Ensuring Operability During Disruptions: Hybrid Energy Systems for Critical infrastructure

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Part 1 “Operability During Disruptions”

Ensuring Operability During Disruptions: Hybrid Energy Systems for Critical infrastructure

POLAND, Rzeszów, 24.09.2024

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Part 2 “Low-Power Renewable Energy Communities”

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Introduction

Our Research Focus:

- Explore strategies for autonomous operation of Renewable Energy Communities in Ukraine's energy reform landscape
- Analyze these systems during autonomy conditions or blackouts
- Optimize existing hybrid power systems integrating diverse renewable sources
- Enhance the country's energy security through resilient Renewable Energy Communities structures

In this presentation, we will:

- Provide an overview of Ukraine's renewable energy landscape
- Outline our mathematical modeling approach for Renewable Energy Community operation
- Present results on achieving Renewable Energy Communities autonomy through capacity optimization
- Discuss implications and recommendations for fortifying energy

Renewable Energy Landscape in Ukraine

Ukraine's energy reforms prioritize distributed generation, aligning with the EU's directives. Renewable Energy Communities exemplify this trend, forming decentralized energy systems. Amid energy sector evolution, optimizing hybrid power systems, integrating various Renewable Energy Community, is crucial for resilience, especially post-conflict or natural disasters

Table 1. Renewable Energy Sources Market Segmentation Based on Power Plant Capacities

Power, MW	< 1	1–5	5–10	10–50	50–100	100–200	> 200
Number of plants, pcs.	492	337	168	188	15	2	2
Total capacity, MW	184,827	846,398	1 191,735	3 134,697	1 102,824	362,875	569,444

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Renewable Energy Landscape in Ukraine

Regionally, Vinnytsia, Khmelnytskyi, Ivano-Frankivsk, Kyiv, and Zakarpattia lead in small Renewable Energy Sources capacity.
Biogas is gaining traction, with 140 MW installed capacity and 505.4 GWh generated in 2022 across 83 plants, enhancing regional energy autonomy

Table 2. Technological Composition of Small Renewable Energy Power Plants: Regional Installation Structures

Region	Regional Installed Capacity, MW			
	WPP	Mini-micro HPP’s	SPPs	Total
Vinnytsia	0	4,83	17,33	22,16
Dnipropetrovska	0	0,13	11,34	11,47
Transcarpathian	0	6,71	6,01	12,72
Ivano-Frankivsk	0,6	2,44	12,19	15,23
Kyiv	0,45	2,02	9,37	11,84
Lviv	0	0,62	8,59	9,21
Ternopil	0,66	2,64	8,9	12,19
Khmelnytsky	0	7,55	8,29	15,85
Cherkasy	0	3,15	6,55	9,7

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Research Objectives

1	Strategies to ensure the autonomous operation of Renewable Energy Communities within the Ukrainian context
2	Autonomous systems sustainability, particularly during autonomy or blackouts modes
3	Optimizing existing hybrid power systems

Methodology

Target functions

$$F_{jt}\left(\boldsymbol{P}\right)=\sum_{i=1}^{n} b_{ji}P_{it}$$

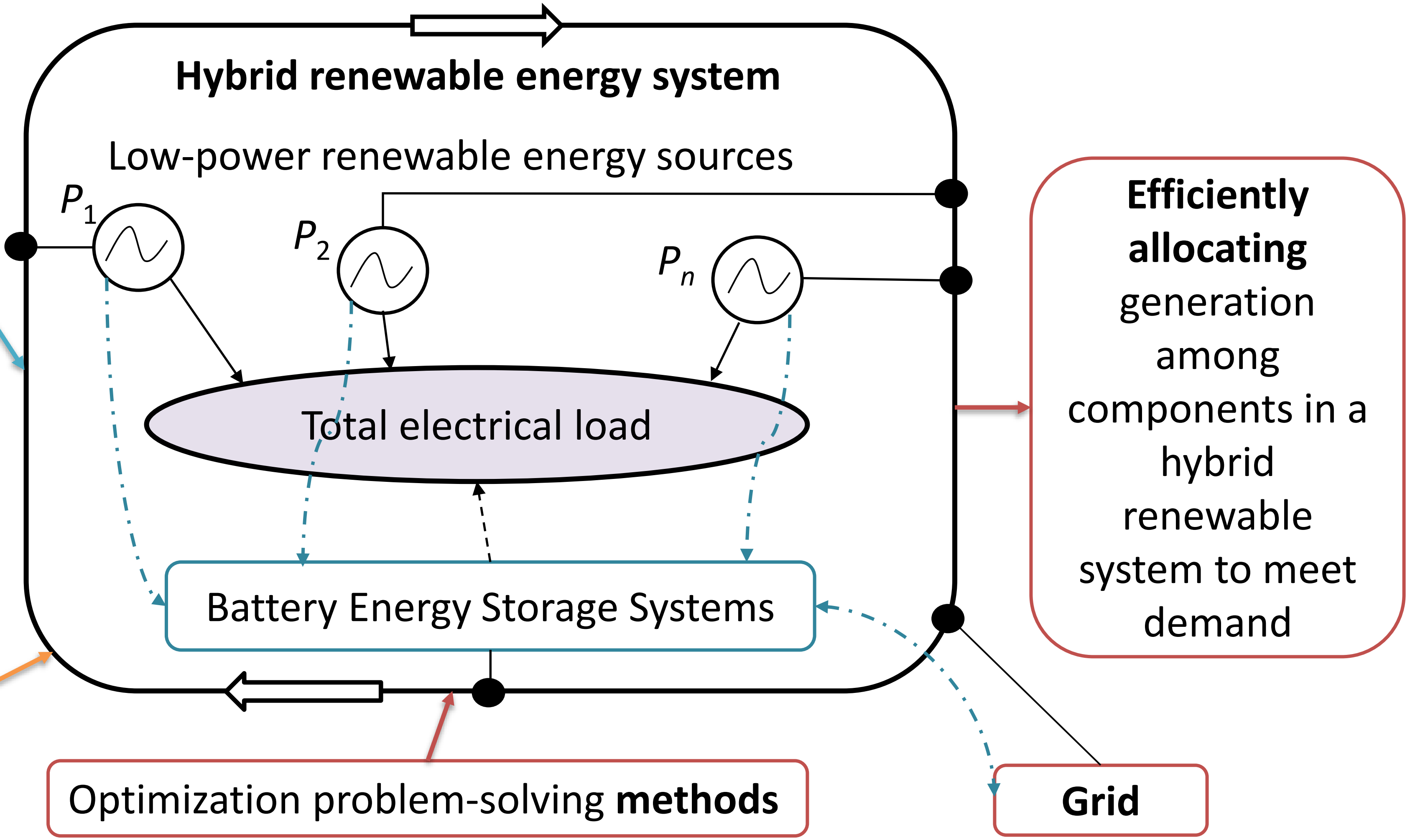
For instance: prioritizing energy sources with elevated specific capital costs:

$$F_1(\boldsymbol{P})=b_{11}P_1+\ldots+b_{1n}P_n \rightarrow \max$$

Restrictions

$$P_{it}^{\min} \le P_{it} \le P_{it}^{\max} \qquad \sum_{i=1}^{n} P_{it} = \boldsymbol{A}_t$$

daily resources of respective generators and operational conditions for individual sources



Methodology

Objective functions are represented in a linguistic form:

The structure of each objective function will be as follows

$$F_{jt}(\boldsymbol{P}) = \sum_{i=1}^{n} a_{ji} P_{it}$$

where j = 1, ..., m – total number of objective functions;
n – number of generating sources (factors); t – specific period of time

e.g.: 1) give preference to energy sources with higher specific capital costs:

$$F_1(\boldsymbol{P}) = a_{11}P_1 + a_{12}P_2 + a_{13}P_3 + a_{14}P_4 \rightarrow \max$$

where a_{11}, a_{12}, a_{13}, a_{14} correspond to the specific (per 1 kW) value of capital expenditures of the generated capacity typical for individual generating plants

To formulate the target functions that characterize different electricity **market actors**, such as suppliers and operators, and their respective interests.

In specific conditions, the list of target functions can be **expanded**

Methodology

Restrictions

- Current technical capabilities of individual generating sources — $P_{it}^{\min} \leq P_{it} \leq P_{it}^{\max}$
- Current generation-consumption **balance** (if necessary, taking into account the potential of energy storage facilities and power losses for network sections) — $\sum_{i=1}^{n} P_{it} = \boldsymbol{A}_t$
- Conditions of average daily energy limitation by individual generating sources — daily resources of the relevant generating sources for example: ‘the volume of gas in a storage tank’; ‘the volume of water in the micro-hydroelectric power plant basin’

Operational conditions for the use of individual generating sources

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Methodology

Operational conditions for the use of individual generating sources

$$F(\boldsymbol{P}) = a_{11}P_1 + a_{12}P_2 + a_{13}P_3 + a_{14}P_4 \rightarrow \max$$

a = 1, when there are no load restrictions on the *i*-th source;

a = 0,6–0,8 if it is undesirable to utilize the *i*-th source for meeting consumer loads in the *t*-th mode;

a = 0,2–0,4 – if it is highly undesirable to deploy the *i*-th source in the *t*-th mode.

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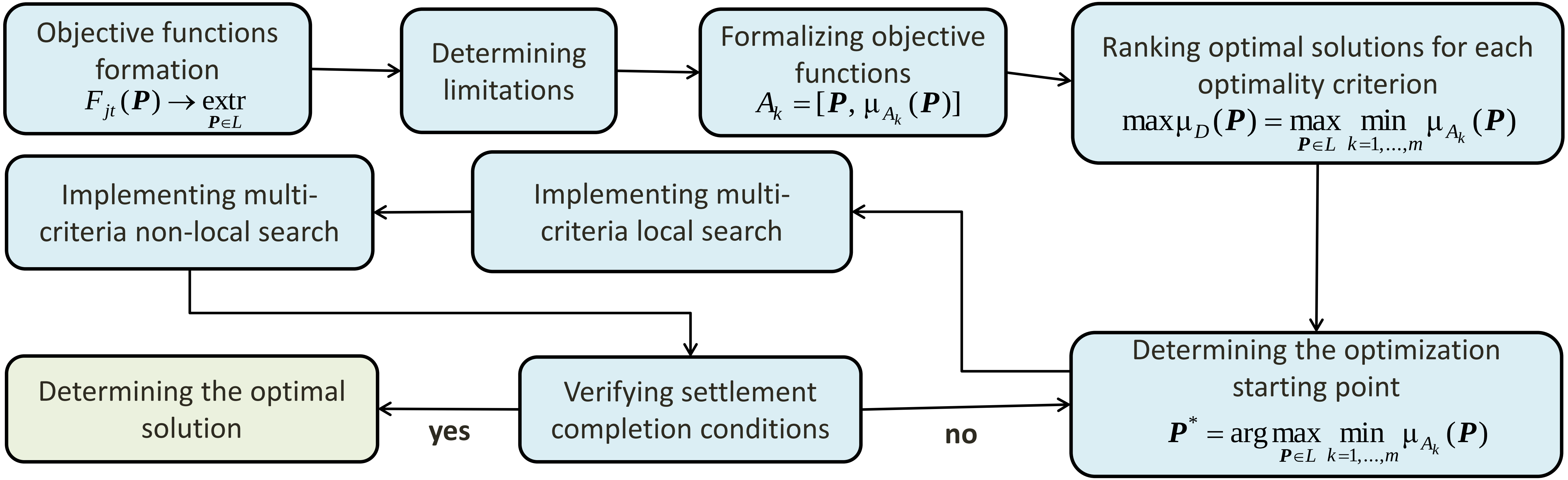
Methodology

We used the Bellman-Zadeh method, rooted in fuzzy set theory, for its advantages:

1. It considers both quantitative and qualitative factors simultaneously.
2. It defines a clear optimality criterion, aimed at maximizing all target functions.
3. It ensures the solution lies within the Pareto optimal region, offering a balanced resolution.



Simulation Setup

We conducted simulations across four distinct Renewable Energy Community structures

Structure 1: 44 % biogas, 27 % solar, 29 % hydro

Structure 2: 33 % biogas, 32 % solar, 35 % hydro

Structure 3: 38 % biogas, 23 % solar, 39 % hydro

Structure 4: 28 % biogas, 27 % solar, 45 % hydro

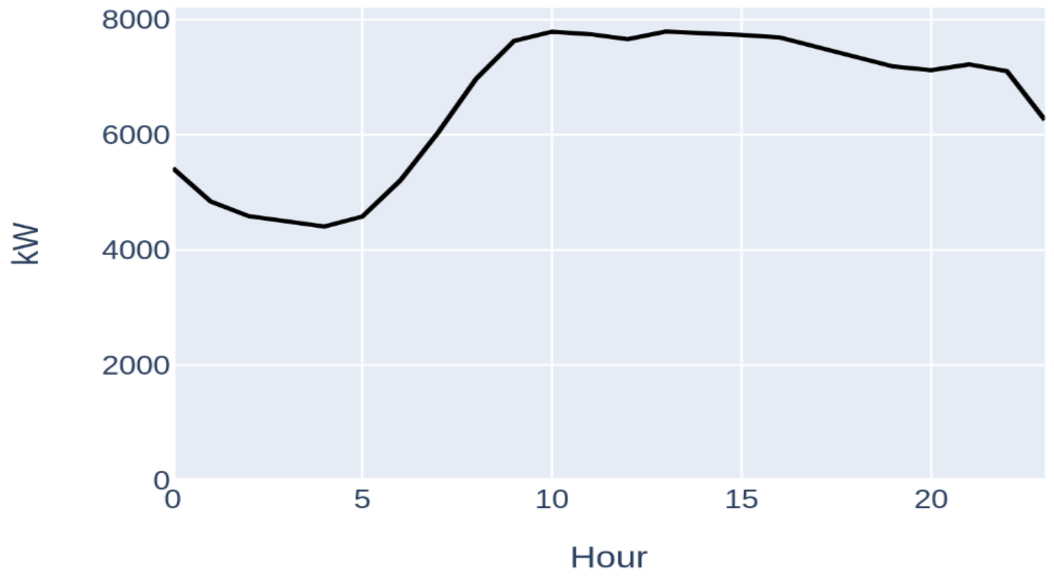
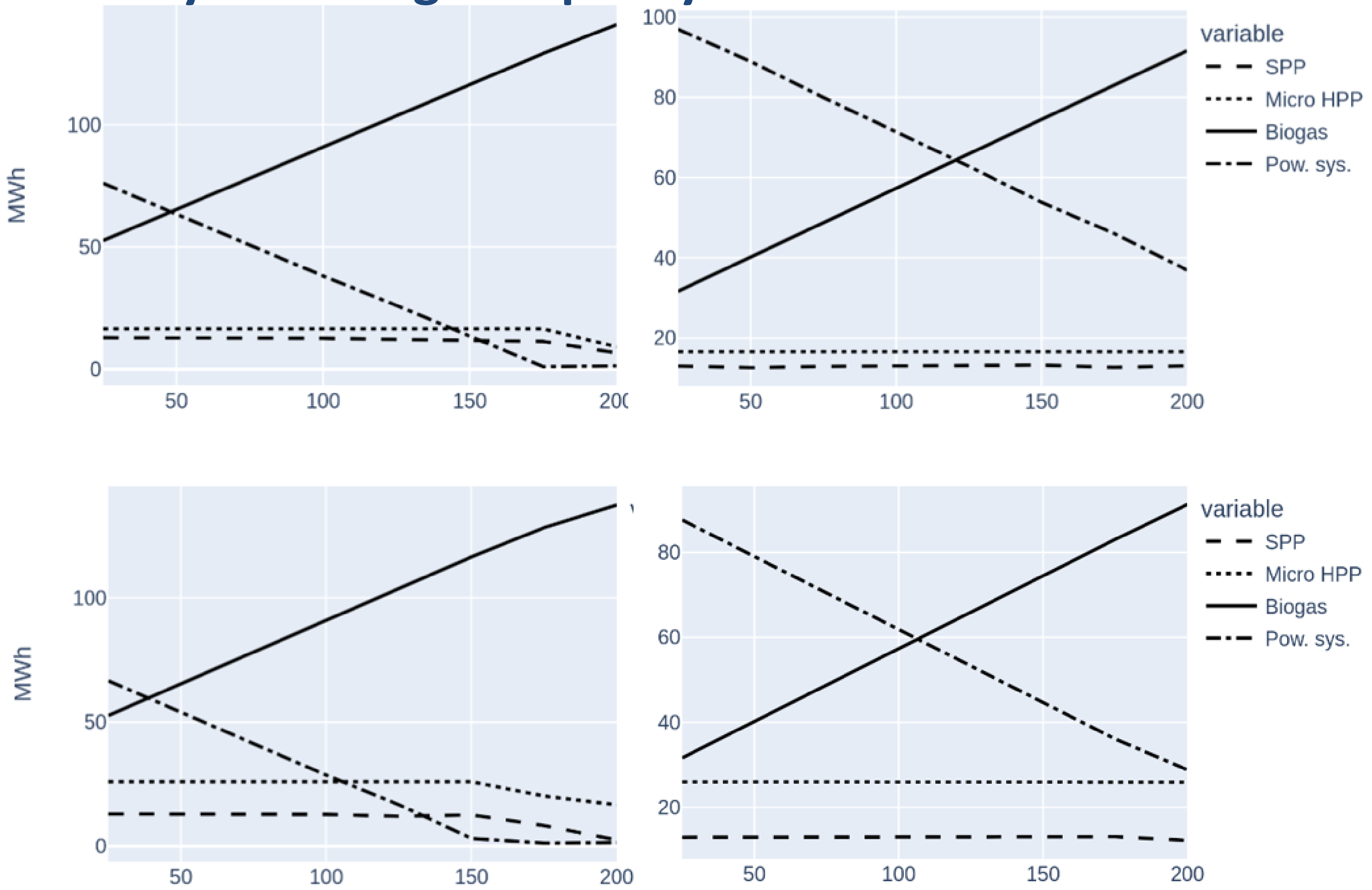
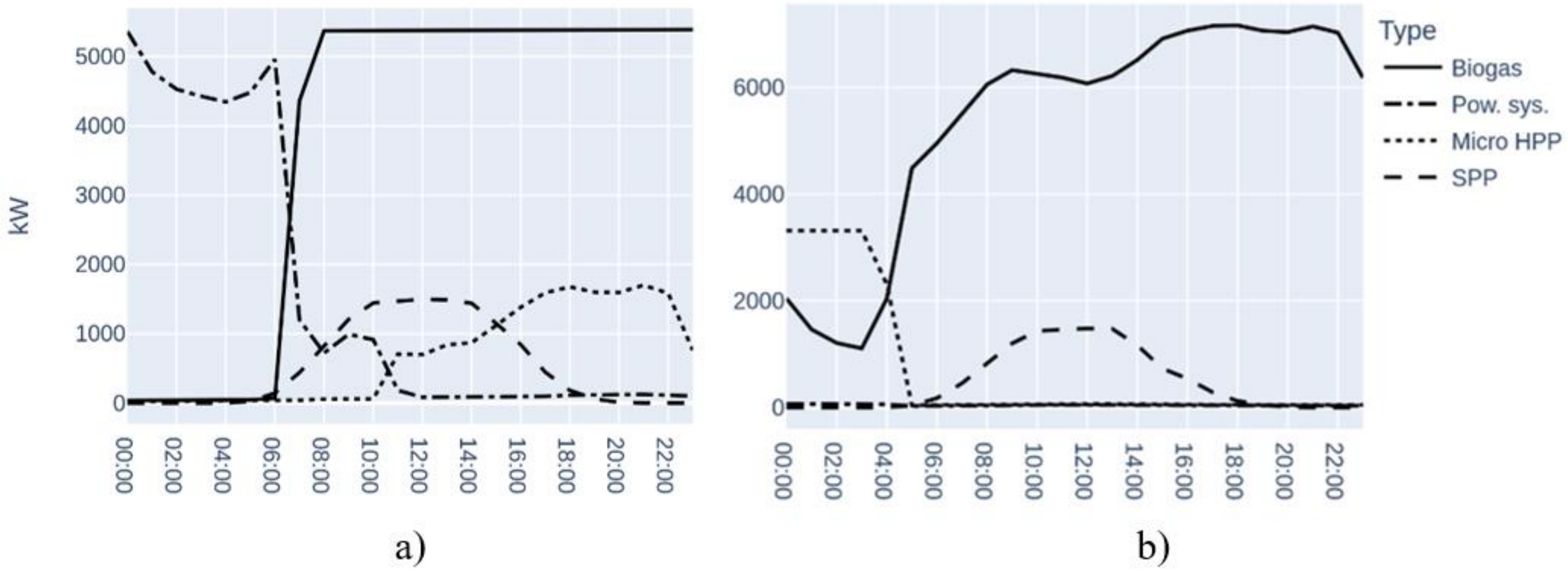


Figure 1. Electricity Consumption Graph in the Renewable Energy Community

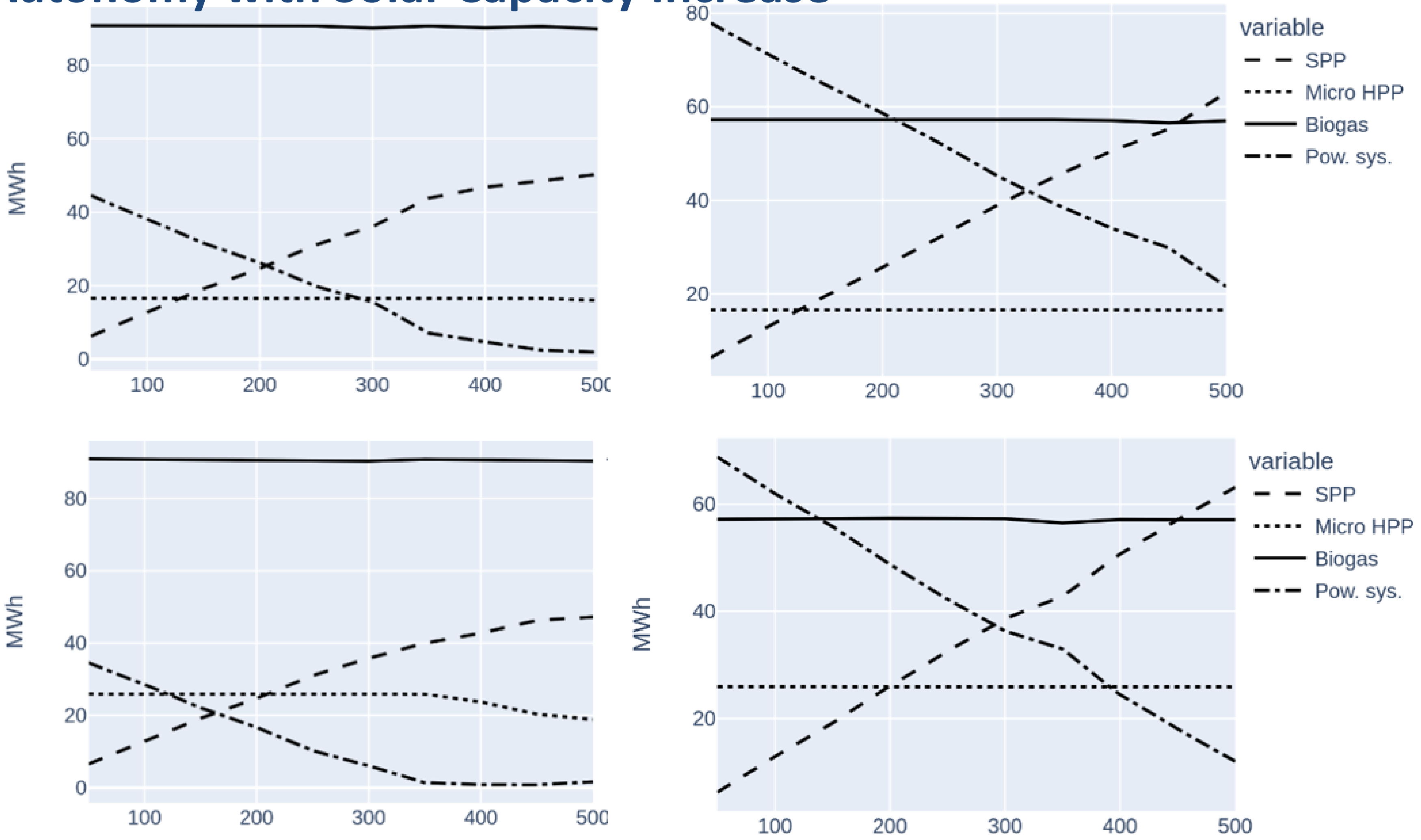
Results - Autonomy with Biogas Capacity Increase



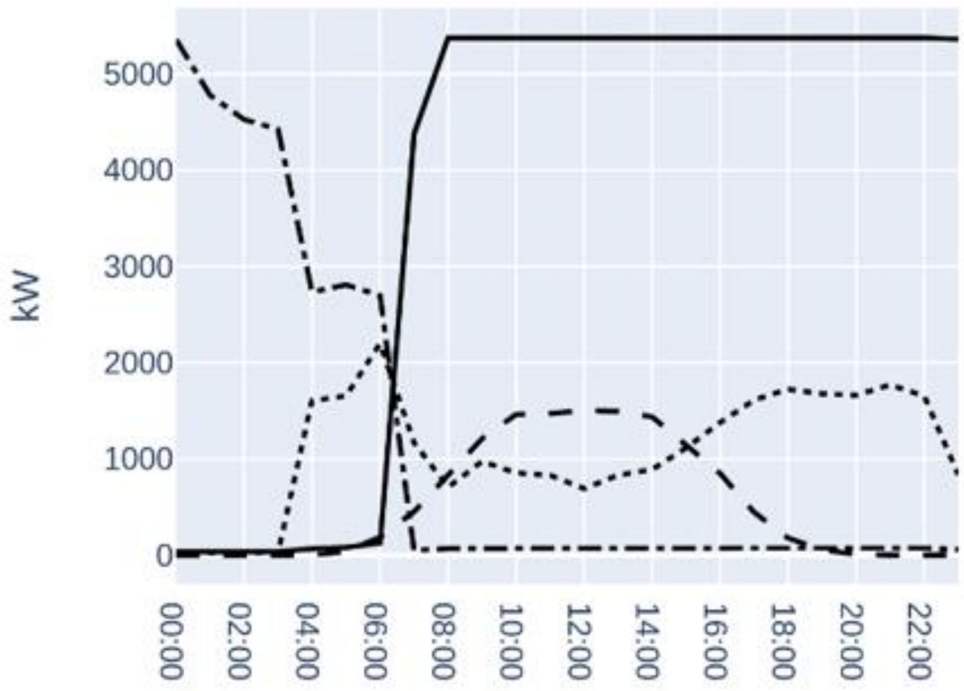
Results - Autonomy with Biogas Capacity Increase



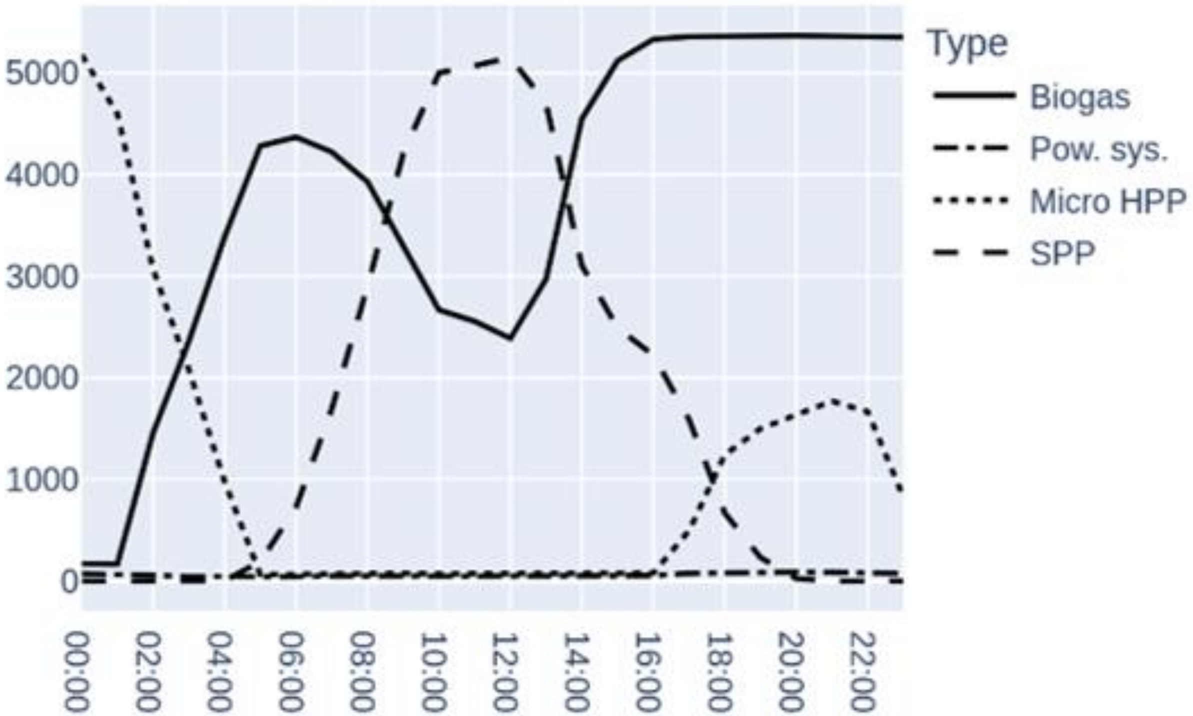
Results - Autonomy with Solar Capacity Increase



Results - Autonomy with Solar Capacity Increase



a)



b)

Discussion

Type 1 & Type 3 Attaining Self-Sufficiency

Type 1: Requires a 175 % increase in biogas capacity or a 450 % increase in solar capacity for autonomy

Type 3: Needs a 150 % increase in biogas capacity or a 350 % increase in solar capacity for autonomy

Acknowledging Uncertainties & Limitations:

- Natural factors, grid configurations, load fluctuations, and other variables impact performance;
- Technical, economic, and environmental constraints must be considered;
- Optimize structure by considering resource potential, generation variability, costs, and environmental impacts.

Tailored Approach for Sustainability:

- Local conditions and priorities influence the optimal pathway;
- Customized strategies are essential for successful implementation and long-term sustainability.

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Conclusion

Our research illuminates prospects and strategies for achieving autonomous operation of renewable energy communities in Ukraine

Aligns with ongoing energy sector reforms towards decentralized, resilient systems

Feasibility Demonstrated:

- Rigorous simulations show achieving autonomy is feasible but requires substantial capacity increases;
- For biogas-dominant structures: Up to 175 % increase in biogas capacity;
- For balanced structures: Up to 350 % increase in solar photovoltaic capacity.

Future Directions:

- Further exploration and refinement of strategies for modernizing energy systems;
- Leveraging renewable energy communities and hybrid systems for enhanced energy security and sustainable development in Ukraine.

Thank you for your attention!

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