukraine's wide-scale green transformation of energy and industry.

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