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Original Scientific Article

ENERGY TRANSITION IN MUNICIPALITIES – A MODEL FOR SUSTAINABLE RENEWABLE ENERGY MANAGEMENT

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Abstract This study explores optimal strategies for utilizing the electricity generated from already installed PV systems at the local level, aiming to reduce electricity costs and increase revenues through the sale of surplus electricity. Two scenarios are analyzed: (1) individual consumption of the generated electricity within each building and the sale of surplus electricity at the time of production, and (2) collective energy management through a municipal energy enterprise, where surplus electricity is distributed among buildings, and the remaining surplus is sold on the free market. By analyzing existing research and case studies, the study seeks to determine which strategy is more efficient regarding energy efficiency and financial viability, and to propose a model for the collective management of electricity generated from PV systems at the municipal level.

Keywords
PV systems, energy management, electricity cost reduction, surplus electricity, municipal energy enterprise

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1 Introducton

With the increasing demand for sustainable and economically viable energy supply solutions, municipalities are investing increasingly in PV systems for their public buildings. These systems not only contribute to reducing greenhouse gas emissions, but also offer the potential for significant financial savings and revenue generation. However, there is an ongoing debate about whether it is more efficient for each building to utilize the generated energy for its own needs, or to establish a centralized management system where energy is distributed among buildings, with any surplus being sold.

According to [1], due to lower electricity tariffs and the limited increase in self-consumption with battery storage, investing in battery systems is not justified economically in most cases. This indicates the need for alternative strategies to optimize the utilization of electricity generated by PV systems. If surplus electricity from PV systems is transferred between buildings, they can function as virtual storage units.

Additionally, the "Connected Communities" concept proposed in [2] suggests coordinated energy management across multiple buildings, maximizing benefits through resource sharing and consumption optimization. This implies that collective energy management may be more effective than an individual approach.

Therefore, this study proposes a model for joint management of electricity generated from PV systems in a municipality in North Macedonia. It aims to avoid selling surplus electricity on the free market at the time of production due to low market prices while also avoiding investment in battery systems, as the electricity surplus is insufficient to make such an investment cost-effective. The objective of this study is to analyze the advantages and disadvantages of both individual and collective approaches, and to provide recommendations for municipalities seeking to maximize the benefits of their PV system investments.

2 Materials and methods

Achieving the objective—reducing electricity costs and generating revenue from selling surplus electricity through PV system installations—necessitates the implementation of collective management of the produced electricity and the procurement of additional electricity, particularly for municipal buildings. To this end, this study analyzes public buildings in a municipality in North Macedonia, examining specifically electricity generation from existing PV systems on eight buildings and the electricity consumption of all public buildings in the municipality. Two scenarios are analyzed:

1. **Independent operation** of buildings with installed PV systems, including financial analyses based on electricity supply and sales contracts with the universal supplier and the free market.
2. **Collective management** of PV electricity surpluses and procurement for all public buildings in the municipality through a municipal energy enterprise.

The analyses are conducted using monthly electricity consumption data for one calendar year for all public buildings in the municipality, and electricity generation data from PV systems based on the fundamental PV system project documentation.

The results presented in this study are based on hourly-level analyses, demonstrating their relevance. The distribution of monthly electricity consumption across the buildings follows the standard electricity consumption curve provided by EVN Macedonia. The electricity generation from the installed PV systems is distributed on an hourly basis, considering the orientation and location of PV modules on each building, as calculated using the licensed software tool PV*SOL premium, which has an accuracy of approximately 97%.

The techno-economic analyses are conducted using Excel, incorporating relevant financial analysis parameters, electricity prices sourced from the reference electricity market in North Macedonia (HUPX), the average electricity procurement price published by the Energy and Water Services Regulatory Commission, and Regulations governing renewable energy sources.

3 Analysis of the municipal buildings

The analyzed municipality has a total of 28 public institutions under its jurisdiction. Among these, PV systems have been installed on eight buildings, with a total installed capacity of 187.53 kWp, and an expected annual electricity generation of 281,774.31 kWh. The electricity consumption of these eight public buildings, without utilizing the electricity generated by the PV systems, amounts to 2,517,420.85 kWh.

3.1 Electricity Consumption

The electricity consumption of the remaining 20 buildings, which do not have PV systems, is 594,343.12 kWh, bringing the total electricity consumption of all the public buildings in the municipality (excluding PV-generated electricity) to 3,111.76 MWh.

The monthly electricity consumption for each of the 8 municipal facilities that have PV systems installed, as well as the electricity consumption of the remaining 20 municipal facilities, is shown in the Appendix. Given the large number of buildings, the remaining 20 public buildings are categorized into three groups—educational institutions, kindergartens, and administrative buildings.

3.2 Electricity Production

The installed capacity of PV systems for each public building is as follows:

- Public Building (PB) 1 – 28.05 kWp;
- Public Building (PB) 2 – 39.6 kWp;
- Public Building (PB) 3 – 15.12 kWp;
- Public Building (PB) 4 – 15.12 kWp;
- Public Building (PB) 5 – 15.12 kWp;
- Public Building (PB) 6 – 15.12 kWp;
- Public Building (PB) 7 – 19.8 kWp;
- Public Building (PB) 8 – 39.6 kWp.

The total installed capacity of the 8 PV systems in the municipality is 187.53 kWp, and the total annual electricity production is 281,774.31 kWh. The electricity production for each of the installed PV systems at the 8 municipal facilities is shown on a monthly basis in the Appendix.

4 Techno-economic analysis

The expected hourly, monthly, and annual electricity production from each PV system was obtained using PV*SOL premium through simulations of the PV power plants. The additional required electricity was determined as the difference between the hourly electricity production and the hourly electricity consumption for each building individually.

The surplus electricity from the PV systems represents the energy generated by the system that exceeds the hourly consumption of the building. This surplus was calculated by comparing the energy production of the PV system with the consumption demand on an hourly basis using Microsoft Excel. The surplus energy was identified and recorded whenever production exceeded consumption [3].

The obtained technical parameters serve as a framework for conducting the financial analyses. The financial analyses were also performed on an hourly basis.

For Case 1: Independent operation of buildings with installed PV systems, two types of financial analyses were conducted:

- Under a Power Purchase Agreement (PPA) for electricity with the Universal Supplier;
- Under a Power Purchase Agreement (PPA) for electricity with another supplier on the free market.

Based on the results of Case 1, only the Power Purchase Agreement (PPA) for electricity on the free market is considered in Case 2.

4.1 Case 1: Independent operation of buildings with installed PV systems

Case 1 examines the independent management of the electricity generated by the PV systems for each of the eight buildings. Specifically, the electricity produced by the PV system is used for the building's consumption, while any surplus electricity is sold. In this way, each building benefits from savings on electricity consumption due to the use of self-generated electricity, and generates revenue from the sale of surplus electricity. The results of the technical analysis for Case 1 are presented in Table 1.

Table 1: Results of technical analysis for buildings with PV systems

Month	Electricity Consumption	Electricity Production	Required Additional Electricity	Surplus Electricity
January	257,355.75	12,200.95	246,807.65	1,652.86
February	241,813.90	16,520.16	228,320.57	3,026.84
March	205,803.80	23,368.16	191,358.78	8,923.14
April	206,432.52	26,853.96	191,129.51	11,550.95
May	190,650.90	33,059.00	173,846.72	16,254.82
June	176,924.89	34,572.67	165,317.16	22,964.93
July	185,329.42	34,540.06	175,099.89	24,310.53
August	188,862.28	32,093.13	178,823.48	22,054.34
September	184,341.12	25,457.23	172,242.47	13,358.58
October	205,190.69	19,842.08	192,997.19	7,648.58
November	213,255.09	12,467.25	202,337.08	1,549.24
December	261,460.50	10,799.65	251,903.00	1,242.15
Total [kWh]	**2,517,420.85**	**281,774.31**	**2,370,183.50**	**134,536.96**

It can be observed that the electricity production from all PV systems is less than 1% of the total electricity consumption of the analyzed public buildings. However, at certain hours, there are electricity surpluses that the buildings will not be able to utilize, and these are presented in Table 1.

The financial analyses for the free market are based on the current electricity supply contracts of the public buildings in the analyzed municipality, where electricity is purchased at prices 20% higher than the HUPX market prices. It is assumed that the procurement price of electricity will be 20% higher than HUPX market prices, while the public buildings will sell their surplus electricity at HUPX-10% prices.

The financial analyses for the Universal Supplier are conducted based on the average procurement price in Macedonia and the calculation formula according to the Renewable Energy Sources Regulation [11]:

$$C = PCE \cdot 0.9 \tag{4.1}$$

if in an accounting period $E_i >= E_p$

$$C = PCE \cdot 0.9 \cdot \frac{E_i}{E_p} \tag{4.2}$$

if in an accounting period $E_i < E_p$

Table 2: Results of the analysis of savings and revenues for public buildings with PV systems

PPA	Savings	Revenues	Savings + Revenues	Gross Profit
free market	€25,553.72	€13,734.33	€39,288.05	-€372,096.18
Universal Supplier	€33,878.67	€6,396.85	€40,275.52	-€509,116.19

Table 3: Cost analysis results with and without PV systems

PPA	Electricity Expenses without PV Systems	Electricity Expenses with PV Systems
free market	€436,939.69	€411,384.23
Universal Supplier	€549,391.71	€515,513.04

From Table 2, it can be observed that, under a Power Purchase Agreement (PPA) with an alternative supplier operating in the free market, the electricity cost savings for all public buildings with PV systems, due to self-consumption, would amount to approximately €25,553. The revenues from selling surplus electricity generated by the PV systems would be €13,730, resulting in total savings and revenues of approximately €39,300. According to Table 3, the costs for purchasing additional electricity would be around €411,390. Therefore, if the revenues from surplus electricity sales are allocated for additional electricity procurement, the net financial result would be a loss of €372,100 per year, meaning public buildings would need to secure additional funds for electricity procurement.

In the case of a PPA with the Universal Supplier, according to Table 2, the savings from self-consumption of electricity would be around €33,880, while the revenues from surplus electricity sales would be approximately €6,400, leading to total savings and revenues of about €40,275. According to Table 3, the costs for purchasing additional electricity would amount to approximately €515,513. Thus, if the revenues from surplus electricity sales are allocated for electricity procurement, the net financial result would be a loss of €509,116 per year, requiring public buildings to secure additional funds for electricity procurement.

Based on the conducted analyses and the presented results, it can be concluded that electricity bill savings are higher when public buildings procure electricity through the Universal Supplier. This is due to the currently high electricity purchase price in North Macedonia. On the other hand, revenues from surplus electricity sales are consistently higher when electricity is purchased on the free market, and the costs of additional procurement are lower. Consequently, according to the obtained results, the costs for additional electricity procurement on the free market are 21% lower than the costs of electricity supply through the Universal Supplier. Therefore, it can be concluded that, at present, it is more financially viable for public buildings to enter into a PPA with an alternative supplier operating on the free market.

The analyses are based on the current electricity supply agreements for public buildings in the analyzed municipality, where electricity is purchased at prices 20% higher than the HUPX market prices. It is assumed that the electricity purchase price will be 20% higher than the HUPX market prices, while the public buildings will sell surplus electricity at HUPX-10% prices.

4.2 Case 2: Collective management of PV electricity surpluses and procurement for all public buildings in the municipality through a municipal energy enterprise

The analysis for the second scenario was conducted under the following conditions: Each of the buildings equipped with PV systems will use the electricity generated for their consumption. During hours when surplus electricity is available, municipal buildings with PV systems will supply the surplus electricity to the remaining 20 buildings at prices equal to those on the HUPX market. Any electricity generated by the PV systems that is not consumed by the 28 municipal buildings will be sold on the free market at HUPX-10% prices. Since, as established in previous analyses, the electricity produced by the installed PV systems will not be sufficient to meet the energy needs of all 28 municipal buildings, there is a need for additional electricity procurement. Therefore, it is planned that the legal entity will purchase electricity for all 28 municipal buildings for, at HUPX+20% and sell it to the municipal buildings at the same price, HUPX+20%.

Table 4 presents the electricity consumption of the 20 municipal buildings before and after utilizing the surplus electricity from PV systems, as well as the total additional electricity that the energy enterprise will need to procure to meet the energy needs of all 28 public buildings in the municipality.

By transferring surplus electricity from PV systems to the remaining 20 municipal buildings, their consumption will decrease by approximately 20%. Additionally, 16.90 MWh of surplus electricity will remain and be sold on the free market. As a result, the electricity costs for buildings without PV systems will be 20% lower compared to purchasing the same amount from the free market. Meanwhile, the energy enterprise's revenue will be 10% higher if it sells this electricity to municipal buildings rather than on the free market.

Table 4: Results of technical analysis when transferring surplus electricity to the remaining 20 public buildings

Month	Electricity Consumption for the 20 Buildings when using the surpluses from the PV Systems	Total Surpluses from the PV Systems	Total Electricity Procurement for all the Buildings in the Municipality
January	59,360.54	67.25	306,168.20
February	54,887.24	309.85	283,207.81
March	41,142.46	1,317.69	232,501.23
April	38,640.36	1,650.18	229,769.88
May	31,329.32	2,261.34	205,176.04
June	21,952.56	3,793.01	187,269.72
July	21,310.66	2,725.15	196,410.55
August	23,834.95	2,084.60	202,658.43
September	31,317.77	1,413.74	203,560.24
October	41,945.28	1,191.21	234,942.48
November	49,234.10	34.22	251,571.18
December	61,747.52	48.35	313,650.52
Total (kWh)	**476,702.76**	**16,896.60**	**2,846,886.26**

Table 5: Results of analysis of savings, revenues, and costs for the energy enterprise

Month	Savings	Revenues from Surplus Electricity sale	Revenues from Surplus Electricity sale to the 20 Buildings	Savings + Revenues	New Electricity Expenses	Expenses without PV Electricity
January	2,853.57	12.61	263.28	3,129.46	58,457.28	61,093.39
February	3,330.75	38.89	367.68	3,737.32	50,760.76	53,815.34
March	3,643.78	129.51	763.20	4,536.49	32,415.02	35,919.88
April	3,908.07	115.41	941.60	4,965.09	29,320.50	33,132.12
May	3,665.46	146.03	905.30	4,716.79	20,771.06	24,097.90
June	4,092.45	195.91	1,508.26	5,796.62	20,965.94	25,263.11
July	4,099.03	187.04	1,622.27	5,908.35	21,739.34	26,106.94
August	3,920.87	113.53	1,514.13	5,548.53	23,815.77	27,975.52
September	3,291.48	99.84	965.41	4,356.74	24,624.65	27,884.57
October	2,747.11	116.26	561.07	3,424.44	29,443.00	31,996.59
November	1,943.52	2.50	144.09	2,090.11	32,011.65	33,619.23
December	1,491.39	4.83	96.71	1,592.93	32,723.67	33,899.45
Total (€)	**38,987.47**	**1,162.38**	**9,653.00**	**49,802.85**	**377,048.65**	**414,804.04**

The total savings on electricity bills for all the municipal buildings will be approximately €38,900, while the revenue from selling surpluses on the free market at HUPX - 10% will amount to €1,160. The energy enterprise will generate an additional €9,650 from selling surplus electricity to buildings without PV systems. The total electricity costs for all the municipal buildings have been reduced from €540,100 to €377,050, representing a 30% reduction. Comparing the total costs of the eight municipal buildings with PV systems and the remaining 20 municipal buildings, which amount to €514,540, the overall cost reduction for all the municipal buildings is approximately 27%.

5 Results and discussion

The analysis demonstrates that it is more cost-effective for a single entity to manage the electricity generated from PV systems rather than each building managing it independently. Therefore, a model has been proposed for centralized energy management through a municipal energy enterprise. The model operates as follows:

– Each building with a PV system uses its generated electricity for self-consumption.

– Surplus electricity is transferred to the 20 municipal buildings at HUPX market prices.
– Any remaining surplus is sold on the free market at HUPX - 10%.
– The energy enterprise procures electricity for all 28 municipal buildings at HUPX + 20% and sells it at the same price.

Under this model, municipal buildings without PV systems achieve 20% savings, generating annual savings of €1,930. The total savings for all the municipal buildings amount to €38,900. The enterprise earns €1,160 from selling surplus electricity on the free market and €9,650 from selling surplus PV electricity to non-PV buildings, with the total revenue reaching €10,870 and reducing additional electricity procurement costs by 30%.

The energy enterprise's responsibilities include:

– Managing installed PV systems in schools, kindergartens, and other municipal buildings;
– Trading the produced electricity;
– Procuring electricity for all the municipal buildings;
– Engaging in additional activities, such as street lighting, energy efficiency investments, and reducing reliance on fossil fuels.

Currently, there is no established legal framework in North Macedonia that regulates the formation and operation of energy cooperatives or energy communities, which are the envisioned organizational structures for the future development of municipal enterprises. These entities, which could serve as platforms for collective ownership and management of local renewable energy sources, remain undefined legally.

Moreover, the existing Law on Trade Companies does not allow public utility companies—especially those under municipal ownership—to engage directly in the supply of electricity, or the commercial sale of surplus electricity generated from municipal PV systems. To address this regulatory gap, the municipalities have established limited liability companies (LLCs) as separate legal entities under commercial law. These companies can enter into Power Purchase Agreements

(PPAs) with licensed electricity suppliers, and handle centralized procurement of electricity for all municipally owned facilities.

While the proposed model is fully in line with EU policies promoting decentralized energy systems and community-based renewable energy, its implementation would benefit greatly from a more supportive and clearly defined regulatory framework that recognizes energy communities explicitly and facilitates active municipal participation in energy markets.

6 Conclusion

This study demonstrates that the implementation of PV systems in public buildings can reduce reliance on traditional energy sources significantly, while providing financial benefits to the municipality. The analysis of 28 municipal buildings in the analyzed municipality reveals that centralized energy management through a municipal energy enterprise is more cost-effective than individual energy management by each building.

Through this model, the eight municipal buildings equipped with PV systems consume the energy they generate for their own needs, while surplus electricity is redirected to the remaining 20 buildings. This leads to a 30% reduction in electricity costs, resulting in annual savings of approximately €38,900. Additionally, selling surplus electricity on the free market generates €1,160 in revenue, while selling surplus electricity to public buildings without PV systems provides an additional €9,650 in income for the energy enterprise.

One of the key findings is that this strategy not only brings economic benefits, but also contributes significantly to the municipality's energy transition. Reducing the costs of electricity procurement from traditional sources, alongside the increased utilization of renewable energy, enhances energy independence and stability. Furthermore, this model opens opportunities for additional investments in energy efficiency, such as modernizing street lighting, improving building insulation, and introducing smart energy management systems.

The long-term benefits of this approach are clear: reducing carbon dioxide emissions, increasing the resilience of the energy sector against market price fluctuations, and promoting sustainable energy policies at the local level. This analysis highlights that an integrated approach to managing renewable energy sources is not only financially viable, but also strategically essential in the energy transition process.

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Nomenclature

(Symbols)	(Symbol meaning)
PV	photovoltaic
HUPX	Hungarian Power Exchange
PB	Public Building
PPA	Power Purchase Agreement
C	Price for surplus electricity
PCE	Average purchase electricity price
Ei	Total electricity delivered by the supplier and taken over by the consumer-producer within the accounting period and expressed in kWh

(Symbols)	(Symbol meaning)
Ep	Total electricity delivered to the electricity distribution network by the consumer-producer within the accounting period and expressed in kWh.
LLCs	Limited Liability Companies

Povzetek v slovenskem jeziku

Energetski prehod v občinah – model za trajnostno upravljanje z obnovljivimi viri energije. Študija raziskuje optimalne strategije za izrabo električne energije, proizvedene iz že nameščenih fotonapetostnih sistemov na lokalni ravni, s ciljem zmanjšanja stroškov električne energije in povečanja prihodkov s prodajo presežne električne energije. Analizirana sta dva scenarija: (1) individualna poraba proizvedene električne energije znotraj vsake stavbe in prodaja presežne električne energije v času proizvodnje ter (2) kolektivno upravljanje energije prek občinskega energetskega podjetja, kjer se presežek električne energije porazdeli za energetske potrebe stavb, preostali presežek pa se proda na prostem trgu. Z analizo obstoječih raziskav in študij primerov želi študija ugotoviti, katera strategija je učinkovitejša glede energetske učinkovitosti in finančne upravičenosti, ter predlagati model za kolektivno upravljanje električne energije, proizvedene iz fotonapetostnih sistemov na občinski ravni.

Appendix A: Electricity consumption

Table A1: Electricity consumption of municipal facilities with PV systems

Electricity Consumption for Public Buildings with PV Systems								
Month	**PB 1**	**PB 2**	**PB 3**	**PB 4**	**PB 5**	**PB 6**	**PB 7**	**PB 8**
January	5,130	5,663	4,016	3,563	227,109	655	3,565	7,656
February	5,637	5,089	2,789	4,741	209,817	754	3,673	9,313
March	3,474	3,651	1,733	4,166	182,957	528	2,698	6,597
April	5,397	4,458	1,071	2,426	184,109	413	2,297	6,262
May	3,883	5,102	519	4,810	168,116	220	2,009	5,993
June	1,798	4,344	336	820	164,375	107	1,432	3,713
July	1,278	4,508	1,002	199	174,531	52	927	2,832
August	1,390	3,900	874	1,371	178,006	64	747	2,511
September	2,557	4,314	457	2,530	167,883	100	1,532	4,968
October	3,719	4,837	689	3,059	183,333	322	2,181	7,051
November	6,243	5,959	2,048	2,214	182,327	594	3,616	10,253
December	7,142	5,408	3,614	7,392	220,556	1,108	4,910	11,331
Total [kWh]	47,646	57,232	19,149	37,291	2,243,118	4,916	29,587	78,482

Table A2: Electricity consumption of municipal facilities that do not have PV systems

Electricity Consumption for Public Buildings without PV Systems				
Month	**Educational Institutions**	**Kindergartens**	**Administrative objects**	**Total**
January	12,472	28,324	17,182	57,978
February	15,172	34,457	20,902	70,531
March	10,747	24,408	14,807	49,962
April	10,202	23,169	14,055	47,425
May	9,762	22,172	13,450	45,384
June	6,049	13,738	8,334	28,121
July	4,613	10,476	6,355	21,444
August	4,090	9,289	5,635	19,015
September	8,093	18,381	11,150	37,625
October	11,487	26,088	15,826	53,400
November	16,702	37,933	23,011	77,646
December	18,458	41,921	25,431	85,810
Total (kWh)	127,847	290,357	176,139	594,343

Appendix B: Electricity production

Table B1: Electricity production from the 8 PV systems

Electricity Production								
Month	**PB 1**	**PB 2**	**PB 3**	**PB 4**	**PB 5**	**PB 6**	**PB 7**	**PB 8**
January	1,855	2,396	1,005	1,005	1,005	1,005	1,310	2,619
February	2,500	3,309	1,355	1,355	1,355	1,355	1,764	3,529
March	3,503	4,854	1,898	1,898	1,898	1,898	2,473	4,945
April	3,996	5,736	2,165	2,165	2,165	2,165	2,820	5,641
May	4,902	7,153	2,656	2,656	2,656	2,656	3,460	6,920
June	5,111	7,557	2,770	2,770	2,770	2,770	3,608	7,216
July	5,109	7,542	2,768	2,768	2,768	2,768	3,606	7,212
August	4,769	6,888	2,584	2,584	2,584	2,584	3,366	6,733
September	3,805	5,345	2,062	2,062	2,062	2,062	2,686	5,372
October	2,991	4,033	1,621	1,621	1,621	1,621	2,111	4,223
November	1,890	2,477	1,024	1,024	1,024	1,024	1,334	2,668
December	1,644	2,111	891	891	891	891	1,160	2,321
Total [kWh]	42,075	59,400	22,800	22,800	22,800	22,800	29,700	59,400