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ELECTRICITY CONSUMPTION OPTIMISATION TRENDS FOR EDUCATIONAL, COMMERCIAL AND INDUSTRIAL FACILITIES

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The study explores emerging trends and strategies in electricity consumption optimisation for educational, commercial, and industrial facilities, focusing on the integration of digital technologies, smart metering, and tariff-driven energy management systems. In response to rising energy costs, environmental policy constraints, and the growing need for operational sustainability, these facility types are increasingly investing in tailored energy efficiency solutions. It identifies distinct patterns in consumption behaviour and optimisation tactics across facility categories, highlighting that educational institutions often rely on behavioural interventions and scheduling-based load management. At the same time, commercial buildings prioritise building automation systems and demand response participation. In contrast, industrial facilities adopt process-level optimisation, load shifting, and renewable integration to reduce peak demand and stabilise operational costs.

A multi-method approach has been applied, combining energy consumption case studies, time-of-use data analysis, and stakeholder interviews. The results reveal that data-driven electricity consumption tracking, combined with dynamic pricing awareness and customised load control strategies, significantly reduces energy waste and improves economic performance. Additionally, the adoption of energy management systems, when linked to real-time consumption data and production cycles, leads to enhanced energy autonomy, particularly in industrial facilities. The study emphasises the importance of cross-sectoral learning, standardised performance benchmarking, and the role of digital infrastructure in enabling adaptive energy consumption practices. It concludes that future optimisation efforts must align not only with cost reduction but also with broader goals of energy resilience and decarbonisation. These findings contribute to the understanding of sector-specific optimisation pathways and inform the development of integrated electricity consumption strategies that support both operational efficiency and policy compliance.

Keywords: *Commercial buildings, efficiency, energy, optimisation, public buildings, renewable, sustainability.*

1. INTRODUCTION

In the European Union (EU), analysing and recommending actions on electricity consumption trends within regions aligns with broader EU goals of sustainability, energy efficiency, and reduced greenhouse gas (GHG) emissions. The EU's Green Deal [1] and the Fit for 55 Package [2] target climate neutrality by mid-century, emphasising the optimisation of energy use across the sectors. A significant reduction in carbon dioxide (CO_2) emissions has been observed in the EU countries and the UK from 2005 to 2020 and from 2019 to 2020 – 38.69 % and 21.15 %, respectively [3], [4].

To reduce CO_2 emissions, achieve the EU decarbonisation targets, and optimise the proportion of electricity produced, attempts are often made to combine renewable energy sources (RES) with electricity storage applications and green and low-carbon hydrogen technologies [5]–[8].

The EU electricity demand saw a reduction of 3.4 % in 2023, with expectations of further changes as electrified technologies became more widespread. This includes the electrification of the transport sector, increased use of electric heating solutions like heat pumps, and the broader adoption of electric vehicles. Between 2000 and 2020, the EU achieved significant reductions in primary and final energy consumption, largely influenced by EU energy efficiency policies and a shift towards RES. These efforts are part of a broader aim to meet the EU 2030 targets for energy efficiency and renewable energy (RE) consumption [9].

The EU also liberalises its electricity market to enhance competition, reduce prices, and improve energy security. This includes measures to monitor and possibly reduce the market share of dominant electricity generators within Member States to encourage a more competitive and diverse energy market [10]. Looking towards 2050, the EU envisions a significant increase in electricity demand, driven by the national hydrogen strategies, the electrification of various sectors, and the rise of electromobility. The share of renewable energies in electricity generation is projected to reach 74 % by 2050, with wind and solar power making up the largest share. The long-term vision includes a drastic reduction in generation capacity from dispatchable thermal power plants, highlighting a future where the EU's electricity generation is largely characterised by fluctuating renewable energies and a minimal role for fossil fuels [11].

Recent geopolitical developments have accelerated the EU's efforts to reduce dependency on fossil fuel imports. This has led to increased commitments to RE expansion and re-evaluating planned investments in fossil fuel-based power generation. Countries heavily reliant on imported fossil fuels are leading the way in adopting ambitious RE policies [12], [13].

Although the electricity market in Latvia is liberalised, electricity users can choose a specific service provider depending on the financial attractiveness of their offers. The Latvian electricity market is a part of the Nord Pool energy exchange, which ensures competition and flexible price formation depending on demand and supply. The day-ahead market determines the trading of electricity, where the price is set every day for each hour for the next 24-hour period. The capacity market is a long-term market where transactions related to the availability and supply of capacity can be made. The futures market is characterised by contracts for the supply of electricity in the future, which allow participants to hedge against price fluctuations. In Latvia and other Baltic countries, electricity prices are determined by the overall market price, which may vary from hour to hour. At the national scale, the Latvian electricity market is monitored and regulated by the Public Utilities Commission, the institution responsible for setting up tariffs for energy transmission and distribution services.

The actual electricity price fluctuations depend on various factors. As seen in data reported by the Latvian electricity transmission operator "Augstsprieguma tīkls", in 2024, a decrease in the average electricity price in Latvia reached 87.43 EUR/MWh, 7 % less compared to 2023. The increased electricity production from RES and the decrease in natural gas prices determined the price decrease. The lowest monthly price level in 2024 was identified in April – 60.23 EUR/MWh, while the highest – 117.22 EUR/MWh – was reached in January. Due to the increase in the proportion of energy generated by solar power plants on sunny days between 9:00 and 18:00, the electricity price was up to 75 % lower than during the rest of the day. The number of hours of negative electricity prices in Latvia reached 184 hours, which was caused by the high volume of electricity production from RES when demand was low [14].

In Latvia, electricity consumption planning and broader energy policy are shaped by several strategic documents to foster a sustainable, competitive, and climate-neutral economy. The National Energy and Climate Plan for 2021–2030 outlines Latvia's long-term energy sector objectives. This plan prioritises enhancing energy security, promoting the use of negative emission technologies in electricity generation, supporting economically viable energy production, and encouraging self-consumption of energy [15], [16]. In addition, Latvia's energy policy emphasises the reduction of CO_2 emissions. It integrates various initiatives, such as training programs for energy efficiency, demand-side management, and promoting RE, which are central to achieving the country's decarbonisation and energy transition targets [17], [18].

Latvia's energy profile reflects a strong commitment to reducing GHG emissions, aiming to achieve a 65 % reduction from 1990 levels by 2030 and reaching net zero emissions by 2050. The country's electricity generation is primarily dominated by RES, with bioenergy and hydropower accounting for approximately three-quarters of domestic production. However, sectors such as transport and buildings continue to be major energy consumers, heavily reliant on outdated infrastructure [19], [20]. Addressing inefficiencies and promoting fuel switching in these sectors are essential for further reducing energy consumption and GHG emissions.

The hydro-dominated electricity system of Latvia provides a robust foundation for using clean electricity to decarbonise other sectors of the economy. Additionally, the shift towards clean energy is crucial for enhancing energy security and reducing energy costs, particularly in reducing dependency on fossil fuel imports [21]. Latvia's energy consumption trends and approach to energy efficiency and RE integration demonstrate a clear commitment to a sustainable energy future. The country's energy consumption per capita remains approximately 40 % below the EU average, with electricity consumption declining by 4 %, reaching 6.7 TWh in recent years. This transformation of Latvia's energy mix, supported by substantial RE consumption, positions the country to meet its climate and energy goals [17].

The integration of RES is a priority not only for large-scale facilities but also for smaller-scale installations [22], [23]. Furthermore, the deployment of smart electricity meters, which began over four years ago, plays a crucial role in monitoring and analysing the electricity supply network's parameters, supporting the efficient management of energy consumption at the end-user level [24].

Over 220 million building units, about 85 % of the EU's total, were built before 2001, and up to 95 % of these are expected to still be in use by 2050. This highlights the need to prioritise the renovation of existing buildings.

Most of these buildings are energy-inefficient, often relying on outdated fossil-fuel-based systems and wasteful technologies. As a result, energy poverty continues to affect millions of Europeans. The building sector accounts for roughly 40 % of the EU's total energy consumption and 36 % of its energy-related greenhouse gas emissions, making it a key target for decarbonisation and sustainable transformation.

All the examined sectors – industry, educational institutions, and commercial buildings – represent key players in the overall final electricity consumption balance of the EU. Their collective electricity demand significantly influences the EU's energy use patterns, making them critical targets for energy efficiency measures and sustainable development policies.

In 2022, the industrial sector was one of the largest energy consumers in the EU, accounting for 25.1 % of the EU's final energy consumption. Within the sector itself, electricity and natural gas played a dominant role, representing 33.3 % and 31.2 %, respectively, of its total final energy use. Combined, these two sources formed the core of industrial energy supply, highlighting the sector's strong dependence on both electricity and fossil fuels to sustain manufacturing processes and daily operations [25].

Energy use is essential in the industry sector, not only for powering core industrial processes such as manufacturing, refining, and material transformation, but also for non-process-related purposes, including space heating, cooling, ventilation, lighting, and the operation of auxiliary equipment. These non-process energy needs, while often overlooked, contribute significantly to overall energy demand and offer important opportunities for efficiency improvements and emissions reductions [26].

Despite data inconsistencies and the various challenges faced by the EU Member States in integrating RES into the industrial sector and pursuing climate neutrality targets, progress is nevertheless evident. The share of RES in industry is gradually increasing across the EU, and projections suggest that this trend will continue in the coming years. Countries such as Germany, Bulgaria, and Luxembourg are already showing significant advances, while policy frameworks, financial instruments, and energy efficiency measures serve as key enablers in accelerating this transformation [27]. The EU's non-residential buildings represent approximately 25 % of the total building stock. These buildings account for about 13.6 % of the EU's final energy consumption, equivalent to approximately 146.9 Mtoe. This category includes a wide range of building types such as offices, schools, hospitals, and retail spaces. Energy consumption varies significantly across sub-sectors: for commercial buildings, it typically ranges from 200 to 335 kWh/m^2 annually. The primary energy demand in non-residential buildings is driven by heating systems (more than 60 %) and lighting (more than 10 %), with ventilation, cooling, and equipment use also playing a significant role depending on the building type and usage patterns.

In recent years, schools across Europe have increasingly installed on-site RE systems, illustrating the role educational institutions can play in the energy transition. These projects typically involve PV panels, biomass boilers, geothermal systems, and combinations thereof. By empowering students, reducing costs, and lowering emissions, these initiatives foster sustainability literacy and contribute to municipal energy strategies.

In the United Kingdom, the government's £ 200 million GB Energy scheme has allocated £ 80 million to installing solar panels on school rooftops in England, aiming to cut energy bills and improve energy security [28]. Community energy organisations, such as the Low Carbon Hub in Oxfordshire, have funded installations in schools through local cooperative models, enabling them to buy their green electricity at a discount, reducing operational costs [29].

In Germany, solar energy is wellintegrated in schools, like the Schule am Park in Berlin, which incorporates solar PV and geothermal heating systems. These installations serve dual purposes: lowering carbon emissions and providing educational tools for students to understand energy dynamics [30].

Spain and Portugal have implemented cross-border programs like ClimACT and EU4Schools, funding PV installations and energy-efficiency upgrades [31]. In Albania, solar panels installed in vocational and high schools are projected to meet 90 % of annual energy needs, cutting around 12 tons of CO_2 per year [32]. In BrodPosavina County (Croatia) and Tuzla (Bosnia), solar PV and biomass boilers in seven schools cut energy use by 7 % and CO_2 emissions by 853 tons annually [33].

The green school movement in Copenhagen International School, Denmark, utilises PV facades and educational integration. These systems are often part of broader municipal partnerships, such as the E.ON-Coventry collaboration, which includes school decarbonisation [34]. Similarly, Malta's St. Nicholas College underwent a deep retrofit and installed PV, achieving a "positive energy" status [35].

The Netherlands, Sweden, Austria, and Switzerland similarly feature schools with rooftop PV, with notable examples like the International School of Amsterdam and Vienna International School. These projects are often supported by EU structural funds [36]. RE systems in the selected schools across the EU and UK are summarised in Table 1.

Table 1. RE Systems in the Selected Schools across the EU and UK (based on [28]–[36])

Country/region	Technology	Energy savings/ generation	Educational benefit	Funding mechanism
UK (1)	Solar PV	Savings 20–50 % of school energy bills	Direct price transparency for students	Government + community co-op funding
UK (2)	PV + storage + drones + EV/battery systems	Enhanced efficiency via drones	Student engagement in energy audits	Cityutility partnership
Germany	PV + geothermal	CO_2 reduction	Curriculum integration in class labs	Municipal + school budgets
Spain / Portugal	PV	Multi-school reductions, bill savings	Training modules across countries	Interreg ERDF funding
Croatia	PV +nbiomass boilers	1,042,200 kWh generated, €89k savings	Energy camp, innovation outcomes	Interreg IPA funding
Denmark	PV facades	Major reductions (not quantified)	Visual and architectural teaching elements	Municipal/national renewable grants
Malta	Zerocarbon renovation + PV	Zero emissions achieved	Building as a living lab	ERDF funds

On-site school renewables across the EU create a compelling synergy of energy efficiency, cost reduction, and educational impact (Table 1). While technical implementation varies, from PV systems to integrated bioclimatic design, common enablers remain EU funding, municipal leadership, and curricular integration. When combined with smart behaviour-change programs, these installations not only save energy and costs but also underpin a transformative model where schools become living testbeds for sustainability in the European energy transition.

In Latvia, according to Cabinet of Ministers Regulation No. 383, the primary energy consumption threshold for buildings, including public buildings (schools, etc.), is ≤ 45–150 kWh/m²/year [37].

Latvia's ambition to have cities like Riga and Liepaja among the first 100 climate-neutral cities [38] by 2030 aligns with the European Green Deal's objectives. Liepaja has set a goal to reduce CO_2 emissions by 80 % by 2030 compared to 2006. In the industrial sector, energy efficiency and the transition to RES in industrial processes have been set as a priority. In the municipal sector, which concerns educational facilities as well, a transition to the wider use of RES in electricity and heating is on its way. Most industrial and municipal buildings, as well as buildings belonging to the port authority of Liepaja, were built several decades ago. They are energy inefficient, and industrial buildings are additionally characterised by outdated equipment and high electricity consumption [39], [40].

Riga's commitment by 2030, as set by the Sustainable Energy and Climate Action Plan 2030 (SECAP), has set goals to reduce CO_2 emissions by 70 % compared to 1990, as well as by 30 % compared to 2019. Key driving points of the plan are increasing the energy efficiency of public places and municipal buildings, as well as the integration of RES [41].

In Riga, in sectors such as ports, municipal buildings, schools, and the industrial segment, there are significant energy efficiency problems related to outdated infrastructure and technologies. Several energy audits have been conducted in Riga recently, including one conducted by the Riga Energy Agency on 120 public buildings. It has been found that many Latvian schools and public buildings have outdated ventilation and heating systems, which not only reduce comfort in the premises but also cause unnecessary energy losses [42]. After an energy audit by Riga Municipality, it was determined that a large part of the municipality's buildings still have Soviet-era heating systems, which means that they are not balanced – one part of the building can be overheated. At the same time, the other is cool, and it is also not possible to set the temperature in the rooms. There are still 40 and 50-year-old luminaires with inefficient bulbs [43].

However, this study is not focused on the capital – it addresses electricity consumption trends across educational, industrial, and commercial facilities in a Latvian municipality – City A, located on the western seashore of the country. It is the largest city in the Courland region and the third largest in the country after the capital Riga and Daugavpils.

The goal of the study is to analyse electricity consumption patterns across educational, commercial, and industrial sectors in City A, with a focus on identifying seasonal trends, energy inefficiencies, and sector-specific optimisation opportunities. The study also aims to evaluate the potential benefits of integrating RE technologies, particularly PV systems, within each sector to support Latvia's and the EU's broader climate and energy goals.

The hypothesis of the study is that electricity consumption patterns in educational, commercial, and industrial sectors demonstrate seasonal variability and contain significant inefficiencies that can be addressed through targeted technological interventions, such as solar PV integration and energy-efficient equipment upgrades, resulting in improved energy performance and reduced carbon footprint.

From the hypothesis, the following research questions are derived:

- What are the main seasonal trends and variability in electricity consumption across the three sectors?
- Which sector exhibits the highest potential for energy savings through RE integration and efficiency measures?
- What economic and environmental benefits can be derived from adopting PV and other optimisation technologies?
- How do pricing structures and electricity market dynamics influence the cost-efficiency of RES in the Latvian context?
- What are the key barriers and drivers for implementing energy efficiency measures in each sector?

Scientific novelty of the study is that it provides a multi-sectoral, data-driven comparison of electricity consumption patterns and evaluates them in the context of RE integration and energy efficiency strategies. It introduces a quantitative framework combining consumption analysis, economic modelling (LCOE, NPV), and policy context, highlighting how sector-specific dynamics affect the feasibility and efficiency of RE deployment. The cross-comparison between educational, commercial, and industrial entities with sectoral specificity is relatively underexplored in the Latvian context.

The study is limited by the incomplete dataset for the final months of 2023, restricting full-year comparative analysis. There is also a lack of hourly-level data, consumer behavioural metrics, and detailed technical building characteristics, which constrain the precision of energy consumption modelling. Additionally, the economic evaluations are based on average parameters and do not account for individual building-specific constraints or behavioural patterns.

2. MATERIALS AND METHODS

The present section systematically evaluates electricity consumption optimisation strategies in educational, commercial, and industrial facilities. The methodological framework combines quantitative data analysis, case study investigation, and literature synthesis to derive patterns and operational insights that inform demand-side management approaches. The research focuses on three main facility types due to their distinct energy use profiles, operational hours, equipment diversity, and interaction with regulatory and market-based energy signals.

The study began with the identification and classification of representative facilities across the three sectors: higher education campuses and secondary schools for the educational category, retail centres and office complexes for the commercial sector, and manufacturing plants and food processing units for the industrial category. A purposive sampling strategy was used to select a group of facilities covering all three sectors. These facilities were chosen based on data availability, diversity of energy systems, and willingness to participate in the research.

Energy consumption data was collected over 24 months (January 2022 to December 2023) to account for seasonal variation, operational cycles, and potential changes in occupancy and production patterns due to external factors such as the post-COVID recovery and inflationary energy pricing. The datasets included hourly and daily electricity load profiles, peak and off-peak usage, building management records, equipment-level submetering, and energy bills. Supplementary data such as heating, ventilation, and air conditioning (HVAC) usage patterns, lighting schedules, and operational hours were also obtained through facility audits and interviews with energy managers.

To assess optimisation potential, the study utilised a baseline-normalised comparison using a combination of energy intensity indicators. These included kWh/m² for commercial and educational buildings, and kWh/unit of output for industrial sites. Facility-specific key performance indicators were also established based on production volume, occupancy rates, or usage schedules.

Qualitative data were gathered through semi-structured interviews with facility managers, energy consultants, and operations staff. These interviews were coded and analysed using thematic content analysis to identify organisational, behavioural, and technological barriers to optimisation, such as lack of awareness, budget limitations, and technological lock-in.

The study also applied a multi-criteria decision analysis framework to rank optimisation strategies according to technical feasibility, financial viability, and ease of implementation. The analytic hierarchy process method was used to weigh criteria based on expert feedback. All collected data and modelling outputs were synthesised to formulate sector-specific recommendations that align with EU energy efficiency directives, decarbonisation targets, and national energy performance strategies.

This integrated methodology ensures a robust and replicable approach to identifying electricity optimisation trends across diverse facility types, providing both strategic and operational guidance for future energy management interventions.

3. RESULTS

A combination of structural, operational, and external factors shapes energy consumption in educational, commercial, and industrial facilities. Understanding the dynamics of energy use in each facility type allows for the identification of optimisation strategies that are both technically feasible and economically rational.

In educational facilities, energy demand is strongly influenced by climatic zone, occupancy schedules, seasonal variation, building envelope characteristics, and the type and intensity of equipment used, such as lighting, ventilation, and information technology infrastructure [44]. HVAC systems typically account for a significant portion of energy usage due to comfort requirements and inflexible daily occupancy patterns.

Commercial buildings exhibit high variability in energy use due to diverse end-use profiles. Factors such as building design, automation systems, business operating hours, and customer footfall patterns significantly impact energy intensity [45]. Moreover, commercial facilities often have high internal heat gains from lighting and electronic equipment, which in turn increase cooling loads. Building automation systems and energy management strategies play a critical role in monitoring and controlling these loads efficiently.

In industrial settings, energy consumption is predominantly process-driven, with electricity and thermal energy being used to power machinery, perform chemical transformations, and maintain environmental conditions for sensitive manufacturing processes. The nature of the industrial process, production scale, load factor variability, and the integration of waste heat recovery systems all determine the total energy profile. In sectors such as food processing, chemicals, or metalworking, energy intensity can be particularly high due to temperature and process continuity requirements.

To optimise energy consumption in educational buildings, dynamic occupancy-based control systems, daylight harvesting, and improved insulation are widely recommended. Moreover, aligning academic schedules with peak RE availability could offer systemic benefits. In commercial buildings, retrofitting with energy-efficient lighting like LED, demand-controlled ventilation, and smart thermostats offers immediate gains. Integration of PV systems and battery storage further reduces grid dependence and smoothens peak demand [46].

Industrial facilities benefit most from process-level audits, heat integration techniques, motor efficiency upgrades, and digitalisation through Industrial Internet of Things platforms. Predictive maintenance and real-time process analytics allow companies to adjust loads dynamically, reducing energy waste.

The three sectors also present distinct characteristics in terms of energy use profiles and pose specific challenges for integrating RE sources into their operations. Understanding these differences is essential for developing targeted energy efficiency measures and decarbonisation strategies.

Educational facilities, such as schools and universities, typically exhibit moderate energy intensity levels. Their energy consumption is primarily driven by HVAC systems, lighting, IT infrastructure, and laboratory equipment [47]–[49]. These facilities often operate on a fixed schedule (8–10 hours per day, five days a week), with significant seasonal variation corresponding to academic calendars. Peak loads generally occur during morning hours, aligning with class activities and administrative functions. Energy use per square meter tends to be lower than that of industrial settings. Still, it can vary depending on the presence of high-energy facilities such as research labs or indoor sports centres.

In contrast, commercial facilities, including office buildings, retail centres, and hospitality venues, show a higher and more diverse range of energy demands. HVAC systems, lighting, elevators, and plug loads for electronics dominate their consumption. Unlike educational buildings, commercial operations are less affected by seasonal shutdowns and often maintain extended or continuous operating hours. These facilities place greater emphasis on occupant comfort, environmental control, and lighting aesthetics, which increase overall energy intensity. Moreover, commercial buildings tend to be more adaptable to smart energy management systems and load-shedding technologies, creating favourable conditions for RE integration and demand response programs [50].

Industrial facilities, by far, exhibit the highest energy intensity, mainly due to process-related consumption. Manufacturing plants, foundries, chemical refineries, and logistics centres rely heavily on mechanical drives, compressed air systems, heat processes, and continuous production lines. Their energy use is less variable but significantly more robust, with electricity and thermal energy playing critical roles. The nature of industrial operations often necessitates a baseload energy supply, posing a challenge for intermittent renewable sources such as solar and wind. Additionally, these facilities are more sensitive to energy quality and reliability, especially where uninterrupted processes and equipment integrity are paramount [51].

While the energy consumption profiles vary, the adoption of RE systems in each sector faces shared and sector-specific barriers. In educational settings, budgetary constraints, limited technical expertise, and policy inertia can delay the implementation of photovoltaic systems or geothermal heating. However, such facilities also present an excellent opportunity for solar energy deployment due to their extensive roof space and predictable load curves. Furthermore, educational institutions can act as living laboratories for sustainability, fostering awareness and innovation among students and faculty.

Commercial facilities, although generally more financially capable, face challenges related to space availability, split incentives between building owners and tenants, and aesthetic concerns. Nevertheless, advancements in building-integrated PV, energy storage systems, and dynamic pricing schemes have created favourable conditions for renewable deployment. These buildings are increasingly equipped with energy monitoring and automation systems, making them suitable candidates for smart-grid interactions and hybrid renewable integration.

Industrial sectors confront the most complex integration challenges. High energy demands, continuous operations, and stringent power quality requirements limit the share of intermittent renewables that can be absorbed without extensive storage or backup systems. Additionally, retrofitting older industrial plants with renewable systems may require substantial capital investment and infrastructure adaptation. Nevertheless, sectors with significant thermal demand can benefit from solar thermal collectors, biomass boilers, or waste heat recovery systems, while large factory rooftops are ideal for high-capacity solar arrays. Moreover, industrial clusters offer synergies for shared renewable installations and microgrid configurations [52]. Examples of energy use and RES integration challenges in educational, commercial, and industrial sectors are listed in Table 2.

Table 2. Energy Use and RES Integration Challenges (based on [46]–[52])

Criterion	Sector		
	Educational Facilities	**Commercial Facilities**	**Industrial Facilities**
Primary energy loads	HVAC, lighting, IT, labs	HVAC, lighting, plug loads, elevators	Process energy, motors, heat, compressed air
Operational schedule	Fixed (academic calendar), ~8–10 h/day	Extended or continuous	Continuous or shift-based
Energy intensity (kWh/m²/year)	150–300	200–500	400–3000
Peak load period	Morning/early afternoon	Varies by function; often midday	Continuous or peak-aligned with shifts
Key integration barrier	Budget constraints, limited policy incentives	Space limitations, ownership complexities	Baseload requirements, retrofit difficulty
Renewable potential	High (PV on roofs, geothermal heat pumps)	Moderate to high (BIPV, storage integration)	Site-dependent (solar thermal, biomass)
Flexibility for load shifting	Moderate	High (smart systems feasible)	Low without storage or demand response

3.1. Data Analysis in Educational Institutions

Electricity consumption in nine schools (Schools A–I) of City A was analysed. Their yearly working schedules characterise a high seasonality, which is directly correlated with the electricity consumption scatterplot pattern for 2022 as depicted in Fig. 1.

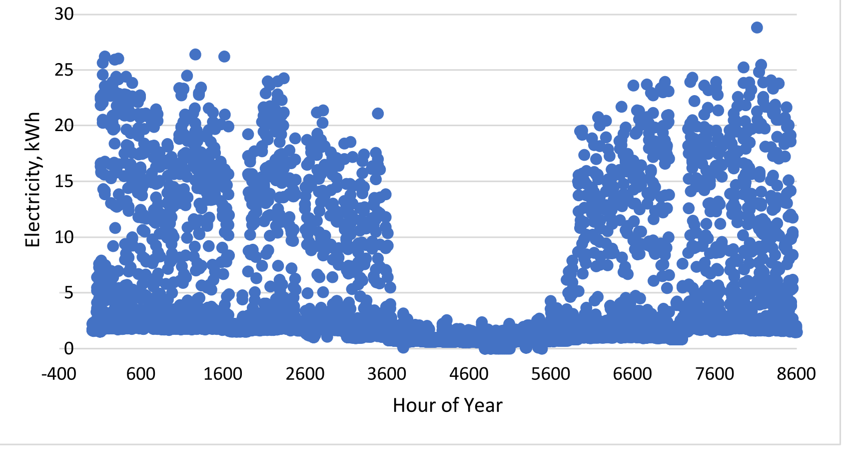

Fig. 1. Electricity consumption data in schools, 2022.

The data points to a substantial drop in electricity consumption during the summer months, correlating with the school vacation period when educational activities are suspended, and only minimal electricity is required for basic functions. Concurrently, this period aligns with the peak potential for solar energy generation due to Latvia's higher solar radiation levels, as shown in Table 3.

Table 3. Solar Irradiation Level and Average Monthly Temperature in Central Latvia

	01	02	03	04	05	06	07	08	09	10	11	12
Solar irradiation (kWh/m^2)	12.1	28.6	79.1	120	170.3	206.3	192	146.5	87	43.4	15.4	9.1
Temperature (°C)	-4.7	-4.3	-0.6	5.1	11.4	15.4	16.9	16.2	11.9	7.2	2.1	-2.3

Table 3 demonstrates the correlation between monthly solar irradiation intensity (kWh/m^2) and average ambient temperature for Central Latvia. It indicates that the largest irradiation intensity corresponds to summer vacations throughout June, July, and August. Out of regular school months, only months of September, April, and July show monthly solar irradiation intensity surpassing the benchmark of 100 kWh/m^2. For the Western part of Latvia, taking data from Fig. 2 as a reference, the direct normal solar irradiation level could be estimated at least 10–15% higher.

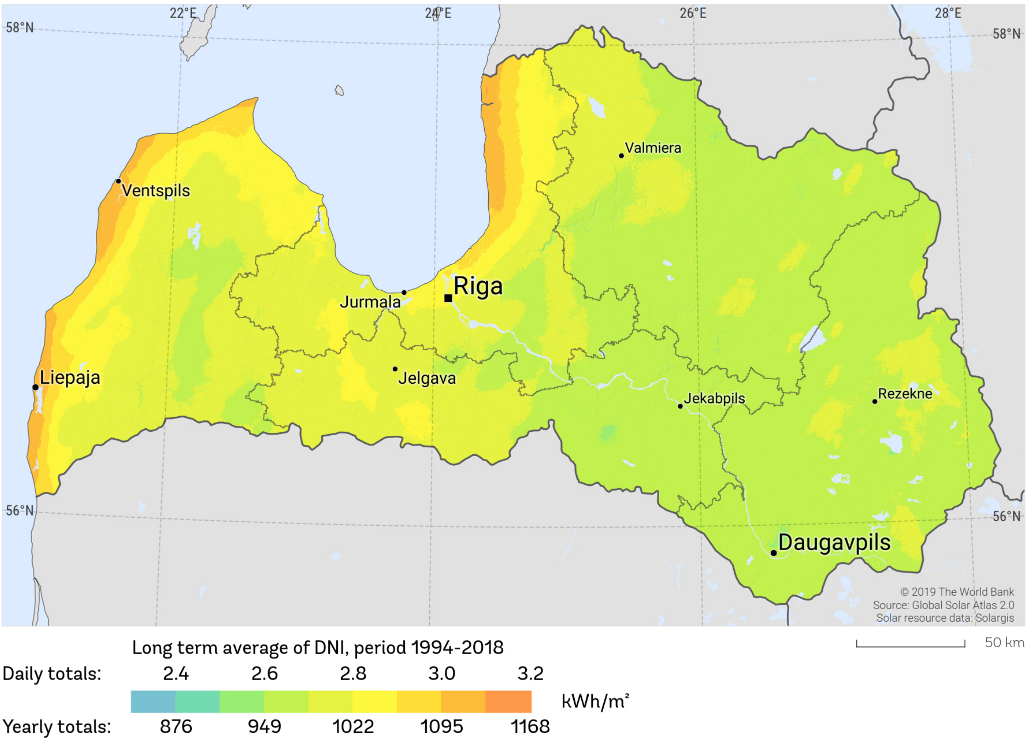

Fig. 2. Direct normal solar irradiation in Latvia [53].

Regardless of solar irradiation level, the performance of PV installation is determined by two key parameters: the Capacity Factor, which is defined as the annual actual AC electric energy output (in kWh/year) divided by the annual generated DC output peak power rating (in kWp) multiplied by 8760 h/year, according to Eq. (1), and the Performance Ratio (PR), which is defined according to Eq. (2).

$$CF = \frac{Actual\_annual\_AC_{output}}{DC\ peak\ power\ rating.8760}. \quad (1)$$

$$PR = \frac{CF}{DCpower_{(peak).}\ 8760\ .\ Irr_{avg}\ .\ 10^{-3}}. \quad (2)$$

Despite the seasonal challenges, installing PV panel systems on school buildings or other available spaces presents a sustainable opportunity.

Two strategic approaches are suggested for sizing the solar PV systems:

- Minimal Investment Approach: design the PV system capacity to match the energy needs during the low-consumption summer period. This would involve minimal investment and align energy production closely with consumption.
- Maximum Capacity Approach: size the PV system to the maximum possible capacity, constrained only by the availability of space for the panels and the capacity of the electrical network connections. This would ensure a surplus of energy generation during the summer months, which feeds into the grid and offsets higher consumption during autumn and winter (using net metering or a similar arrangement). The preliminary analysis of the available data indicates that schools have adequate grid connection capacity. The integration of solar PV systems would contribute to energy production and ensure the optimal and efficient use of the grid connection throughout the year, particularly during periods of intensive operation.

A comprehensive assessment, including an energy audit and a feasibility study, is necessary for each school to tailor the most suitable PV installation proposal. The consumption data for schools presents a compelling case for investing in PV systems, exploiting the natural lull in summer consumption and the potential for RE generation. The results of the statistical processing of the electricity consumption of schools in 2022 are summarised in Table 4.

Table 4. Results of Statistical Processing of Electricity Consumption of Schools (2022)

School	**A**	**B**	**C**	**D**	**E**	**F**	**G**	**H**	**I**
Average value (kWh)	10.40	9.34	12.49	13.66	8.37	3.76	14.67	18.78	11.93
Median (kWh)	7.31	5.11	8.24	8.66	3.97	1.47	8.16	8.50	6.05
Standard deviation (kWh)	9.54	9.98	11.93	13.39	10.32	5.39	17.69	19.32	14.21
Maximum (kWh)	52.67	62.50	73.88	81.04	63.18	25.03	106.51	98.28	70.24

Table 4 presents a statistical overview of electricity consumption in Schools A–I, where key metrics include the average, median, standard deviation, and maximum electricity consumption measured in kWh. This quantitative assessment is crucial for understanding the school energy demands and identifying opportunities for energy management and sustainability initiatives.

The statistical data from 2022 reveals significant variations in electricity consumption across the different schools. While some schools exhibit relatively modest energy usage, others have notably higher consumption, as indicated by the maximum values. The standard deviation suggests a variability in consumption attributed to differences in size, infrastructure, and utilisation of the schools. Such disparities in energy usage patterns underscore the need for tailored energy efficiency measures and reinforce the potential benefits of implementing RES, especially solar PV systems, to accommodate the unique energy needs of each school.

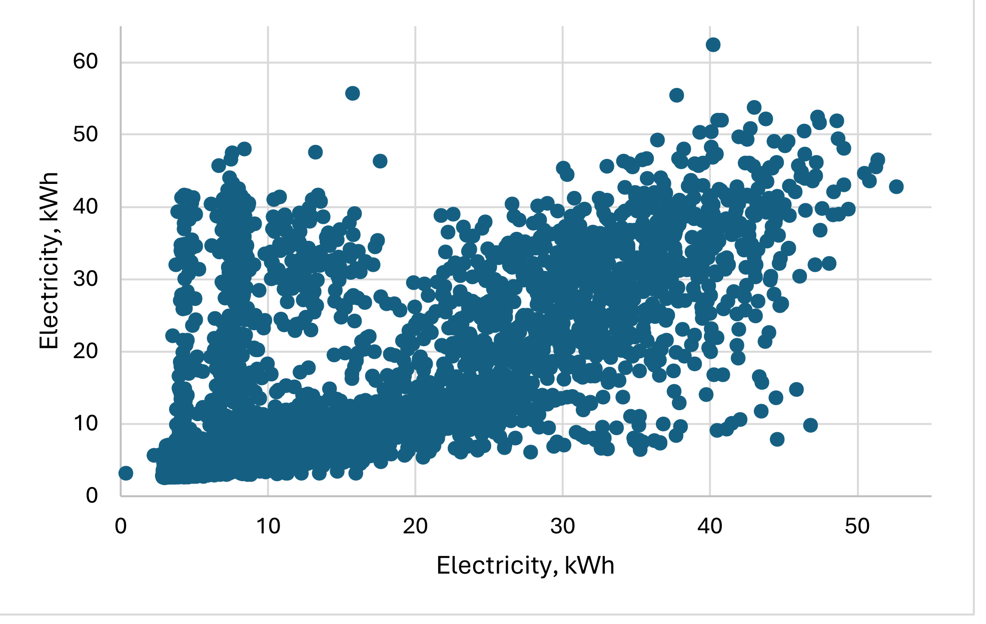

Fig. 3. Relationship among school electricity consumption.

The correlative analysis shows that electricity consumption trends are very similar for all schools – the correlation between them is very high and positive (Fig. 3).

The scatter plot in Fig. 3 indicates a strong positive correlation in school electricity consumption trends. The clustering of data points along a generally upward trajectory suggests that as one variable increases, so does the other, implying that the schools exhibit similar usage behaviours in response to the variable. This high degree of correlation supports the premise that schools benefit from a unified strategy in managing electricity consumption, such as implementing energy-saving measures or adopting RE systems, which are effective across multiple institutions.

It needs to be added also that heating systems play a crucial role in shaping the overall energy consumption profile of educational institutions, particularly in temperate and cold climate regions [54]. These systems are typically the largest single contributor to institutional energy demand, accounting for up to 60–70 % of total energy use in primary and secondary school buildings during the heating season [55]. This dominance is due to the large internal volumes of school structures, such as classrooms, hallways, and gyms, and the need to maintain stable indoor thermal comfort levels during occupancy hours, often between 20–22 °C [56]. In older or poorly insulated buildings, this demand is further exacerbated by thermal inefficiencies in the building envelope and aging equipment.

The type of heating system employed significantly influences both energy consumption and GHG emissions. Conventional systems based on natural gas or fuel oil boilers remain prevalent across Europe, particularly in public educational infrastructure. These systems, while reliable, are associated with high CO_2 emissions and limited flexibility in responding to external temperature fluctuations or user needs. In contrast, modern systems such as district heating, heat pumps, or hybrid gas-electric setups offer greater energy efficiency and lower carbon intensity, particularly when integrated with renewable sources (solar thermal or biomass). However, these alternatives often face higher upfront investment barriers and require institutional commitment to long-term sustainability planning [57].

Thermal zoning, control strategies, and occupancy-based heating, as shown in Table 5, also influence the energy profile. Educational facilities typically experience peak heating loads during early morning hours, necessitating predictive pre-heating schedules or intelligent building management systems to optimise start-up and setback temperatures. Poorly tuned thermostats, lack of demand-driven controls, and limited maintenance often lead to unnecessary energy losses. Moreover, variations in class schedules, occupancy levels, and ventilation strategies have further complicated energy dynamics in these settings [58], [59].

Table 5. Thermal Zoning for Educational Facilities (based on [59]–[62]

Zone	**Included spaces**	**Occupancy Pattern**	**Thermal Load Profile**	**Comfort Requirements**	**HVAC Control Strategy**
Learning	Classrooms, seminar rooms	High (daytime, scheduled)	High internal gains (people, lights)	Stable temperature, moderate ventilation	Time-scheduled control, CO_2 sensors
Administration	Offices, meeting rooms, and reception	Medium (daytime, extended hours)	Moderate (equipment, low density)	Office comfort, moderate humidity	Individual zone thermostats
Laboratories	Science labs, computer rooms, research rooms	High (intermittent or extended)	High (equipment-intensive)	Tighter temperature/ humidity control	Specialised HVAC systems, air exchange control
Recreation, sports	Gyms, sports halls, fitness rooms	Variable (scheduled use)	Variable (physical activity)	Temperature flexibility, high ventilation	Demand-based HVAC, enhanced airflow
Common areas	Corridors, lobbies, stairwells	Low (transitory movement)	Low	Minimal comfort requirements	Minimal HVAC, passive strategies
Cafeteria	Dining areas, food prep zones	High (peak hours)	High (cooking, occupancy)	Ventilation priority, odour extraction	Zoned ventilation, kitchen hoods
Library/ Study	Libraries, quiet study zones	Medium (daytime/evening)	Moderate (lights, equipment)	Quiet operation, stable temperature	Low-noise HVAC, continuous control
Storage/ Service	Storage rooms, utility rooms, janitorial closets, etc.	Very low (infrequent)	Low	Minimal heating/ cooling	Limited HVAC

Heating systems are not merely infrastructural necessities but critical determinants of energy efficiency, operational costs, and climate performance in educational institutions. Optimising these systems through retrofitting, demand-responsive control, and integration with low-carbon technologies is vital for aligning educational buildings with broader energy efficiency requirements and climate neutrality goals.

3.2. Data Analysis in Ports, Industrial, and Commercial Objects

The analysis of the available data delineates distinct seasonality in electricity consumption across ports, industrial, and commercial consumer groups for the examined years, as illustrated in Figs. 4–6. A notable reduction in electricity use is observed during the summer months (May through August, with the downturn commencing as early as April in industrial parks), while the winter months experience a surge in consumption. The unavailability of complete autumn-winter 2023 data precludes a definitive comparison of trends across the two years. Nevertheless, the September and October 2022 data reveal a trend of reduced electricity consumption, which is attributed to climatic influences such as a milder autumn. Comprehensive conclusions await the acquisition of additional data. Despite the limitations posed by the partial dataset, the current findings suggest the necessity for energy-monitoring authorities to undertake detailed analyses of significant variances in electricity consumption trends, especially in port areas. Such an investigation is warranted for the following observations:

- a marked decrease in February, June, and August of 2023 relative to the corresponding months in 2022, hinting at possible operational disruptions or downscaled production;
- conversely, an uptick in consumption in May 2023 compared to May 2022 indicates a need to explore underlying causes, such as increased activity or operational changes.

These trends necessitate a closer inspection to elucidate the drivers behind these energy consumption shifts and inform targeted energy management and policy decisions. The bar chart in Fig. 3 indicates a strong seasonal influence on electricity usage in ports, with lower consumption in warmer months and increased demand in colder months.

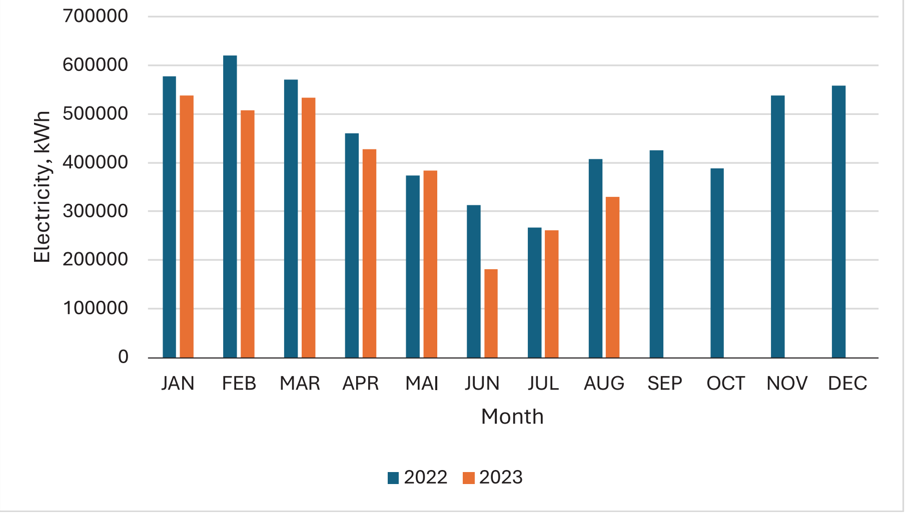

Fig. 4. Electricity consumption in the port, kWh.

The sharp reductions (Fig. 4) in February, June, and August 2023 compared to 2022 suggest operational changes or decreased production levels. The rise in May 2023 requires further investigation to determine the causes, such as potential increases in port activities. Given the incomplete data for late 2023, further research is needed for a full assessment. Nonetheless, these initial findings underscore the importance for energy authorities to closely monitor and analyse these consumption patterns to support informed decision-making and optimise energy usage in port operations.

The data provided for industrial sites indicate a discernible shift in energy consumption patterns between 2022 and 2023. Notably, consumption decreased in January 2023 compared to January 2022. However, this trend reversed in later months, with a significant increase in consumption in March and July of 2023 relative to those same months in the previous year.

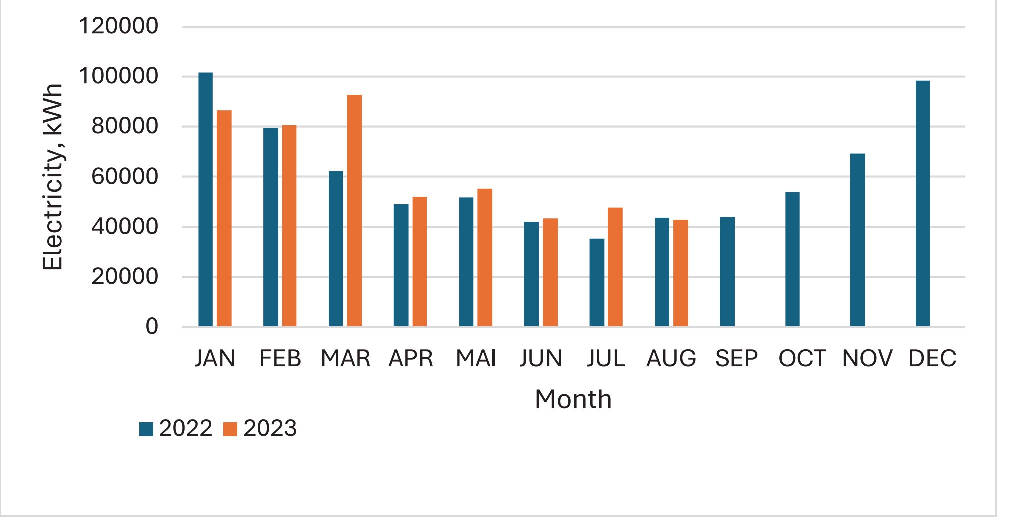

Fig. 5. Electricity consumption, industrial objects, kWh.

The electricity consumption trends at industrial sites in Latvia demonstrate significant variability. Particular attention needs to be paid to the reasons behind the increased energy demands in March and July 2023 (Fig. 5).

These insights (Fig. 5) can be pivotal for industrial energy management, indicating periods when energy conservation efforts are intensified or when capacity planning needs to be adjusted to meet higher demands. The data underscores the importance of continued monitoring to inform energy strategies and adapt to shifting patterns in industrial electricity use.

The electricity consumption data for commercial entities in Latvia, as shown in Fig. 6, presents a fluctuation pattern across the two years under consideration. The data reveals variations that warrant a thorough investigation due to the complexity introduced by the diverse nature of commercial activities and the sheer number of entities involved.

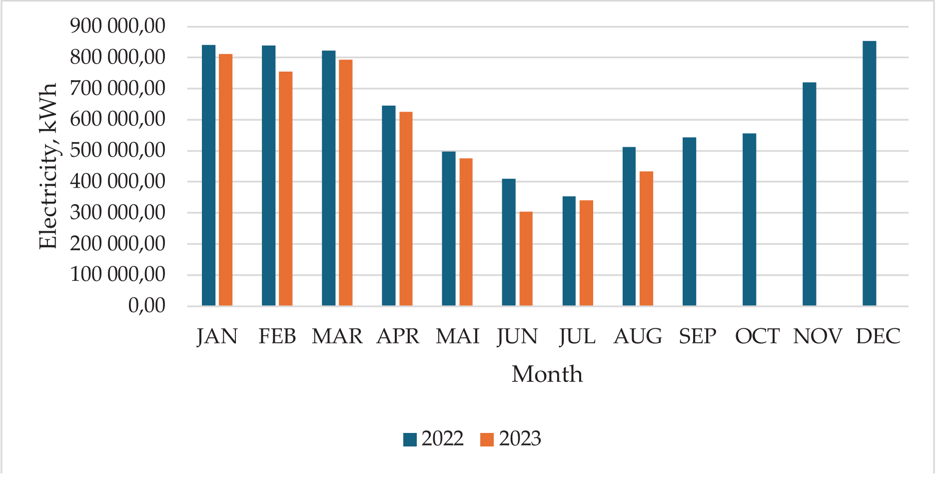

Fig. 6. Electricity consumption in other commercial objects, kWh.

The electricity consumption data of the commercial sector (Fig. 6) indicates variable demand, with certain months in 2023 experiencing different consumption levels compared to the same months in 2022. These fluctuations highlight the need for an in-depth analysis to understand specific energy usage behaviours of commercial entities. Identifying the factors contributing to these consumption changes is crucial for developing targeted energy efficiency strategies. It can help formulate more accurate and effective energy policies for the commercial sector in Latvia.

3.3. Economic Assessment

3.3.1. Available Roof and Adjusted Areas

The usable space on the roof for the installation of PV panels, HVAC systems, etc. must be identified in advance, and in the case of PV panels, the appropriate space must be provided [63]. It depends on the strength of the roof structures and the available space, considering that a crystalline-based solar PV panel occupies an area of approximately 1.6 m^2 and its nominal capacity is in the range of 260 to 285 kW. 1 kW of installed capacity occupies approximately 6 m^2; the slope of the roof can determine the permissible weight limits; the slope of the solar PV panel; desire to employ solar tracking system in case if the part of PV array is to be located on the ground [64].

3.3.2. Electricity Production

Data from various studies shows that the annual PV potential in Latvia is 1000–1200 kWh/m^{2,} depending on the geographical location. In 2023, solar panels generated more than 128 gigawatt hours (GWh) of electricity, with an input of Latvia's total electricity production balance of about 2 %.

Considering the 14 % PV solar panel system losses, when installing solar PV panels with a nominal capacity of 1 kW in the Riga region, the potential generation varies significantly depending on the months (Fig. 7). The data should be adjusted according to Fig. 2 for the Western part of Latvia, where City A is located.

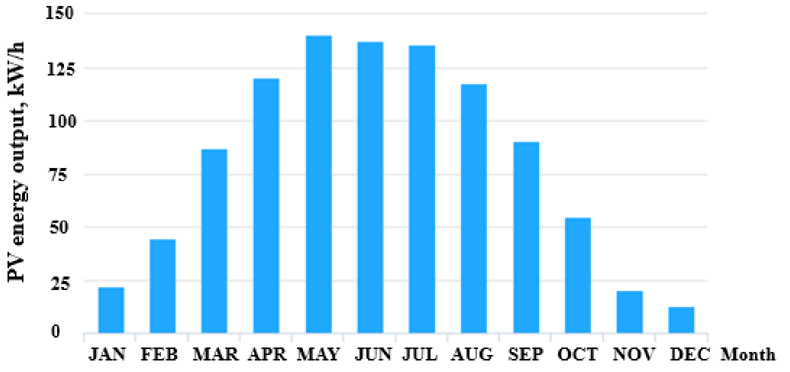

Fig. 7. Monthly energy output from a fixed-angle PV system [65].

The greatest benefit of PV solar panels can be obtained from May to July, approximately 130–140 kWh/month, while the lowest benefits can be obtained from November to December, approximately 10–20 kWh / month. In the case of HVAC and machinery optimisation equipment, like PV solar panels, the ability of this equipment to save electricity is determined. HVAC and machinery automation, each investment must be individually analysed, considering the characteristics and needs of the corresponding premises and the characteristics of the individual machinery work cycle.

3.3.3. CAPEX and OPEX

Solar PV industry incurs high CAPEX as most costs come during construction, when equipment acquisition (PV panels, inverters, etc.) and installation are done. CAPEX can be divided into two main categories: soft and hardware costs. Soft or non-hardware costs include permitting, financing, and installing PV and the expenses solar companies incur to acquire new customers, pay suppliers, etc. [66]. Hard costs, on the other hand, cover expenses related to the physical equipment that goes into a solar PV system, like modules, inverters, balance of system components, optional batteries, and even electric vehicle charging, if applicable.

PV projects are cheap to operate over their lifetime (land lease and operation of the asset), so they have reasonably low OPEX. While PV CAPEX is funded with upfront financing, OPEX is funded through ongoing revenues. As these costs reflect an investment that depreciates gradually rather than an immediate expense, they can cause considerable changes in a company's balance sheets but not its income statements.

In the case of non-residential buildings, PV installations' CAPEX can be assumed to be around EUR 1300/kW (up to 20 kW), while correspondingly, OPEX is EUR 19.5/kW, as sometimes OPEX can be assumed to be 1.5 % of CAPEX. Other sources indicate that PV installation OPEX ranges between 0.8 and 1.2 % of CAPEX per year [67].

On the other hand, calculations are made for small and large rooftop PV installations and PV utility-scale CAPEX, which differ significantly in terms of CAPEX range. Table 3 shows that the average CAPEX for small rooftop installations reached EUR

1300/kW, while for large rooftop installations, the average CAPEX was significantly lower – EUR 900/kW. As in schools, commercial and industrial facilities, small rooftop PV systems do not apply; the large rooftop PV or utility-scale PV average CAPEX estimate should be taken as a reference.

Table 3. CAPEX for Small, Large Rooftop and Utility-Scale PVs

CAPEX (EUR/kW)	Small rooftop PV (5–15 kWp)	Large rooftop PV (100–1000 kWp)	Utility-scale PV (>2MWp)
Low investment	1200	800	600
High Investment	1400	1000	800

In the case of HVAC and machinery optimisation, the project's CAPEX and OPEX can be very different, considering the adaptation of the project to individual requirements and needs, which results in different levels of complexity.

3.3.4. Electricity Price Impact

The electricity market impact on PV installations for self-consumption and/or commercial purposes is directly dependent on two different level factors: the electricity wholesale price in Nord Pool exchange and the NETO billing system, which determines the monetary value of the electricity produced and consumed. At the same time, an electricity producer who generates electricity from RES can distribute the production over several sites. This allows the value of the electricity produced to be used to pay the electricity bill for all the user's connections. The international exchange Nordpool regulates electricity prices in the Baltic States and Latvia. Electricity wholesale prices for the LV market for 2024 are presented in Table 4.

Table 4. NordPool Exchange Prices for the LV Market, Year 2024 [68]

Month	Price, EUR/MWh
January	117.16
February	74.78
March	64.21
April	60.25
May	75.85
June	91.64
July	98.02
August	106.96
September	83.95
October	91.38
November	88.75
December	90.51

Regarding NETO billing system, the prosumer can use one of its variations: if the PV installations have a capacity of up to 50 kW, it is possible apply for the universal NET billing, but if PV installations have a capacity of up 999.9 kW, one can use other net billing system services determined by agreement with the electricity trader. In both cases, the price formation mechanism is different, namely, for installations below 50 kW, the price is determined by the agreement with the electricity trader and based on the contract terms. The contract terms are additionally regulated by the Regulation of the Cabinet of Ministers No. 635 for these systems. The purchase price is determined according to the relevant hourly price of the Latvian trading area of the Nord Pool exchange, applying a reduction that may not exceed 20 EUR/MWh or 0.02 EUR/kWh.

The purchase price may never be lower than 0 EUR/MWh. The minimal contracting period is set to be 6 months. There are no such regulations for PV installations with a capacity above 50 kW. The price of buying and selling electricity is determined only by the agreement with the trader [69]. The installed solar panels could provide economic benefits, especially from May to July, when the generated electricity reaches its peak, and the market price is relatively high. Market prices are important when installing machinery optimisation, HVAC and other devices.

3.4. Basis for Economic Evaluation of PV Projects

In its economic evaluation aspect, the study focuses exclusively on the economic assessment of PV system installations for schools and commercial facilities. The primary justification for this targeted scope lies in the urgent need for decision-makers and facility managers to understand the financial viability of distributed RE investments in public and semi-public infrastructure. Schools and commercial entities often operate within constrained budgets and require clear, quantifiable economic indicators to justify capital-intensive transitions to renewable technologies. Therefore, an economic evaluation provides the most relevant and actionable insights for stakeholders considering PV adoption.

By focusing on key financial metrics, such as Capital Expenditure (CAPEX), Operational Expenditure (OPEX), Payback Period (PP), Levelized Cost of Electricity (LCOE), and Return on Investment (ROI), the study offers a robust foundation for cost-benefit analysis and investment planning. CAPEX and OPEX delineate the upfront and ongoing costs, respectively, while LCOE provides a normalised measure of the electricity cost over the system's lifetime. PP assesses the time needed to recoup the initial investment, and ROI highlights long-term financial performance. Together, these metrics enable transparent comparison with conventional energy procurement models and alternative energy efficiency measures.

However, only a combination of several criteria can highlight the project's strong points and potential challenges, which should be avoided. For example, NPV and ROI are frequently applied to different RES projects, including PV [70]. NPV can also be coupled with PP or LCOE [71], [72].

LCOE is a metric that enables different technologies to be compared on a cost basis. The metric measures lifetime costs divided by energy production. LCOE calculates the present value of the total cost of building and operating a power plant over an assumed lifetime. Economic calculation is important to determine the possible optimisation of an investment. LCOE indicates the ratio between the life-time costs of a project and the electricity generated by the project during its life. Equation (3) calculates LCOE:

$$LCOE = \frac{\sum_{t=1}^{n} \frac{C_{opex.t}}{d_t} + C_{sum}}{\sum_{t=1}^{n} \frac{C_{gen}}{d_t}}, \quad (3)$$

where
$C_{opex.t}$ – total OPEX expenses in period t;
d_t – a discount rate;
C_{sum} – initial cost of investment expenditures;
C_{gen} – the sum of all electricity generated over the lifetime.

LCOE is especially important if a company or educational institution plans to sell the produced electricity to the market. However, it should be noted that LCOE calculations are often regarded as a guideline, not hard proof that the project is viable. Higher or lower LCOE is purely a theoretical prediction. Still, it is one of the main elements that can influence investors' interest, as it is considered proof of the financial viability of solar PV power installation. LCOE calculations can even include tax benefits, such as depreciation of the installation [73].

The costs calculated by LCOE can fall under three major categories: wholesale, retail, and external costs. Additionally, calculations involved in the LCOE need to account for the present and future values that will come into effect. Costs include financing, annual expenses and site irradiance characteristics. Some authors indicate LCOE as the preferred indicator for minimising the lifecycle cost of a project [74]. In contrast, others note that LCOE does not capture the variability and integration between different energy sources [75].

To understand the project viability and calculate as precise an LOEC as possible, the following additional factors need to be considered:

- Location assessment: The ease of access to both natural and manmade resources in the area, like exposure to sunlight and structural assets, needs to be considered. This will ensure, for example, that there is space available for various roof- and ground-mount PV installations.
- Upfront cost calculation: It is important to know how much transition to solar energy will cost upfront and how that upgrade will be funded in the short term.
- Energy needs and output estimates: The project's base energy needs should be projected and compared with the estimated output of a PV installation.
- Performance of uncertainty and risk analyses: These analyses will seek to account for unforeseen issues in the cost estimates.
- Comparison of different RES options: obtain quotes and run tests to compare different options' output, cost, and efficiency.

Therefore, assessing the potential lifetime value of a solar energy upgrade for the specific project more effectively and avoiding mistakes during the process is possible [76].

NPV is used to calculate the current value of a future stream of payments from a company, project, or investment, and shows the effectiveness of the investment made. To calculate NPV, it is necessary to estimate the timing and amount of future cash flows and pick a discount rate equal to the minimum acceptable rate of return. The discount rate may reflect the cost of capital or the returns available on alternative investments of comparable risk. If the NPV of a project or investment is positive, its return rate will be above the discount rate [76].

When the interest rate increases, the discount rate used in the NPV calculation also increases. This higher discount rate reduces the present value of future cash inflows, leading to a lower NPV. As a result, projects or investments become less attractive because their potential profitability appears diminished when evaluated against a higher required rate of return. Choosing a project with a higher NPV is advisable because it indicates greater profitability and value creation. A higher NPV means the projected cash inflows, discounted to their present value, significantly exceed the initial investment and associated costs. This suggests the project will likely generate wealth, enhancing the business's financial health and growth prospects. Also, a higher NPV aligns with maximising shareholder value [77].

The NPV formula does not evaluate a project's return on investment (ROI), a key consideration for anyone with finite capital. Though the NPV formula estimates how much value a project will produce, it does not show if it is an efficient use of investment in actual euros or other cash. NPV and ROI serve different purposes. NPV provides a euro amount that indicates the projected profitability of an investment, considering the time value of money. At the same time, ROI shows an investment's efficiency as a percentage, showing the return relative to the investment cost. NPV is often preferred for capital budgeting because it gives a direct measure of added value, while ROI is useful for comparing the efficiency of multiple investments. In the studies applying ROI metrics, the simplicity of the approach should be highlighted, as most of them rely on non-discounted approaches frequently based on accounting profit metrics and metrics combined with simple PP [78].

PP is an alternative to NPV. It calculates how long it will take to recoup an investment. One drawback of this method is that it fails to account for the time value of money. For this reason, PP calculated for longer-term investments has a greater potential for inaccuracy. Moreover, PP calculation does not concern itself with what happens once the investment costs are nominally recouped. An investment's rate of return can change significantly over time.

To calculate PP of PV installations, several factors need to be considered:

- total cost of PV installation;
- incentives received;
- electricity usage pattern;
- energy production efficiency of the system;
- cost of electricity on the market.

PP is determined by Eq. (4):

$$PP = \frac{C_{in}}{CF_t}, \tag{4}$$

where:
C_{in} – investment;
CF_t – annual cash flow.

Considering the previous steps, it is possible to predict the approximate economic indicators of investments in solar panels, HVAC, machinery optimisation, etc.

- **General Example**

Table 5. Input Data for Calculations

Parameter	Value	Additional Comment
Power, kWp, [P]	100	-
CAPEX, EUR	90 000	Medium investment, large rooftop, Table 3
OPEX, EUR / year	900	1 % of CAPEX / year [79]
Lifespan, years	25	25–30 years [80]
Discount rate, %, [r]	5	Social discount rate: the European Commission benchmark [81]
Productivity, kWh/kWp/year [Prod]	1100	Medium value, PV potential in Latvia is 1000–1200 kWh/m^2
Electricity price, EUR/kWh, [Price, el.]	0.08	Medium, varies from 117.16 EUR/MWh (highest) to 60.25 EUR/MWh (lowest)

- **Annual solar generation**

1) $Q_y = P * Prod = 100 * 1100 = 110000 \frac{kWh}{year},$

where

$Q_y - production \ / \ year.$

- **Annual income**

2) $\boldsymbol{Sy = Qy * Price, el. = 110000 * 0.08 = 8800 \ EUR},$

where

$S_y - annual \ income, EUR.$

- **Annual cash income after annual expenses**

3) $CF_t = S_y - OPEX = 8800 - 900 = 7900 \ EUR/year.$

- **Net present value**

4) $oneNPV = \sum_{t=1}^{t} \frac{CF_t}{(1+r)^t} - CAPEX,$ (7)

where

$r - discount \ rate, \%;$
$t - period \ of \ time, years$

It results in:

$\sum_{t=1}^{25} \frac{7900}{(1+0.05)^1} = 7523.81 \ EUR.$

.

Table 6. NPV Calculation (by year)

Year, n	CF_t **, EUR**	$\sum_{t=1}^{n} \frac{CF_t}{(1+r)^t}$ **, EUR**
1	7900	7523.81
2	7900	7165.53
3	7900	6824.32
4	7900	6499.35
5	7900	6189.86
6	7900	5895.1
7	7900	5614.38
8	7900	5347.03
9	7900	5092.41
10	7900	4849.91
11	7900	4618.97
12	7900	4399.02
13	7900	4189.54
14	7900	3990.04
15	7900	3800.04
16	7900	3619.08
17	7900	3446.74
18	7900	3282.61
19	7900	3126.3
20	7900	2977.43
21	7900	2835.64
22	7900	2700.61
23	7900	2572.01
24	7900	2449.54
25	7900	2332.89
	TOTAL	111342.16

It results in:

$$NPV = \sum_{t=1}^{t} \frac{CF_t}{(1+r)^t} - CAPEX = 111342.16 - 90000 = 21342.16\ EUR.$$

- **LCOE acc. (3) for the 25 years**

$$LCOE = \frac{\sum_{t=1}^{25} \frac{900}{0.05} + 90000}{\sum_{t=1}^{25} \frac{1100}{0.05}} = \frac{25 * \frac{900}{0.05} + 90000}{25 * \frac{1100}{0.05}} = 0.0098 \frac{EUR}{kWh}.$$

- **PP according to (4)**

$$PP = \frac{C_{in}}{CF_t} = \frac{90000}{7900} = 11.39 \approx 12\ years.$$

Based on the input data (see Table 5), the calculations show that the Net Present Value (NPV) is positive, indicating the project's financial viability. The calculated LCOE is 0.0098 EUR/kWh, which represents the minimum price at which electricity must be sold to ensure profitability. The estimated payback period is approximately 12 years.

3.5. Energy Management Strategies and RE Integration Solutions

3.5.1. Energy Management Strategies

Effective energy management is a fundamental component of sustainable development across diverse facility types, particularly in educational institutions, commercial buildings, and industrial complexes. As electricity costs rise and environmental concerns deepen, organisations are increasingly turning to integrated energy strategies to optimise consumption, reduce carbon footprints, and enhance operational efficiency.

For educational facilities, energy management must balance budgetary constraints with functional requirements such as lighting, HVAC, IT infrastructure, and laboratory operations. A central strategy involves real-time energy monitoring through building management systems and smart metering. These tools enable the visualisation of consumption patterns and the identification of energy-intensive operations, particularly during peak hours. Educational institutions benefit from daylight harvesting, automated lighting controls, and occupancy sensors, which collectively reduce energy waste in classrooms and offices. Demand response participation, wherein schools reduce or shift usage in response to grid signals, can also yield financial incentives.

Commercial facilities typically feature extensive HVAC systems and variable occupancy profiles. Here, zonal heating and cooling strategies, advanced thermal insulation, and smart thermostats form the backbone of consumption reduction. Commercial buildings are also increasingly adopting energy-as-a-service (EaaS) models, where external providers manage and optimise building energy use. In addition, green building certifications (BREEAM, LEED, etc.) are influential in shaping design and retrofit decisions that enhance efficiency. Integration of RE sources, such as rooftop solar PV and solar thermal systems, provides long-term stability against volatile grid prices and supports decarbonisation goals.

In industrial facilities, electricity consumption optimisation is more complex due to the high-power demands of manufacturing equipment, processing heating, and continuous operations. Strategies here centre on predictive maintenance, process automation, and equipment upgrades. High-efficiency motors, variable frequency drives, and compressed air system optimisation can dramatically reduce electricity loads. Industrial energy management systems incorporate real-time data analytics, which allow for adaptive scheduling and load shedding during peak tariff periods. Additionally, cogeneration (CHP) systems can be employed to produce electricity and useful heat from a single fuel source, significantly improving overall efficiency.

Strategies applicable to all facility types include staff training, energy audits, and data-driven policy design. Energy dashboards, accessible to managers and occupants alike, help cultivate a culture of accountability. Strategic energy procurement, such as long-term contracts or purchasing from renewable providers, can also mitigate cost volatility. Furthermore, digital twins and machine learning algorithms emerge as high-potential tools for simulating energy flows and predicting optimal intervention points.

3.5.2. RE Integration Solutions

Achieving energy sustainability and decarbonisation in schools, businesses, and industries necessitates exploring renewable technologies that balance capacity, reliability, cost-effectiveness, and environmental impact. These buildings differ in scale, load profiles, and coupling opportunities: schools typically have moderate daytime usage, commercial facilities experience daytime peaks and evening declines, and industrial sites often require high, constant power levels. Thus, the design of renewable systems and their integration strategies must reflect these patterns.

Solar PV remains the cornerstone of distributed clean energy. For schools and commercial rooftops, 50 kW to 500 kW PV arrays seamlessly cover daytime loads, especially during school hours and business operations. Like schools, which benefit from shaded midday peaks due to solar production aligning with class hours, commercial buildings often export excess power during the day and draw at night. In combined systems, PV penetration reduces peak demand charges, cuts procurement costs, and supports net-metering frameworks. For industrial facilities seeking on-site generation, larger PV parks sized between 500 kW and several megawatts are suitable, provided sufficient roof or ground space is available. While solar intermittency can limit self-consumption during nighttime, coupling PV with battery energy storage systems (BESS) enhances dispatchability and load-following capability.

On-site wind deployment, on the other hand, is location dependent. Schools and commercial sites in urban environments rarely have sufficient wind resources or space. In contrast, industrial facilities in suburban or rural areas with ≥6 m/s average wind speeds can benefit from small- to medium-scale turbines (100 kW to 1 MW). Wind can complement PV by generating electricity during overcast but windy conditions. For example, a 500-kW wind turbine in moderate-wind regions can add ~1.5 GWh/year capacity, reducing grid reliance and smoothing retail electricity loads. However, the variable nature of wind requires careful integration with battery or demand response systems.

Battery Energy Storage Systems (BESS) provide short-to-medium-term flexibility, voltage regulation, and resilience. For schools and commercial sites, 100 kWh–500 kWh battery units can handle daily solar export and evening consumption, boosting self-consumption to 80–90 %. Industrial applications often require larger BESS (1–5 MWh) to support peak shaving, or contingency against demand charges and production disruptions. It is important to align battery types (lithium-ion, flow batteries, etc.) with cycle-life needs and site-specific charge/discharge patterns.

Ground-source or air-source heat pumps (1–10 MW capacity) can effectively replace fossil-fuel boilers in schools and commercial buildings, particularly when paired with thermal storage. Integration with PV can further electrify heating, cooling, and hot water. For industrial plants with process-heat needs, industrial heat pumps combined with waste heat recovery and thermal storage systems reduce reliance on gas-fired boilers.

While combined heat and power (CHP) systems often rely on natural gas, they can be decarbonised by substituting biogas or renewable gases. For universities or schools with on-site biomass waste (food services), small CHP units (100 kW–1 MW) integrated with solar PV and BESS can offer continuous electricity and hot water. Commercial and industrial facilities using agricultural or municipal biogas can adopt micro-CHP systems (500 kW–2 MW), enabling round-the-clock base-load generation complementing intermittent renewable sources.

Combined PV, wind and BESS systems can enhance reliability and grid independence of all types of facilities, such as schools and commercial facilities (PV and BESS represent the most feasible option because of limited space and modest load, and on-site energy usage can exceed 50 %, improving sustainability and reducing grid charges), agricultural, industrial and suburban areas (adding small wind turbines leverages stronger wind resources). PV, wind and micro-BESS deliver consistent power, reduce intermittency, and maintain production continuity. Industrial facilities (large-scale PV, wind, BESS, heat pumps, and micro-CHP) are integrated under energy management systems: this may achieve 70–100 % self-sufficiency, decarbonising both electrical and thermal demands. Average RES system scale and suitability for use in educational, commercial and industrial facilities are shown in Table 7, but the key advantages and constraints of different RES applications are summarised in Table 8.

Table 7. RES System Scale and Suitability for Use in Educational, Commercial and Industrial Facilities (based on [82–86])

Facility type	**PV (kW/MW)**	**Wind (kW/MW)**	**BESS (kWh/MWh)**	**Heat Pumps (kW/MW)**	**CHP (kW/MW)**
Educational facility	50 kW–500 kW	0–100 kW	100–500 kWh	100–500 kW	100 kW biomass
Commercial facility	100 kW–1 MW	0–500 kW	500 kWh–2 MWh	500 kW–2 MW	500 kW biogas
Industrial facility	1 MW–10 MW	100 kW–2 MW	1–5 MWh	1–10 MW	500 kW– 5 MW

Table 8. Key Advantages and Constraints of Different RES Applications (based on [87]–[92])

Technology	**Advantages**	**Limitations**
PV	Scalable, low maintenance	Daytime-only, requires space
Wind	Complements solar variability	Site-dependent, zoning and noise constraints
BESS	Enhances flexibility, supports self-consumption	High upfront cost, cycle degradation over time
Heat pumps	Efficient heating/cooling, electricity-driven	Requires thermal storage to optimise
Renewable fuel-based CHP	Continuous power and heat, resilient	Needs fuel sourcing, emissions controls

An effective integration strategy for on-site RE systems should begin with a comprehensive energy audit to evaluate the facility's load profiles, spatial constraints, and the availability of local renewable resources. This foundational analysis informs the initial system design, typically centred around a PV system coupled with BESS to offset daytime electricity consumption. Where site conditions support it, the PV array can be supplemented with small-scale wind turbines to enhance generation diversity [93]. To address thermal energy needs, it is recommended that traditional heating systems be replaced or supported by electric heat pumps, which can be further optimised with thermal energy storage units to reduce peak load demand. In facilities where waste heat or biomass is available, such as industrial buildings or rural campuses, hybrid CHP units can be introduced to provide continuous base-load coverage and improve overall system efficiency [94].

The integration of these systems offers several key benefits. First, it enhances on-site self-consumption of renewable electricity, reducing dependency on external grid supply. Second, it improves energy resilience by enabling continued operation during outages or grid instability. Third, it leads to a reduction in carbon emissions across both electrical and thermal energy usage profiles. In many cases, integrated systems can also generate revenue through time-of-use arbitrage and participation in grid services, such as frequency response or demand management schemes. Furthermore, these systems provide significant educational and stakeholder engagement opportunities, particularly in school settings where energy systems can be embedded into the curriculum and community outreach efforts.

To maximise these benefits, deployment should follow a phased implementation model. Initial investments should focus on optimally sizing the PV installation based on baseline consumption data [95]. Subsequent phases can incrementally incorporate battery storage, thermal systems, and CHP units as operational data and user needs evolve. The use of digital energy management systems is critical in this context. These platforms enable real-time monitoring of energy generation, storage, and consumption, allowing for dynamic dispatch and performance optimisation. Regulatory considerations are also essential. Project developers should align the system configuration with available incentives, including subsidies, net-metering arrangements, and demand-response tariffs. Finally, lifecycle planning must be embedded into system selection. Technologies chosen for such integrated deployments should offer low maintenance requirements and predictable component replacement timelines, which is particularly important for schools, small businesses, and public facilities operating under constrained budgets and long planning horizons.

4. CONCLUSIONS

This study provides valuable insight into electricity consumption patterns across different consumer groups, based on data from 2022 and part of 2023. Despite several limitations, including the absence of consumer behaviour information, seasonal trends and possible inefficiencies in energy use have been successfully identified. The analysis has revealed a clear seasonal trend in electricity consumption across educational, commercial, and industrial sectors in City A. For example, in educational institutions, electricity use dropped significantly during the summer months, with monthly average consumption in schools such as School F falling to a minimum of 1.47 kWh, while maximum values like 106.51 kWh were observed in winter (School G). These trends correlate with operational inactivity during school breaks and increased heating demand in winter.

Electricity consumption trends among the nine analysed schools exhibit a strong positive correlation, indicating a systemic similarity in energy-use behaviours. The recurring seasonal pattern – with higher demand during winter due to heating needs and lower usage in summer months – further supports this observation. These parallels suggest that collective photovoltaic system procurement or shared energy efficiency measures could be both practical and impactful.

One kWp PV system generates its highest monthly output – over 130–140 kWh – between May and July, while output drops to 10–20 kWh from November to December. This generation pattern mirrors school electricity consumption trends, which typically fall during summer holidays. Such alignment suggests that installing PV at full capacity could enable surplus energy export to the grid in summer and offset heating demands in winter, particularly when storage or net metering is available.

Industrial electricity demand rose considerably in March and July 2023 when compared to those months in 2022, reversing the downward trend recorded in January 2023. This increase might be driven by resumed production cycles or previously delayed operations. The rebound underscores the importance of adaptable forecasting models and dynamic energy-saving systems that respond to variations in output levels.

Figure 6 indicates inconsistent electricity usage across commercial enterprises, with some months in 2023 surpassing and others trailing the figures from 2022. This irregularity likely reflects the diverse nature of commercial sectors, including retail, office spaces, and hospitality services. The observed variation highlights the necessity for detailed energy audits by sub-sector, along with the implementation of advanced metering technologies to enable more precise analysis of consumption patterns.

Latvia is part of the Nordic "Nord Pool" electricity exchange, where electricity prices are determined by supply and demand dynamics. In 2024, electricity prices in Latvia fell by 7 %, largely because of increased RE production, particularly solar energy. Approximately 75 % of Latvia's electricity is generated from hydropower and bioenergy, while per capita electricity consumption remains about 40 % lower than the EU average.

Electricity prices in Latvia during 2024 varied greatly – from 117.16 EUR/MWh in January to just 60.25 EUR/MWh in April. This volatility, paired with increased solar production during lower-price periods, creates a strong rationale for adopting PV-based self-consumption strategies. Moreover, with 184 hours of negative electricity pricing recorded in 2024, the importance of adaptable consumption and energy storage systems becomes evident to make the most of excess RES generation.

CAPEX for large rooftop PV systems (100–1000 kWp) ranges from 800 to 1000 EUR/kW, noticeably lower than for smaller installations. When this is coupled with an annual operational cost of 0.8–1.2 % of CAPEX, the overall investment becomes particularly attractive for energy-intensive buildings like schools and industrial sites. Under Latvia's net metering framework and a fluctuating electricity market, such installations promise a solid return on investment.

The alignment of local energy practices with broader strategic goals, such as the EU Green Deal and Latvia's National Energy and Climate Plan, is reinforced by the study. These policies aim for a 65 % reduction in GHG emissions by 2030 and achieving climate neutrality by 2050. The integration of solar energy and the implementation of smart grid technologies directly contribute to fulfilling these ambitions.

The findings underscore the need for energy planning to reflect both structural differences and time-based usage patterns across sectors. In educational institutions, electricity consumption is tied to academic schedules and occupancy, while in industry, it is production processes and machinery that determine demand. Designing effective energy solutions, therefore, requires integrating both the physical characteristics of buildings and the operational rhythms of each sector.

This study highlights that Latvia's port infrastructure and educational institutions are major electricity consumers and notable contributors to CO_2 emissions. Their outdated infrastructure and high energy intensity make them strategic targets for energy efficiency improvements and RE integration.

The study has effectively reached its goal by undertaking a detailed analysis of electricity consumption across various sectors within a city. Actionable strategies have been developed by collecting and analysing data, identifying peak demand periods, assessing the impact of activities on energy use, pinpointing inefficiencies, and comparing with best practices. These strategies aim to improve energy efficiency, integrate RES, and reduce the carbon footprint.

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REFERENCES

1. EC. (n.d.). *The European Green Deal*. Available at: https://commission.europa.eu/strategy-and-policy/priorities-2019-2024/european-green-deal_en
2. EC. (n.d.). *Fit for 55*. Available at: www.consilium.europa.eu/en/policies/green-deal/fit-for-55-the-eu-plan-for-a-green-transition/
3. EC. (n.d.). *The EU's Main Investment Policy*. https://ec.europa.eu/regional_policy/policy/what/investment-policy_en
4. Portillo Juan, N., Negro Valdecantos, V., Olalde Rodríguez, J., & Iglesias, G. (2024). Environmental Policy vs. the Reality Of Greenhouse Gas Emissions From Top Emitting Countries. *Energies*, *17* (22), 5705. https://doi.org/10.3390/en17225705
5. Clemens, T., Hunyadi-Gall, M., Lunzer, A., Arekhov, V., Datler, M., & Gauer, A. (2024). Wind–Photovoltaic–Electrolyzer–Underground Hydrogen Storage System for Cost-Effective Seasonal Energy Storage. *Energies*, *17* (22), 5696. https://doi.org/10.3390/en17225696
6. Backurs, A., Zemite, L., & Jansons, L. (2024). A Technical and Economic Study of Sustainable Power Generation Backup. *Latvian Journal of Physics and Technical Sciences*, *61* (4), 75–88. https://doi.org/10.2478/lpts-2024-0029

7. Backurs, A., Jansons, L., Zemite, L., & Laizans, A. (2024). The Practical Implementation of Hydrogen-Based Sustainable Power Generation Backup. *Latvian Journal of Physics and Technical Sciences*, *61* (6), 69–79. https://doi.org/10.2478/lpts-2024-0044
8. Ahmed, A., Pompodakis, E. E., Katsigiannis, Y., & Karapidakis, E. S. (2024). Optimizing the Installation of a Centralized Green Hydrogen Production Facility in the Island of Crete, Greece. *Energies*, *17* (8), 1924. https://doi.org/10.3390/en17081924
9. EC. Joint Research Centre. (n.d.). *Energy Consumption Trends in the EU*. Available at: https://publications.jrc.ec.europa.eu/repository/handle/JRC138989
10. Eurostat. (n.d.). *Electricity Production, Consumption and Market Overview*. Available at: https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Electricity_production,_consumption_and_market_overview
11. Schmitt, A. (2020). *EU Energy Outlook 2050: How Will the European Electricity Market Develop over the next 30 Years?* Energy BrainBlog. Available at: blog.energybrainpool.com/en/eu-energy-outlook-2050-how-will-the-european-electricity-market-develop-over-the-next-30-years/
12. Czyzak, P. (2022). *Shocked into Action – EU Countries' Energy Policies.* Ember. Available at: ember-climate.org/insights/research/eu-slashes-fossil-fuels/
13. Wiśniewski, T. P. (2023). Investigating Divergent Energy Policy Fundamentals: Warfare Assessment of Past Dependence on Russian Energy Raw Materials in Europe. *Energies, 16* (4), 2019. https://doi.org/10.3390/en16042019
14. AST. (n.d.). *Elektroenerģijas tirgus apskats* [Electricity Market Overview]. Available at: https://www.ast.lv/lv/electricity-market-review?year=2024&month=13
15. Klimata un enerģētikas ministrija. (2023). *Starts Nacionālā klimata un enerģētikas plāna projekta diskusijām ar sociāliem partneriem, nozaru pārstāvjiem un NVO* [Launch of Discussions on the Draft National Climate and Energy Plan with Social Partners, Industry and NGOs]. Available at: www.kem.gov.lv/lv/jaunums/starts-nacionala-klimata-un-energetikas-plana-projekta-diskusijam-ar-socialiem-partneriem-nozaru-parstavjiem-un-nvo?utm_source=https%3A%2F%2Fwww.google.com%2F
16. Lebedeva, K., Krumins, A., Tamane, A., & Dzelzitis, E. (2021). Analysis of Latvian Households' Potential Participation in the Energy Market as Prosumers. *Clean Technologies*, *3* (2), 437–449. https://doi.org/10.3390/cleantechnol3020025
17. Enerdata. (July, 2024). *Latvia Energy Report*. Available at: www.enerdata.net/estore/country-profiles/latvia.html
18. Augstsprieguma tīkls AS. (2024). *Elektroenergijas tirgus apskats* [Electricity Market Overview]. Available at: ast.lv/en/electricity-market-review
19. Upitis, M., Amolina, I., Geipele, I., & Zeltins, N. (2020). Measures to Achieve the Energy Efficiency Improvement Targets in the Multi-Apartment Residential Sector. *Latvian Journal of Physics and Technical Sciences, 57* (6), 40–52. http://doi.org/10.2478/lpts-2020-0032
20. Kundzina, A., Geipele, I., Lapuke, S., & Auders, M. (2022). Energy Performance Aspects of Non-Residential Buildings in Latvia. *Latvian Journal of Physics and Technical Sciences, 59* (6), 30–42. http://doi.org/10.2478/lpts-2022-0045
21. International Energy Agency. (n.d.). *Latvia – Countries & Regions*. Available at: www.iea.org/countries/latvia
22. Zemite, L., Kazadajevs, J., Jansons, L., Bode, I., Dzelzitis, E., & Palkova, K. (2024). Integrating Renewable Energy Solutions in Small-Scale Industrial Facilities. *Energies, 17* (11), 2792–2792. https://doi.org/10.3390/en17112792
23. Tisenkopfs, M., Jansons, L., Geipele, I., Lapuke, S., & Backurs, A. (2025). Optimization of Electricity Consumption-Associated Costs in a Medium-Sized Logistics Company. *Energies*, *18* (12), 3206. https://doi.org/10.3390/en18123206

24. Jasevics, A., Zemite, L., & Kunickis, M. (2017). Demand load control with smart meters. In: *58th Annual International Scientific Conference on Power and Electrical Engineering of Riga Technical University*, RTUCON 2017 – Proceedings, 2017, (pp. 1–6). 12–13 October 2017, Riga, Latvia. http://doi.org/10.1109/RTUCON.2017.8124757
25. Eurostat. (n.d.). *Electricity and Gas: 64.5% of Industrial Final Energy Use*. https://ec.europa.eu/eurostat/web/products-eurostat-news/w/ddn-20240513-1?utm
26. Eurostat. (n.d.). Final Energy Consumption in Industry – Detailed Statistics. https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Final_energy_consumption_in_industry_-_detailed_statistics&oldid=637442
27. Gajdzik, B., Nagaj, R., Wolniak, R., Bałaga, D., Žuromskaitė, B., & Grebski, W. W. (2024). Renewable Energy Share in European Industry: Analysis and Extrapolation of Trends in EU Countries. *Energies*, *17* (11), 2476. https://doi.org/10.3390/en17112476
28. PV-magazine. (21 March, 2025). *GB Energy Invests in Rooftop Solar Rollout for UK Schools and Hospitals.* Available at: https://www.pv-magazine.com/2025/03/21/gb-energy-invests-in-rooftop-solar-rollout-for-uk-schools-hospitals/#:~:text=The%20GBP%20200%20million%20($258%20million)%20commitment,be%20installed%20by%20the%20end%20of%20summer
29. The Guardian. (18 October 2024). *'Community action': Oxfordshire's Low Carbon Hub on Its Local Renewable Energy Projects.* Available at: https://www.theguardian.com/environment/2024/oct/18/community-action-oxfordshires-low-carbon-hub-on-its-local-renewable-energy-projects
30. Solar Plus. (2 February 2025). *Harnessing the Power of the Sun: The Benefits of Solar Panels for Schools and Educational Institutions.* Available at: https://www.solarnplus.com/harnessing-the-power-of-the-sun-the-benefits-of-solar-panels-for-schools-and-educational-institutions/
31. ClimACT. (n.d.). *INTERREG SUDOE – ClimACT*. Available at: https://www.ecoschools.global/climact
32. Eu4municipalities. (n.d.). *Golem: Harnessing Solar Energy at a High School Using Photovoltaic Panels.* Available at: https://eu4municipalities.al/en/golem-harnessing-solar-energy-at-a-high-school-using-photovoltaic-panels/
33. EC. (10 June 2021). *Cross-Border Schools Initiative Reduces Pollution and Promotes Renewable Energy.* Available at: https://ec.europa.eu/regional_policy/en/projects/Europe/cross-border-schools-initiative-reduces-pollution-and-promotes-renewable-energy
34. The Guardian. (n.d.). *Drones, Driving and Decarbonising Schools: How Coventry is Leading the Way in Energy Innovation.* Available at: https://www.theguardian.com/urban-energy-innovation/2025/mar/18/drones-driving-and-decarbonising-schools-how-coventry-is-leading-the-way-in-energy-innovation
35. EC. (20 February 2018). *Positive Energy Zero Carbon Dioxide Primary School*. Available at: https://www.interregeurope.eu/good-practices/positive-energy-zero-carbon-dioxide-primary-school
36. Tamesol. (25 June 2024). *Explore 2024's Most Impressive Solar Energy Schools in Europe*. Available at: https://tamesol.com/en/solar-energy-schools/
37. Cabinet of Ministers. (15 April 2021). Ēku *energoefektivitātes aprēķina metodes un* ēku *energosertifikācijas noteikumi.* [Methods for Calculating the Energy Performance of Buildings and Rules for the Energy Certification of Buildings]. Latvijas Vestnesis, 72. Available at: https://likumi.lv/ta/id/322436-eku-energoefektivitates-aprekina-metodes-un-eku-energosertifikacijas-noteikumi
38. Garcia, R. (29 April 2022). *The 100 Climate-Neutral and Smart Cities by 2030*. Eurocities. Available at: eurocities.eu/latest/the-100-climate-neutral-and-smart-cities-by-2030/?gad_source=1&gclid=CjwKCAiA_tuuBhAUEiwAvxkgTixE31QPD8VZvOU7n4KuYWi_EMbRbG1WapKy21Q6c9Ak08kiLUF_pBoCtRcQAvD_BwE

39. Ecodoma. (2024). *Liepājas valstspilsētas ilgtspējīgas enerģētikas un klimata rīcības plāns 2023.–2030.gadam* [Liepaja Sustainable Energy and Climate Action Plan 2023–2030]. Available at: https://faili.liepaja.lv/Publikacijas/42__22_02_24__PIELIKUMS__ENERGETIKAS_KLIMATA_RICIB.pdf
40. Liepajniekiem.lv. (n.d.). *Liepājas vakara maiņu vidusskolu plāno pārcelt uz plašākām telpām*. [Liepaja Evening Shift Secondary School to Move to Bigger Premises] Available at: https://www.liepajniekiem.lv/zinas/sabiedriba/liepajas-vakara-mainu-vidusskolu-plano-parcelt-uz-plasakam-telpam/
41. EC. (29 January 2024). *Reinvesting Energy Savings for a Climate-Neutral Future in Riga*. Available at: https://eu-mayors.ec.europa.eu/en/Reinvesting-energy-savings-for-a-climate-neutral-future-Riga-Case-Study
42. Rigas Planošanas reģions. (3 April 2025). *Sanāksmē pārrunā par* ēku *viedās gatavības risinājumiem* [Meeting Discusses Smart Building Readiness Solutions]. Available at: https://rpr.gov.lv/sanaksme-parruna-par-eku-viedas-gatavibas-risinajumiem/?fbclid=IwY2xjawKsUm1leHRuA2FlbQIxMAABHrWQqjA-6FZz1dTbJ9NhJ735JBRPzuXbSuNHdCOX3py_ctJKD_qvDzlwlrIT_aem_XmyrH5cpbwiNRHkDIaRd8A
43. Rigas Dome. (21 January 2025). *Rīgas skolas saņem energosertifikātus – plašs solis galvaspilsētas energoefektivitātes uzlabošanā* [Riga Schools Receive Energy Certificates – A Major Step towards Improving the Capital's Energy Efficiency]. Available at: https://www.riga.lv/lv/jaunums/rigas-skolas-sanem-energosertifikatus-plass-solis-galvaspilsetas-energoefektivitates-uzlabosana?utm
44. Ali-Tagba, A.-R., Baneto, M., & Lucache, D. D. (2024). Factors Influencing the Energy Consumption in a Building: Comparative Study between Two Different Climates. *Energies*, *17* (16), 4041. https://doi.org/10.3390/en17164041
45. Mendoza, D. L., Bianchi, C., Thomas, J., & Ghaemi, Z. (2020). Modeling County-Level Energy Demands for Commercial Buildings Due to Climate Variability with Prototype Building Simulations. *World*, *1* (2), 67–89. https://doi.org/10.3390/world1020007
46. Ekonomou, G., & Menegaki, A. N. (2023). The Role of Energy Use in Buildings in Front of Climate Change: Reviewing a System's Challenging Future. *Energies*, *16* (17), 6308. https://doi.org/10.3390/en16176308
47. Gao, L., Wang, S., Mao, M., Liu, C., & Li, T. (2024). Study on Energy Consumption Characteristics and the Self-Sufficiency Rate of Rooftop Photovoltaic of University Campus Buildings. *Energies*, *17* (14), 3535. https://doi.org/10.3390/en17143535
48. Quispe, E. C., Viveros Mira, M., Chamorro Díaz, M., Castrillón Mendoza, R., & Vidal Medina, J. R. (2025). Energy Management Systems in Higher Education Institutions' Buildings. *Energies, 18* (7), 1810. https://doi.org/10.3390/en18071810
49. Rus, T., Moldovan, R.-P., Pop, M. I., & Moldovan, A.-M. (2025). Assessing the Interplay of Indoor Environmental Quality, Energy Use, and Environmental Impacts in Educational *Buildings. Applied Sciences, 15* (7), 3591. https://doi.org/10.3390/app15073591
50. Bodó, B., Béni, E., L. & Szabó, G. (2023). A Facility's Energy Demand Analysis for Different Building Functions. *Buildings*, *13* (8), 1905. https://doi.org/10.3390/buildings13081905
51. Verstina, N., Solopova, N., Taskaeva, N., Meshcheryakova, T., & Shchepkina, N. (2023). Evaluation of the Energy Efficiency Class of an Industrial Facility: A Rating System and a Scale of Sustainable Development. *Sustainability*, *15* (22), 15799. https://doi.org/10.3390/su152215799
52. Verstina, N., Solopova, N., Taskaeva, N., Meshcheryakova, T., & Shchepkina, N. (2022). A New Approach to Assessing the Energy Efficiency of Industrial Facilities. *Buildings, 12* (2), 191. https://doi.org/10.3390/buildings12020191
53. Solargis. (n.d.). *Solar Resource Maps of Latvia.* Available at: https://solargis.com/resources/free-maps-and-gis-data?locality=latvia

54. Li, J., Liang, C., & Zhou, W. (2024). A Review of Building Physical Shapes on Heating and Cooling Energy Consumption. *Energies, 17* (22), 5766. https://doi.org/10.3390/en17225766
55. Begić Juričić, H., Krstić, H., & Domazetović, M. (2025). Analyzing the Carbon Performance Gap and Thermal Energy Performance Gap of School Buildings in Osijek-Baranja County, Croatia. *Energies*, *18* (7), 1818. https://doi.org/10.3390/en18071818
56. Romero, P., Valero-Amaro, V., Arranz, J. I., Sepúlveda, F. J., & Miranda, M. T. (2025). Indoor Air Quality and Thermal Comfort in University Classrooms in Southwestern Spain: A Longitudinal Analysis from Pandemic to Post-Pandemic. *Buildings*, *15* (5), 829. https://doi.org/10.3390/buildings15050829
57. Mannheim, V., Nehéz, K., Brbhan, S., & Bencs, P. (2023). Primary Energy Resources and Environmental Impacts of Various Heating Systems Based on Life Cycle Assessment. *Energies*, *16* (19), 6995. https://doi.org/10.3390/en16196995
58. Teli, D. (2025). Children's Thermal Comfort in School Classrooms: Influence of Contextual Factors, Thermal Experience, and Diurnal Variations. *Building and Environment*, *277*, 112916 https://doi.org/10.1016/j.buildenv.2025.112916
59. Hossain, J., Kadir, A. F. A., Hanafi, A. N., Shareef, H., Khatib, T., Baharin, K. A., & Sulaima, M. F. (2023). A Review on Optimal Energy Management in Commercial Buildings. *Energies*, *16* (4), 1609. https://doi.org/10.3390/en16041609
60. Lamberti, G., Salvadori, G., Leccese, F., Fantozzi, F., & Bluyssen, P. M. (2021). Advancement on Thermal Comfort in Educational Buildings: Current Issues and Way Forward. *Sustainability, 13* (18), 10315. https://doi.org/10.3390/su131810315
61. Su, B., Jadresin Milic, R., McPherson, P., & Wu, L. (2022). Thermal Performance of School Buildings: Impacts beyond Thermal Comfort. *International Journal of Environmental Research and Public Health, 19* (10), 5811. https://doi.org/10.3390/ijerph19105811
62. Aguilar-Carrasco, M. T., López-Lovillo, R. M., Suárez, R., & León-Rodríguez, Á. L. (2025). Ventilation Strategies to Ensure Thermal Comfort for Users in School Buildings: A Critical Review. *Applied Sciences, 15* (10), 5449. https://doi.org/10.3390/app15105449
63. Nowak S., Gutschner M., Ruoss D., Togweiler P., & Schoen T. (2002). *Potential for Building Integrated Photovoltaics.* Report IEA-PVPS T7-4. Available at: https://iea-pvps.org/wp-content/uploads/2020/01/rep7_04.pdf
64. Vimpari, J., & Junnila, S. (2019). Estimating the diffusion of rooftop PVs: A real estate economics perspective. *Energy*, *172*, 1087–1097. https://doi.org/10.1016/j.energy.2019.02.049
65. EC. (n.d.). Photovoltaic Geographical Information System. Available at: https://re.jrc.ec.europa.eu/pvg_tools/en/#PVP
66. US Department of Energy. (n.d.). Solar Soft Costs Basics. Available at: https://www.energy.gov/eere/solar/solar-soft-costs-basics
67. Shimura, S., Herrero, R., Zuffo, M., & Grimoni, J. (2016). Production costs estimation in photovoltaic power plants using reliability. *Solar Energy*, *133*, 294–304. https://doi.org/10.1016/j.solener.2016.03.070
68. Nord Pool. (n.d.). *Day-ahead Prices.* Available at: https://data.nordpoolgroup.com/auction/day-ahead/prices?deliveryDate=2024-01-01&currency=EUR&aggregation=MonthlyAggregate&deliveryAreas=LV
69. Cabinet of Ministers. (9 November 2023). *Elektroenerģijas tirdzniecības un lietošanas noteikumi*. [Regulations on the Sale and Use of Electricity]. Available at: https://likumi.lv/ta/id/347235-elektroenergijas-tirdzniecibas-un-lietosanas-noteikumi
70. Ramadan, O., Omer, S., Ding, Y., Jarimi, H., Chen, X., & Riffat, S. (2018). Economic Evaluation of Installation of Standalone Wind Farm and Wind + CAES System for the New Regulating Tariffs for Renewables in Egypt. *Therm. Sci. Eng. Prog.*, *7*, 311–325. https://doi.org/10.1016/j.tsep.2018.06.005

71. Carneiro, P., & Ferreira, P. (2012).The Economic, Environmental and Strategic Value of Biomass. *Renew. Energy, 44*, 17–22. https://doi.org/10.1016/j.renene.2011.12.020
72. Talavera, D.L., Nofuentes, G., Aguilera, J., & Fuentes, M. (2007). Tables for the Estimation of the Internal Rate of Return of Photovoltaic Grid-Connected Systems. *Renew. Sustain. Energy Rev*., *11*, 447–466. https://doi.org/10.1016/j.rser.2005.02.002
73. Kabeyi, M.J.B., & Olanrewaju, O.A. (2023). The Levelized Cost of Energy and Modifications for Use in Electricity Generation Planning. *Energy Reports, 9* (9), 495–534. https://doi.org/10.1016/j.egyr.2023.06.036
74. Siddaiah, R., & Saini, R.P. (2016). A Review on Planning, Configurations, Modeling and Optimization Techniques of Hybrid Renewable Energy Systems for Off-grid Applications. *Renew. Sustain. Energy Rev*., *58*, 376–396. https://doi.org/10.1016/j.rser.2015.12.281
75. Ueckerdt, F., Hirth, L., Luderer, G., & Edenhofer, O. (2013). System LCOE: What are the Costs of Variable Renewables? *Energy*, *63*, 61–75. https://doi.org/10.1016/j.energy.2013.10.072
76. AFP. (2024). *Net Present Value vs. Internal Rate of Return.* Available at: https://www.financialprofessionals.org/training-resources/resources/articles/details/net-present-value-vs.-internal-rate-of-return
77. Michigan State University. (n.d.). *Present Value Models.* Available at: https://openbooks.lib.msu.edu/financialmanagement/chapter/present-value-models/
78. Delapedra-Silva, V., Ferreira, P., Cunha, J., & Kimura, H. (2022). Methods for Financial Assessment of Renewable Energy Projects: A Review. *Processes*, *10*, 184. https://doi.org/10.3390/pr10020184
79. Zalitis, I., Dolgicers, A., Zemite, L., Ganter, S., Kopustinskas, V., Vamanu, B., … & Häring, I. (2022). Mitigation of the Impact of Disturbances in Gas Transmission Systems. *International Journal of Critical Infrastructure Protection, 39,* 100569. http://doi.org/10.1016/j.ijcip.2022.100569
80. Jordan, D. C., &Kurtz, S. R. (2012). *Photovoltaic Degradation. Rates – An Analytical Review.* NREL. Available at: https://docs.nrel.gov/docs/fy12osti/51664.pdf
81. EC. (2014). Guide to Cost-Benefit Analysis of Investment Projects. Directorate-General for Regional and Urban Policy. Available at: https://ec.europa.eu/regional_policy/sources/studies/cba_guide.pdf
82. Chwieduk, D., & Chwieduk, B. (2023). Application of Heat Pumps in New Housing Estates in Cities Suburbs as an Means of Energy Transformation in Poland. *Energies*, *16* (8), 3495. https://doi.org/10.3390/en16083495
83. Md Khairi, N.H., Akimoto, Y., & Okajima, K. (2022). Suitability of Rooftop Solar Photovoltaic at Educational Building towards Energy Sustainability in Malaysia. *Sustainable Horizons*, *4*, 100032, https://doi.org/10.1016/j.horiz.2022.100032
84. Walmsley, T.G., Philipp, M., Picón-Núñez, M., Meschede, H., Taylor, M.T., Schlosser, F., & Atkins, M.J. (2023). Hybrid Renewable Energy Utility Systems for Industrial Sites: A Review. *Renewable and Sustainable Energy Reviews*, *188*. https://doi.org/10.1016/j.rser.2023.113802
85. Serrano-Arévalo, T. I., Ochoa-Barragán, R., Ramírez-Márquez, C., El-Halwagi, M., Abdel Jabbar, N., & Ponce-Ortega, J. M. (2025). Energy Storage: From Fundamental Principles to Industrial Applications. *Processes*, *13* (6), 1853. https://doi.org/10.3390/pr13061853
86. Ghaleb, B., Khan, M. I., & Asif, M. (2024). Application of PV on Commercial Building Facades: An Investigation into the Impact of Architectural and Structural Features. *Sustainability*, *16* (20), 9095. https://doi.org/10.3390/su16209095
87. Del Pero, C., Leonforte, F., & Aste, N. (2024). Building-Integrated Photovoltaics in Existing Buildings: A Novel PV Roofing System. *Buildings*, *14* (8), 2270. https://doi.org/10.3390/buildings14082270
88. Ramos-Paja, C. A., Trejos-Grisales, L. A., & Serna-Garcés, S. I. (2025). Building Integrated Photovoltaic Systems: Characteristics and Power Management. *Processes*, *13* (6), 1650. https://doi.org/10.3390/pr13061650

89. Bošnjaković, M., Veljić, N., & Hradovi, I. (2025). Perspectives of Building-Integrated Wind Turbines (BIWTs). *Smart Cities*, *8* (2), 55. https://doi.org/10.3390/smartcities8020055
90. Coccato, S., Barhmi, K., Lampropoulos, I., Golroodbari, S., & van Sark, W. (2025). A Review of Battery Energy Storage Optimization in the Built Environment. *Batteries*, *11* (5), 179. https://doi.org/10.3390/batteries11050179
91. Gabbar, H. A., & Ramadan, A. (2025). Integrated Renewable Energy Systems for Buildings: An Assessment of the Environmental and Socio-Economic Sustainability. *Sustainability*, *17* (2), 656. https://doi.org/10.3390/su17020656
92. Figaj, R. (2024). Energy and Economic Sustainability of a Small-Scale Hybrid Renewable Energy System Powered by Biogas, Solar Energy, and Wind. *Energies*, *17* (3), 706. https://doi.org/10.3390/en17030706
93. Brennenstuhl, M., Otto, R., Pietruschka, D., Schembera, B., & Eicker, U. (2025). Optimized Dimensioning and Economic Assessment of Decentralized Hybrid Small Wind and Photovoltaic Power Systems for Residential Buildings. *Energies*, *18* (7), 1811. https://doi.org/10.3390/en18071811
94. Cangul, O., Rocchetta, R., Fahrioglu, M., & Patelli, E. (2023). Optimal Allocation and Sizing of Decentralized Solar Photovoltaic Generators Using Unit Financial Impact Indicator. *Sustainability*, *15* (15), 11715. https://doi.org/10.3390/su151511715
95. Peng, K., Ma, M., Zhao, W., & Zhang, R. (2025). Multi-Criteria Optimal Operation Strategy for Photovoltaic Systems in Large-Scale Logistics Parks Concerning Climate Impact. *Buildings*, *15* (3), 377. https://doi.org/10.3390/buildings15030377