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Virtual Prosumers and the Impact of Remote Solar Parks on Lithuania's Buildings Decarbonization Efforts

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Abstract **– To reduce the carbon footprint of buildings, the concept of virtual prosumers (consumers who both consume and produce) using remote solar energy parks represents a novel method in Europe. In 2019, Lithuania became the first country in Europe to introduce a digital platform that enables the buying or renting of parts of a remote solar park, making it the first such platform in the world to operate on a national scale. This study examines the effectiveness of this model in Lithuania, assessing the model's success, public engagement, and success factors. The main study focus is on evaluating the impact of remote solar parks on the decarbonization of buildings, particularly through the prism of virtual prosumer participation. This study integrates both qualitative and quantitative data. The quantitative analysis includes a detailed case study, evaluating the amount of energy produced by two selected remote solar parks in Lithuania, as well as their impact on the carbon dioxide emissions and primary energy use of the two individual houses (a detached house and a unit within an apartment building) connected to these remote power plants. In Case Study A, the renewable primary energy usage was 22.19 kWh/m² compared to a minimal 0.22 kWh/m² of non-renewable energy (CO_2 emissions 0.0 kgCO_2/kWh). Case Study B showed 181.38 kWh/m² of renewable energy versus 3.63 kWh/m² of non-renewable energy (CO_2 emissions 6.17 kgCO_2/kWh). Concurrently, qualitative methods involve analysing the existing legal and economic frameworks in Lithuania and Europe, which either facilitate or impede the prosumer model, in addition to examining the necessary technological infrastructure. Key findings of this study highlight the potential of remote solar energy parks to significantly reduce the carbon emissions of buildings. This model is especially beneficial for structures where onsite solar energy solutions are impractical. It fosters greater inclusivity in adopting renewable energy, enabling a variety of stakeholders to participate in and benefit from clean energy production. However, the study identifies several major challenges, including regulatory restrictions, the need for infrastructure development, a shortage of developers, state contributions, public awareness, and the creation of a unified platform.**

Keywords **– Building Decarbonization; carbon emission reduction; energy prosumers; non-renewable primary energy; remote solar power plants; Renewable Energy Sources (RES); renewable primary energy; solar energy adoption.**

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Nomenclature		
$f_{PR,n}$	Non-renewable primary energy factor	units
$f_{PR,r}$	Renewable primary energy factor	units
M_{CO2}	CO_2 emission factor	$kgCO_2/kWh$
A_p	Usable floor area of the building	m^2
k_h	Coefficient for buildings of energy performance classes B, A, A+ and A++	unit
COP	Coefficient of Performance	unit
SPF	Seasonal Performance Factor	unit
Q^{I}_{H}	Normative thermal energy consumption for heating a building	kWh/m^2/ year

1. INTRODUCTION

The energy sector is undergoing a transformation towards a more sustainable and decentralized system, where renewable energy sources (RES) play a key role. Prosumers, defined as consumers who also produce energy, are seen as a promising tool to accelerate this transformation in Europe. The solar power in Europe is growing, so the numbers of prosumers as well. 2022 was marked as a significant year for solar power in Europe, with the addition of 41.4 GW of new capacity, exceeding the previous year's 28.1 GW and surpassing expectations by 10 GW [1].

The Italian National Agency for New Technologies, Energy, and Sustainable Economic Development (ENEA) projects that by 2050, the European Union (EU) will host over 250 million prosumers. These individuals will generate energy either through small domestic setups or within energy communities. The anticipated surge in renewable energy generation necessitates the integration of an extra 700–800 GW into European grids by 2030, compared to 2021 levels, with 70 % expected to derive from decentralized sources [1], [2]. Research by CE Delft, backed by the European Commission, suggests that by 2050, households could generate up to 90 % of their own energy consumption, a stark increase from today's 3 % [1], [2]. Prosumers actively contribute to the energy system in various ways, such as stabilizing the electricity network through battery use or managing their energy consumption more flexibly [4]. Reference [5] highlights that optimal cost for prosumers could include exchanging both electricity and heat with energy grids, underscoring that energy communities often present a more economical model than individual self-consumption schemes. This is because these communities prioritize individual self-consumption for members while also allowing the sale of excess energy at a higher value to peers. As prosumers are also an important part of smart grid technology, the integration of this technology has revolutionized energy systems, enhancing the relevance between demand and generation sides, and significantly reducing energy losses and costs [6].

Gajdzik *et al.* (2023) indicate that prosumers are highly engaged in ecological behaviours, contributing significantly to environmental sustainability [7]. Gajdzik *et al*. (2023), Wang *et al*. (2023), and Postnikov (2023) have identified that environmental sustainability serves as a key motivator for prosumers, who, by generating renewable energy, can lessen their carbon footprints and aid in climate change mitigation [7]–[9]. Economic benefits also play a role, as producing energy can lead to substantial savings on energy bills [7]–[9].

As prosumers are emerging in the power and energy market to provide load flexibility and smooth the use of distributed generation [10], they are also becoming a part of demand response programs. The significance of demand response programs (DRPs) in managing consumption patterns, reducing stress on utility assets, and balancing power at the user end is underscored by their ability to provide bi-directional communication between supply and demand [11]. Therefore, the prosumer model can be perceived as a promising instrument to accelerate the European Green Deal [12] initiative and assist European countries in achieving their climate objectives. Consequently, the primary aim of this study is to investigate the implementation of the prosumer and virtual prosumer models in various European nations and to assess how these models can contribute to the decarbonization of buildings, with a specific focus on the case study of Lithuania.

To facilitate a comparison of prosumer models across European countries, detailed data were collated from the available literature on the Baltic States, Sweden, Finland, Slovakia, Poland, Belgium, Germany, and Spain. This comprehensive dataset provides insights into the wider context of prosumer activity in Europe, including developments in solar energy, the role of prosumers in these developments, challenges encountered, and anticipated future initiatives. Furthermore, the literature review offers an in-depth analysis of the Lithuanian prosumer model and remote solar parks, with particular emphasis on the case of virtual prosumers. Subsequently, the study adopts a more practical focus on virtual prosumers by presenting a detailed case study. This involves analysing the energy output of two specific remote solar parks in Lithuania and their impact on reducing carbon dioxide emissions and primary energy (PE) consumption in two residential cases – a detached house and an apartment unit connected to these parks. Drawing on these case studies, the discussion advances to explore how the prosumer model can contribute to the decarbonization of the building stock.

The goal of this study is to investigate the impact and effectiveness of virtual prosumers and remote solar parks on the decarbonization of buildings in Lithuania. This study aims to assess the success of Lithuania's digital platform for buying or renting parts of remote solar parks, evaluate public engagement, and identify success factors and challenges in the implementation of this model. The primary focus is on examining how virtual prosumers contribute to reducing carbon emissions and primary energy consumption in residential buildings through detailed case studies, thus providing insights into the potential scalability and replicability of this model in other European contexts.

2. LITERATURE ANALYSIS

The following data collates data on solar energy capacity, prosumer initiatives, obstacles faced, and prospective plans in selected European countries. This analysis helps to understand the complexities and dynamics of the solar energy sector. The diverse European countries were selected randomly, aiming to research different parts of Europe – North, South, and Central Europe. Across the surveyed countries, solar capacity and prosumer participation are on an upward trajectory, yet challenges persist, largely influenced by geographical, economic, and policy-related factors.

2.1. Detailed Examination of the Prosumer Model Initiative Across Various European Countries

As stated in the reference [13], the implementation of RES stands as a critical strategic goal for the sustainable development of energy in the Baltic countries. Over the coming decade, the Baltic nations – Estonia, Latvia, and Lithuania intend to significantly invest in renewable energy production and transmission capabilities, embark on a major reduction of fossil fuel-based electricity generation, and achieve desynchronization from the Russian power grid [14].

Based on the national strategies of the Baltic states, there is an anticipated surge in variable renewable energy generation capacity by 460 %, growing from 1.0 GW in 2017 to 5.6 GW by 2030. This expansion is expected to elevate the capacity share of intermittent energy sources in power generation from 13 % to 50 % [14]–[17].

Estonia has significantly advanced in solar energy within the EU, achieving a notable per capita solar power capacity increase from 405 Watts in 2021 to 596 Watts in 2022, ranking 6^{th} among EU nations. This progress has propelled Estonia beyond its 2030 renewable energy targets outlined in the National Energy and Climate Plan, with a strategic focus on fostering solar prosumers, who now number around 10 000 households. These prosumers not only meet their own energy needs but also contribute excess power back to the grid, exemplifying the effectiveness of Estonia’s prosumer model. However, transitioning to a prosumer-centric energy system presents challenges, including potential increases in energy consumption and the need for improved electrical infrastructure to support variable energy production and new technologies. Looking ahead, Estonia aligns its energy strategies with EU goals and public support in Estonia is strongly in favour of government-backed initiatives for household and cooperative energy generation and consumption, reflecting a societal preference for community-cantered sustainable energy solutions [18]–[22].

In the power sector, hydropower and biomass have traditionally dominated Latvia's renewable energy sources, with over 50 % of final electricity consumption coming from RES by 2022. However, a significant shift occurred in 2022, with solar energy adoption doubling the number of household prosumers to 2000, and a notable increase to 15 000 solar photovoltaic (PV) microgenerators by mid-2023, signalling a shift towards solar energy. Challenges remain, as Latvia’s National Energy and Climate Plan 2021–2030 indicates the electricity transmission system's capacity to integrate new renewable energy is limited to an additional 800 MW. The development of energy communities and the legislative framework supporting prosumer engagement are crucial for Latvia's transition towards a more sustainable energy sector [23]–[26].

Finland's solar capacity lags behind the EU average, with seasonal production mismatches presenting grid integration challenges. In Finland, since 2019, solar capacity has steadily increased, with a notable rise in 2022 to nearly 635 megawatts, over 240 megawatts more than the previous year. Finland supports renewable energy communities and prosumer growth with various business models and possible integration of electric vehicles. Prosumers minimally affect peak power loads due to the country’s geography, with high solar production in low-demand summers and minimal output in high-demand winters, challenging grid operators with cost and revenue discrepancies. By 2050, prosumers could self-generate 26 % of electricity consumption, with their batteries adding 32 GWh storage, about 5 % of demand [4], [27], [28].

Sweden and Belgium focus on residential solar investment, with policy incentives aimed at small-scale prosumers, despite concerns over the financial burden on non-prosumers. In 2020, Sweden added 398.5 MW of grid-connected PV capacity, bringing the total PV capacity in the country to 1089.4 MW. Swedes favour solar energy, with 80 % advocating for increased investments, focusing subsidies on the residential sector. Since January 2021, homeowners benefit from green technology tax deductions. The outlook for centralized PV in Sweden is dim due to scarce policy incentives, with utilities focusing more on intermediary roles in decentralized PV, community solar initiatives, and purchasing PV electricity rather than investing in centralized PV parks (1.29). In 2023, Belgium’s PV market saw a 72 % growth with 1.7 GW of new capacity, significantly surpassing the previous year’s 985 MW. Belgium’s region Wallonia implemented a prosumer grid fee to involve small-scale generators in grid maintenance costs, alongside reimbursements to ease the transition. Subsidies encouraged solar installations, offering economic benefits [29]–[31].

Italy and Spain demonstrate rapid market growth, underpinned by prosumer incentives and renewable community developments, though they face infrastructural and administrative hurdles. In Italy, since the early 2000s, renewable energy communities have grown from small local initiatives to larger, more efficient networks, with Enel reporting about 1.5 million prosumers, 70 % with batteries, connected to its Italian grid by end of 2023 [32]–[35]. In Spain recent studies on PV self-consumption regulations and financial impacts for prosumers in Spain have scrutinized installation costs, shared consumption/storage potential, and new business models. Findings across residential, commercial, and industrial sectors indicate profitability of PV self-consumption, especially in the residential area where lower margins are offset by falling installation costs and rising electricity prices, signalling a positive outlook for Spanish prosumers [36]–[38].

Poland and Slovakia are expanding their solar and storage capacities to meet growing energy demands and support renewable expansion. In Slovakia, nuclear power led in electricity generation at 60.11 %, with solar power following 2.57 % during past years. The Slovak energy strategy promotes small-scale electricity generation for higher self-consumption but lacks details on prosumer support [39]–[41]. In 2023, Poland's solar market sustained an installed capacity of about 4.6 GW, indicating stability in the market's size. Energy prosumers include households, collectives, SMEs, and public bodies, with PV installations totalling 8773.91 MW across 1193.053 units. The Institute of Renewable Energy notes nearly one million prosumer users. Poland's Solar sector is challenged by rising energy demand, increasing traditional energy costs, and grid limitations, affecting power affordability and development of renewables [42]–[46].

Germany, leading in solar installations, aims to significantly increase its capacity by 2030, with government incentives supporting prosumer integration despite regulatory limitations on energy feedback mechanisms. Germany's push for prosumer integration into its energy system has limited impact on the power grid due to the lack of Time-of-Use pricing and demand management programs, crucial for market flexibility. Benefits for German prosumers include avoiding grid fees and reducing electricity costs, but the option to feed excess energy back via feed-in tariffs is restricted to new PV system owners [47]–[49].

The summary of the findings indicated above, and the comparison of key indicators are provided in Table 1.

TABLE 1. COMPARISON OF KEY INDICATORS

Country	**Renewable Energy Targets**	**Solar Power Capacity Increase**	**Prosumers' Situation**	**Challenges**
Lithuania	30 % by 2030, 50 % by 2050	Over 800 MW of solar PV	77 000 private prosumers, with 26 000 new in 2023	Grid overload, storage requirements
Estonia	Surpassed 2030 targets, aims to fulfil all domestic energy needs with renewables by 2030	Solar power per capita from 405 W to 596 W (2021-2022)	10 000 households	Energy consumption, production's fluctuating nature
Latvia	RES accounting for over 50 % of the final electricity consumption	Upcoming surge is anticipated, expected to add up to 900 MW	15 000 solar PV microgenerators	Transmission capacity
Finland	51 % renewable energy target by 2030	Reached 635 MW in 2022	By 2050, prosumers to self-generate up	Seasonal mismatches

			to 26 % of final consumption	
Sweden	100 % renewable scenario by 2040, photovoltaic energy contributing 7 TWh	1.6 GW in 2023	Focus on residential prosumers supported by incentives	Solar infrastructure expansion
Belgium	Looking forward to several key solar power projects, including	1.7 GW in 2023	Small-scale generators contributing to grid maintenance	Financial burden on non-adopters
Italy	40.5 % of the energy demands with RES by 2030	3.5 GW in 2023	1.5 million prosumers	Infrastructure hurdles
Spain	Align with the European Union's 2030 renewable energy targets	6.93 GW in 2022	"Prosumer law" for up to 100 kW installations	Installation costs
Poland	4.6 GW in 2023	8773.91 MW in 2023	Nearly one million	Rising demand
Slovakia	Projecting an addition of 300 MW of new PV capacity in 2024	220 MW added in 2023	Lacks detailed prosumer support, focuses on small-scale generation	Nuclear power dominance (60.11 %)
Germany	Aiming for a solar capacity of 215 GW by 2030	Installed capacity reached 60 GW in 2021	Prosumers avoid grid fees and reduce electricity costs	Regulations

Collectively, these findings highlight the diverse landscape of solar energy adoption and the critical role of prosumers in transitioning toward renewable energy economies, necessitating targeted policy adjustments and infrastructure investments to address prevailing challenges.

Lithuania distinguishes itself among the Baltic nations through its innovative virtual prosumers and remote solar parks initiative, meriting more detailed examination.

2.2. Analysis of Lithuanian Remote Solar Parks and Virtual Prosumer Model

To foster active engagement within the electricity market and to elevate the contribution of renewable energy sources, Lithuania introduced prosumers scheme in 2015. This initiative set ambitious targets, aiming for prosumers to constitute 30 % of the total electricity consumer base by 2030 and 50 % by 2050, as reported by the Lithuanian Energy Agency.

Data from the Lithuanian Energy Distribution Operator (ESO) reveal a robust growth in the prosumer population, totalling 77 000 private prosumers, with nearly 26 000 joining the movement in 2023 alone. This trend underscores a significant shift towards self-sufficiency and renewable energy utilization among Lithuanian households [50]. The growth of prosumers in Lithuania is shown in Fig 1.

The cumulative capacity of electricity produced by these prosumers has also seen an upsurge, fuelled by the deployment of new remote solar power parks. Lithuanian electricity consumers are encouraged to participate in this prosumer scheme, benefiting from financial incentives to install small-capacity solar power systems. Legislative adjustments in 2022 capped commercial solar park capacity at 2 GW and a combined capacity of 4.4 GW with generating consumers, emphasizing the priority to preserve space for individual and small-scale producers against the rapid expansion of commercial entities. In 2023, the Lithuanian government has approved the expansion of commercial solar parks beyond a 2 GW capacity limit, albeit with stipulations to mitigate grid overload. Excess electricity generated during peak production periods must be redirected to storage facilities, ensuring a balanced supply and safeguarding grid integrity.

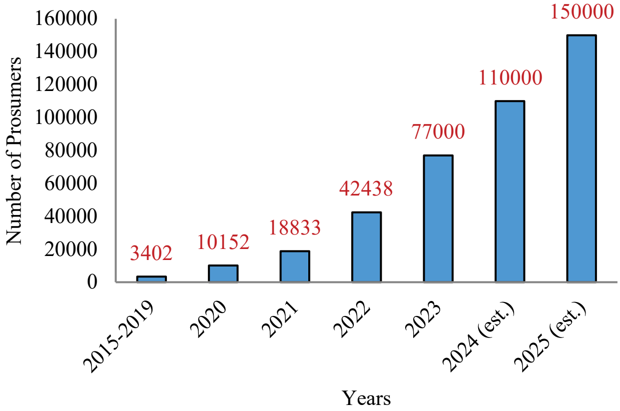

Fig. 1. Number of prosumers in Lithuania over the years [52].

In Lithuania, in the context of energy consumption and generation, a prosumer refers to an entity that both consumes and generates electricity. This dual activity can occur at distinct locations: the consumption might take place at one site, while generation occurs at a power plant situated elsewhere. These locations can be closely situated, such as on the same or adjacent properties, or they can be significantly separated, even located in different regions of the country [50]. By entering a buy-sell or rent agreement for equipment located at a distant solar/wind park and installing a smart metering device, consumers have the potential to transform into virtual prosumers. In 2019, 'Ignitis', Lithuania's electricity and gas provider, presented the 'Eparks' platform, a digital platform that facilitates the acquisition or leasing of segments within remote solar and wind parks. This platform democratized the accessibility of renewable energy, enabling both individuals and commercial entities to invest in or lease portions of remote solar and wind parks, regardless of their geographic location or land ownership status. The customer journey within this platform is characterized by a digitalized process. Initially, customers earmark the requisite power from a chosen solar or wind park, subsequently assessing their energy requirements with the aid of platform tools. Following the reservation phase, the procedure encompasses the finalization of ownership transfer agreements upon the completion of construction, the potential for securing government subsidies, the acquisition of necessary permits, and culminating in the commencement of energy production [51]. By the year 2022, the platform had facilitated a total of 11 200 reservations, contributing to an aggregate customer power capacity of 39.849 kW. Moreover, the number of customers with generating capacity reached 3200 [51].

From the perspective of remote prosumers, the energy generated at a distant power plant is directly supplied to the distribution grid before reaching the consumer. The accounting procedures for remote prosumers mirror those applicable to conventional prosumers. Specifically, a usage fee, determined by the ESO, is levied for grid utilization. Any energy generated but not immediately consumed is stored for a period of up to two years. Should this stored energy remain unused at the end of this period, it is then annulled, and its monetary value is reimbursed to the prosumer. In instances where there is a shortfall in generated energy, the deficit is compensated for by purchasing energy from energy provider, according to the rates stipulated in the prosumer's electricity supply contract [52]–[54].

3. METHODOLOGY AND CASE STUDY

This case study analyses two residential houses located in Lithuania with remote solar parks. One of the houses investigated – case study 'A' – a unit within an apartment building with a gross useful area of 109.79 m^2. Case study 'B' – is a single detached house with a gross useful area of 120 m^2. The following data presents the research consistency (Table 2) and used methodology, parameters, values for primary energy calculation are presented in Tables 3–6.

TABLE 2. CONSISTENCY OF RESEARCH METHODOLOGY

STEP 1	Collection of energy consumption and production data and energy prices (actual data from 2022 and 2023).
STEP 2	Comparison of energy consumption and production data for both reference buildings.
STEP 3	Comparison of energy prices (from remote solar parks and electricity from the grid).
STEP 4	Calculating the share of primary energy comprised of renewable primary energy and non-renewable primary energy (when biomass is used for heating ('B' case) and air-to-water heat pump ('A' case).
STEP 5	Calculating CO_2 emissions from the buildings when heat is supplied by a heat pump, as compared to when heat is obtained from a biofuel boiler.
STEP 6	Results analysis.
STEP 7	Results comparison and the concluding thesis.

Below, the case study overview and mathematical methodology is provided.

TABLE 3. CASE STUDY BUILDINGS

Reference building	**'A' – a unit within an apartment building**	**'B' – a single detached house**
Gross useful area (m^2)	109.79	120
Year of construction	2018	2015
Energy class (56)	A	B
Electricity	Solar, from remote solar park	Solar, from remote solar park
Heating	Air-to-water heat pump	Biofuel boiler

The following table provides comprehensive details regarding the remote solar parks.

TABLE 4. PARAMETERS OF REMOTE SOLAR PARKS

Reference building	**'A' – a unit within an apartment building**	**'B' – a single detached house**
Name	Buktos solar park	Saulės grąža solar park, stage I
Remote solar park view	 [55]	 [56]
Start of operations	2021	2020
Developer	UAB 'Egrupė'	UAB 'Saulės grąžos parkai'

Reference building	'A' – a unit within an apartment building	'B' – a single detached house
Location	Buktos, Lazdijai district 54.243601, 23.523660	Kuršėnai, Šiauliai district 55.997173, 22.979062
Total remote solar park power, kW	1599.2	782.0
Purchase price, €/kW	1299.99	950.0
Maintenance cost, €/kW/year	18.37	22.99
Status	Sold out	Sold out
Distance between the house and the solar power plant, km	~154	~251
Purchased part of the power plant, kW	6.0	2.0

Fig. 2 shows the geographical locations of the remote solar parks and study case buildings.

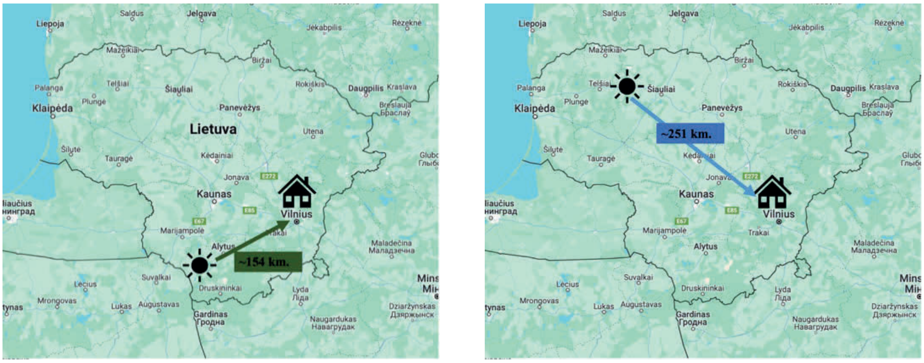

Fig. 2. Locations of remote solar parks (picture in the left — reference building 'A'; picture in the right – 'B').

The SPF used in the heat pump primary energy demand calculations and the COP of the biofuel boiler used in the PE calculations are shown in following table.

TABLE 5. PARAMETERS OF HEATING INSTALLATIONS

	'A'	'B'
Heating	Air-to-water heat pump 'NIBE SPLIT ACVM 270'	Biofuel boiler
Nominal (minimum/maximum) heating power kW	12.0	16.0
COP and SPF values	$SPF = 4.5$	$COP = 0.85$

3.1. Normative thermal energy, primary energy and economical calculations

All the values and equations used in the calculation methodology provided below are taken from the Lithuanian Building Regulation STR 2.01.02:2016 'Design and Certification of Energy Performance of Buildings' [54].

Values for the non-renewable primary energy factor $f_{PR,n}$ (units), the renewable primary energy factor $f_{PR,r}$ (units) and the CO_2 emission factor M_{CO2} ($kgCO_2/kWh$) of the energy sources used for energy production are presented in the Table 6.

TABLE 6. VALUES FOR THE RENEWABLE AND NON-RENEWABLE PRIMARY ENERGY AND THE CO_2 EMISSION FACTOR [54]

Source of energy	f_{PRn}, **units**	f_{PRr}, **units**	M_{CO2}, **kgCO_2/kWh**
Biofuels (wood, straw, biogas, bio-oil, etc.)	0.2	1	0.04
Photovoltaic solar collectors	0.01	1	0

Normative thermal energy consumption for heating a building (part of a building) Q_{H}^{I} (kWh/m^2/year) in energy performance class A and B [54] is calculated based on the Eq. (1):

$$Q_{H}^{I} = k_h \cdot y \cdot A_{p}^{-x}, \tag{1}$$

where:
$k_h = 1$ (k_h – correction coefficient, units);
A_p usable floor area of the building;
$y = 864$ (prescribed value set by the applicable standard [54] for energy class B), $y = 568$ (prescribed value set by the applicable standard [54] for energy class A); and x are respectively 0.36; and 0.37 (prescribed values set by the applicable standard [54] for energy class A and B).

Based on the equation (1): normative thermal energy consumption for heating a 'A' building is:

$$1 \cdot 568 \cdot 109.79^{-37} = 99.85 \text{ (kWh/m}^{2/}\text{year)}$$

Normative thermal energy consumption for heating a 'B' building is:

$$1 \cdot 864 \cdot 120^{-36} = 154.17 \text{ (kWh/m}^2\text{/year)}$$

The primary energy consumption for heating the building for both case study reference buildings was calculated using the equations below.

The primary energy (*PE*) consumption (renewable energy share) (kWh) for heating the building 'A' (solar power and heat pump):

$$PE = \frac{Q_{H}^{I}}{SPF} \cdot f_{PR,r} \tag{2}$$

The primary energy consumption (non-renewable energy share) (kWh) for heating the building 'A' (solar power and heat pump):

$$PE = \frac{Q_{H}^{I}}{SPF} \cdot f_{PR,n} \tag{3}$$

The primary energy consumption (renewable energy share) (kWh) for heating the building 'B' (biomass and biofuel boiler):

$$PE = \frac{Q_{H}^{I}}{COP} \cdot f_{PR,r} \tag{4}$$

The primary energy consumption (non-renewable energy share) (kWh) for heating the building 'B' (biomass and biofuel boiler):

$$PE = \frac{Q_H^I}{COP} \cdot f_{PR,n} \quad (5)$$

The CO_2 emissions (E_m), $kgCO_2$, were calculated based on Eq. (6). The CO_2 emission factor M_{CO2} ($kgCO_2/kWh$) is used in the calculations. As building 'A' uses solar energy, the emission factor equals 0 $kgCO_2/kWh$. Building 'B' uses biomass for heating, thus the emission factor is equal to 0.04 $kgCO_2/kWh$, as shown in Table 6.

$$E_m = Q_H^I \cdot M_{CO2} \quad (6)$$

Economical savings *E* (EUR) are calculated based on the Eq. (7):

E = electricity from the grid – solar energy price (with maintenance costs), (7)

where the solar energy price is the actual price paid by the households of the reference buildings, including maintenance costs and other costs related to their remote solar parks. Electricity from the grid is the calculated electricity price that would be paid if the reference buildings were buying electricity from the grid. In 2023, from January to April, the price from the grid was 0.28 EUR/kWh; from May to December, it was 0.24 EUR/kWh. In 2022, from January to June, it was 0.167 EUR/kWh, and from July to December, it was 0.261 EUR/kWh.

4. Results

4.1. Case Study 'A' – A Unit Within an Apartment Building

Fig. 3 outlines the electricity consumed and produced for case study 'A'. It again shows seasonal variations in production and consumption patterns.

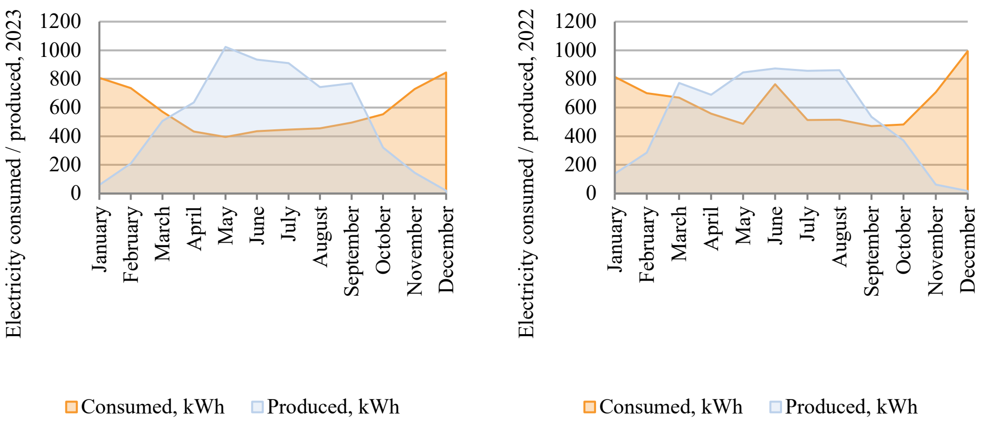

Fig. 3. Electricity Generated and Consumed in 2023 (figure on the left) and 2022 (figure on the right).

The observations from case study 'A' reiterate the impact of seasonal variations on solar energy production. However, the larger scale of production and consumption in 'A' suggests that apartment buildings with larger solar park shares might achieve greater energy self-sufficiency.

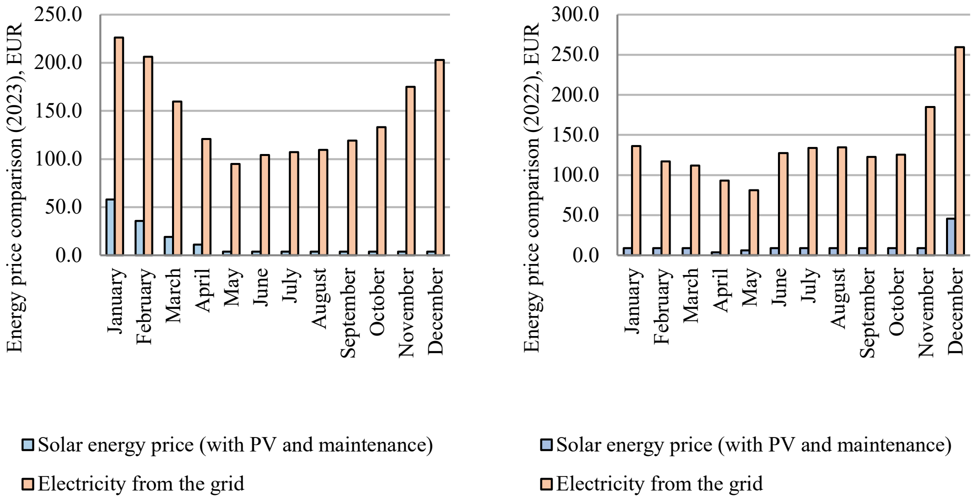

Fig. 4. Energy Price Comparison (Solar Energy Price versus Electricity from the Grid) in 2023 (figure on the left) and 2022 (figure on the right).

For case study 'A', the comparison between solar energy and grid electricity prices over two years (Fig. 4) shows solar energy being considerably cheaper than grid energy, reinforcing the economic advantage seen in case study 'B'. Thus, the significant cost savings from using solar energy in 'A' support the financial feasibility of larger investments in solar energy.

The following table provides a comparative analysis of financial savings achieved and the cost of solar energy for two case studies over the years 2022 and 2023.

4.2. Case Study 'B' – A Detached House

For the years 2023 and 2022, Fig. 5 displays monthly data on electricity consumed and produced for case study 'B'. The visual comparison indicates a pattern of consumption and production, with specific months showing higher production likely due to seasonal variations impacting solar energy generation.

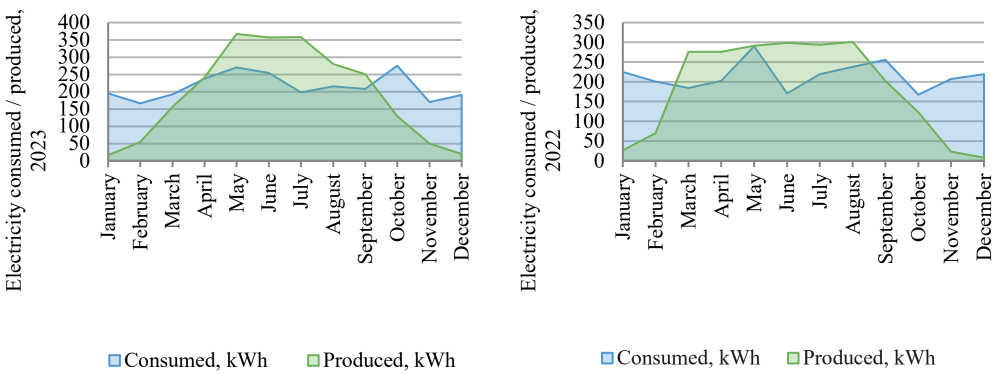

Fig. 5. Electricity Generated and Consumed in 2023 (figure on the left), and 2022 (figure on the right).

The fluctuation in monthly electricity generation and consumption reflects the variability in solar energy production influenced by seasonal changes. This suggests that while solar parks can significantly contribute to the energy needs of buildings, their output can vary, necessitating efficient energy management and storage solutions.

Fig. 6 compares the cost of solar energy (including PV and maintenance) to the electricity from the grid for case study 'B' over the two years. It shows that solar energy prices remained consistently lower than grid electricity prices throughout both years, implying a financial advantage to solar energy consumption.

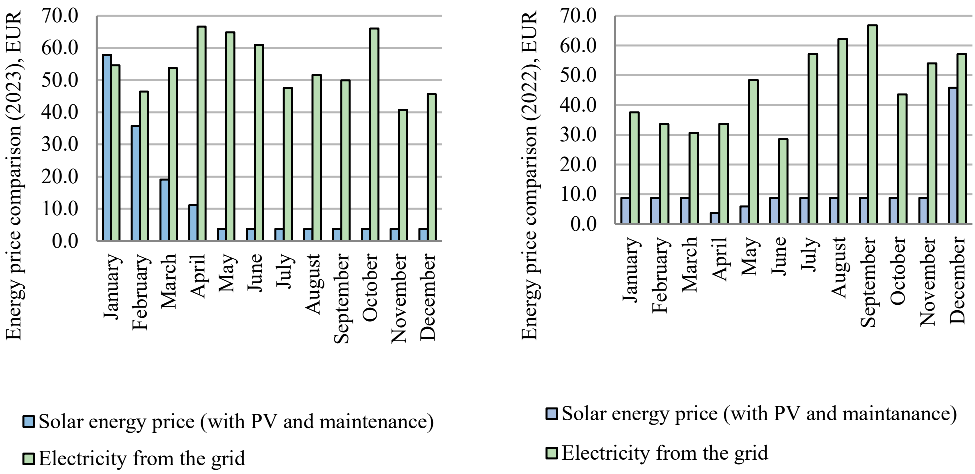

Fig. 6. Energy Price Comparison (Solar Energy Price versus Electricity from the Grid) in 2023 (figure on the left) and 2022 (figure on the right).

The consistent lower cost of solar energy compared to grid electricity across the analysed period demonstrates the economic benefits of investing in solar energy. This highlights the financial viability and potential savings associated with adopting solar energy for residential buildings.

TABLE 7. FINANCIAL SAVINGS AND SOLAR ENERGY PRICE

	Case study 'A'		**Case study 'B'**	
Years	2023	2022	2023	2022
Savings, EUR	1603.8	1491.5	494.1	418.0
Solar energy price, EUR/kWh	0.02	0.02	0.06	0.05

Both case studies demonstrate the economic viability of investing in solar energy. Despite slight fluctuations in the price of solar energy for the detached house, both cases saw an increase in financial savings from one year to the next. This indicates that solar energy not only provides a cleaner alternative to traditional energy sources but also offers substantial economic benefits over time. The stable price of solar energy for the case study 'A' across the two years emphasizes the reliability and predictability in the cost of solar energy. The increase in financial savings from 2022 to 2023 for both case studies highlight an important aspect of solar energy investments – the potential for increased savings over time. As the initial costs of solar panel installation and setup are amortized, the ongoing cost savings on electricity bills become more pronounced.

4.3. Renewable and Non-renewable Primary Energy Shares

Fig. 7 presents a stark contrast between the renewable and non-renewable primary energy shares for both case studies, with a dramatic dominance of renewable energy in both cases.

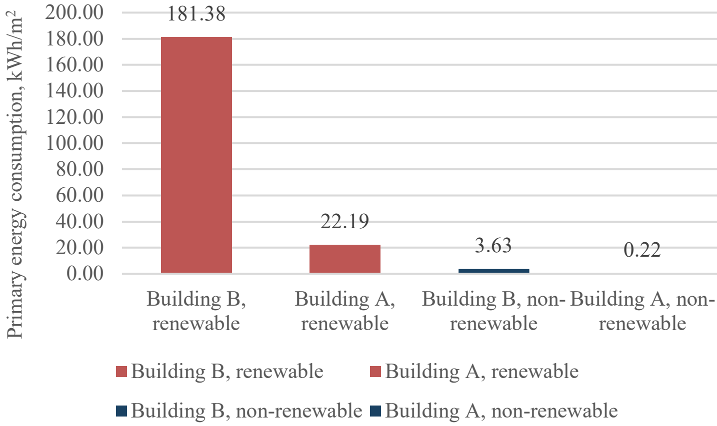

Fig. 7. Renewable and non-renewable primary energy consumption (kWh/m^2) of reference buildings 'A' and 'B'.

The overwhelming share of renewable energy primary energy in the energy mix for both case studies underscores the effectiveness of remote solar parks in contributing to the decarbonization of buildings. It highlights the potential for significant reductions in carbon footprint through the adoption of solar energy. Calculated CO_2 emissions (Eq. (6)) of a building 'A' (solar energy) reached zero emissions (0.0 kgCO_2/kWh), while for a building 'B' (biomass for heating) the emissions were 6.17 kgCO_2/kWh.

5. CONCLUSION

The novelty of the presented data stems from the relatively recent emergence of virtual prosumers in Lithuania, which began in 2019 with the introduction of a digital platform. Here are the main research conclusions:

- High Proportion of Renewable Energy: both case studies demonstrate a high proportion of renewable energy consumption. In Case Study A, the renewable primary energy usage was 22.19 kWh/m^2 compared to a minimal 0.22 kWh/m^2 of non-renewable energy. Case Study B showed 181.38 kWh/m^2 of renewable energy versus 3.63 kWh/m^2 of non-renewable energy. These results illustrate the PE consumption of buildings in different efficiency classes, and show that PE demand, even if it is renewable PE, can be drastically reduced in energy-efficient buildings using a solar energy and heat pump system.
- Carbon Emission Reduction: the adoption of remote solar parks in Lithuania significantly reduces carbon emissions for buildings. For instance, a building using solar energy for heat pump to produce thermal energy (case study A), achieved zero CO_2 emissions (0.0 kgCO_2/kWh) compared to a building using biomass for heating, which had emissions of 6.17 kgCO_2/kWh.
- Economic Benefits: there are substantial economic benefits for households adopting solar energy. The analysis revealed consistent lower costs for solar energy compared

to grid electricity. For example, in 2023, the savings for a detached house were 494.1 EUR, while for a unit within an apartment building, the savings were 1603.8 EUR.

This analysis lends empirical support to the findings of other thematically related studies [57]–[59], suggesting that the adoption of solar energy and heat pump technology represents one of the most effective strategies for the decarbonization of buildings, specifically regarding operational carbon (Use Stage B6) [60]. Moreover, the efficacy of these strategies is significantly influenced by other variables, among which the COP of the heat pump is particularly noteworthy [61], [62]. Consequently, the information offered in this analysis contributes new insights to the field, as there is not a lot of monitoring data, especially for buildings with different efficiencies, so the analysis of this data is very relevant for the development of further algorithms and models of energy demand and production to make residential buildings climate neutral by 2030.

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