

1. Introduction

Microgrids (MGs) are increasingly important in discussions on contemporary electrical networks due to their localized, decentralized nature, driven by their use of distributed generation, especially from renewable sources [1]. Sustainability and resilience are integral to MGs, emphasizing their significance in future networks [2]. MG design involves careful consideration of multiple components to enhance overall performance and exploit distributed energy resources efficiently [3]. Cooperative management is key to well-designed MGs, optimizing resource utilization and ensuring stability [4]. This study explores pathways to tailor MGs for specific energy demands and enhance sustainability across diverse settings, bridging theoretical research and practical application. Stakeholders are equipped with knowledge and tools for holistic MG development, incorporating technical, economic, environmental, and social considerations. Real-world application is demonstrated through a qualitative case study, translating theoretical principles into actionable strategies for sustainable and resilient energy solutions.

2. Microgrids Classifications and Qualitative Assessment

This research discusses the diversity in microgrids and the importance of understanding the reasons behind and the decision-making process for energy organizations. This diagram explores various classifications for microgrids, the factors influencing this diversity, and the guiding criteria for decision-making in microgrid implementation.

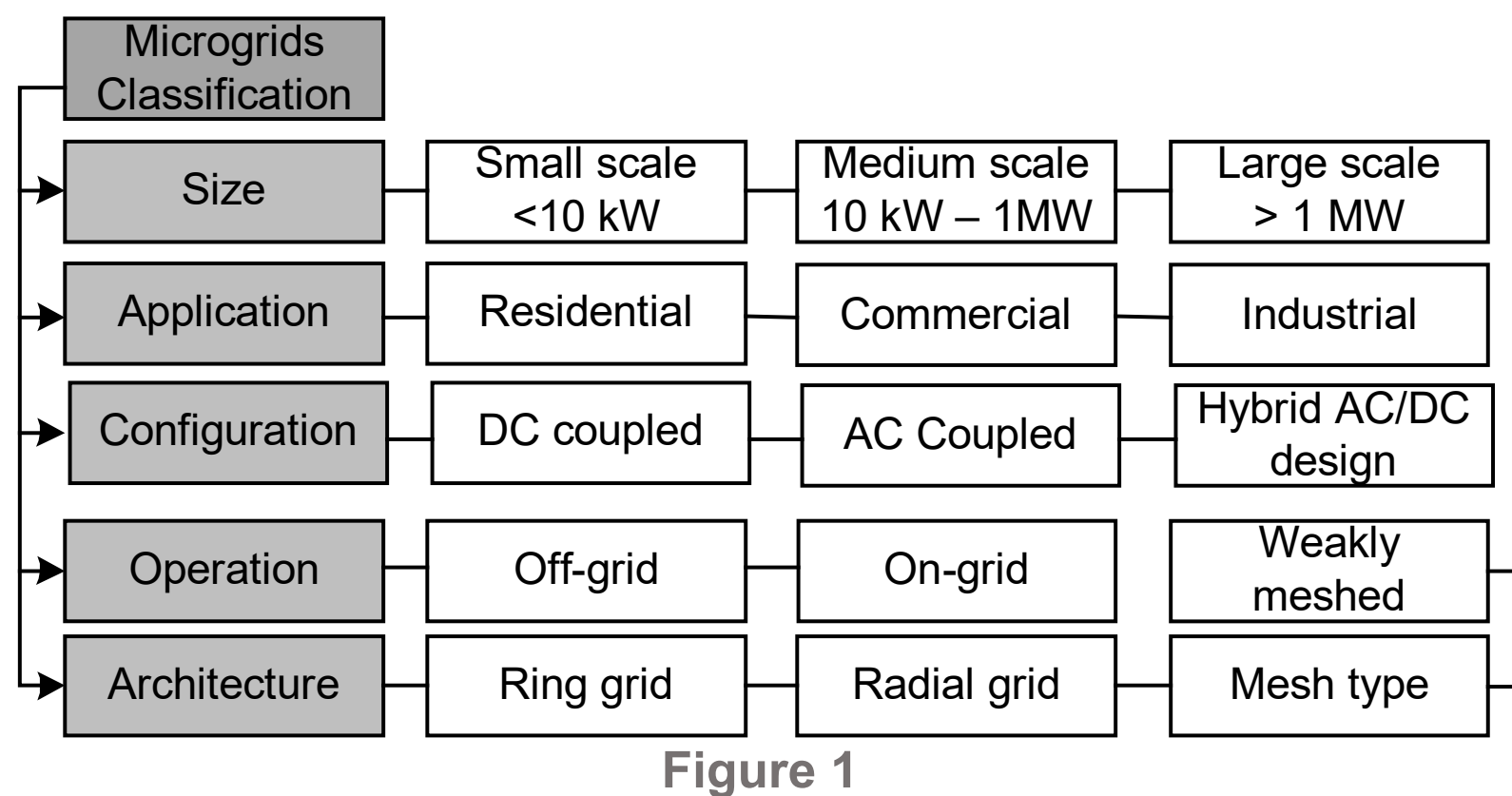


Figure 1

Next figure illustrates diverse options for energy generation. Renewables offer advantages like environmental sustainability, long-term cost stability, and resilience to fuel price fluctuations. However, their intermittent nature challenges MG integration. Non-renewables, while more reliable, have significant environmental and economic drawbacks.

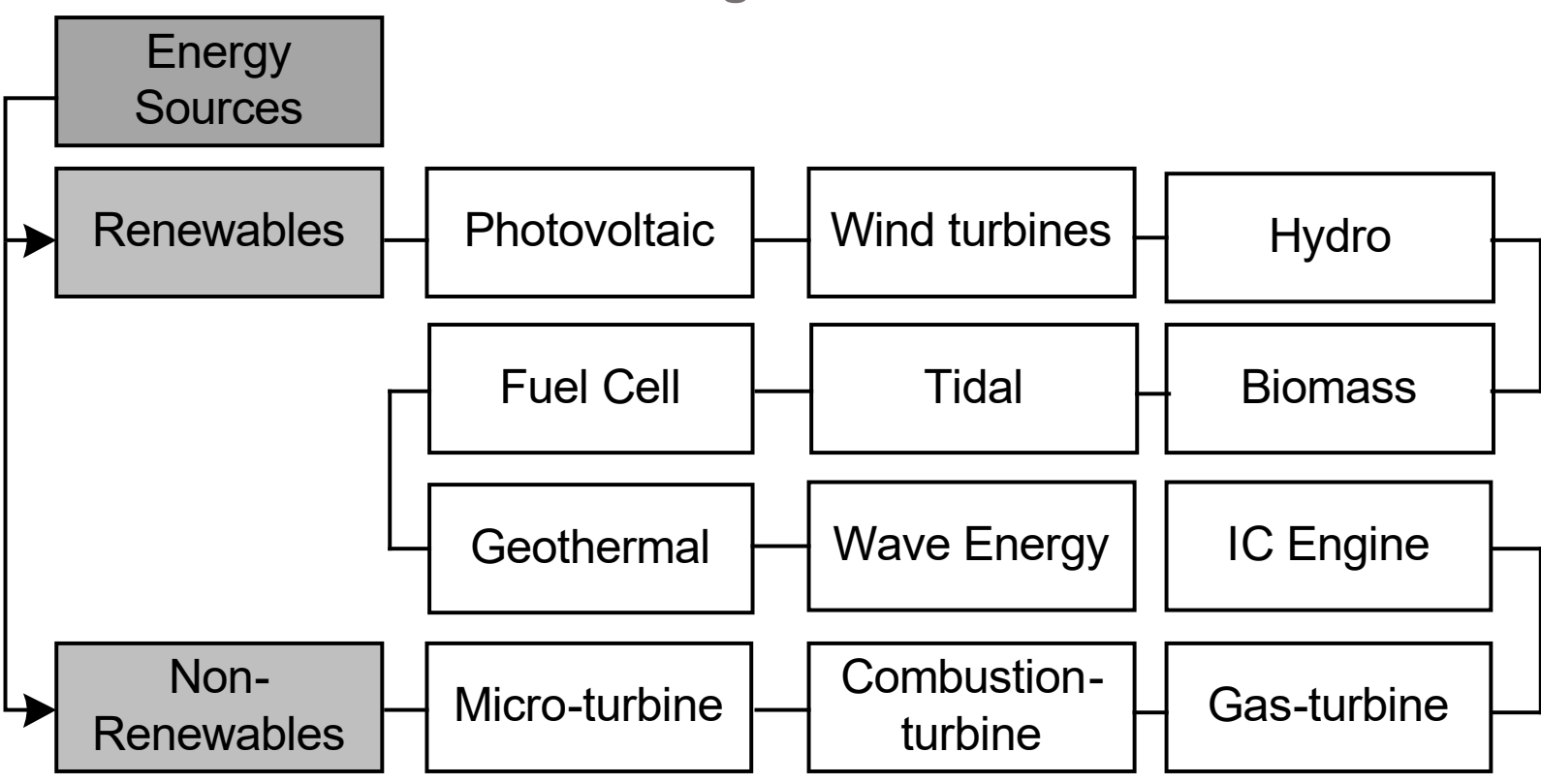


Figure 2

Energy storage is an integral part of microgrids, and has different technologies with unique strengths and weaknesses. Batteries offer flexibility and high energy density but may have durability and safety issues. Supercapacitors provide high power and a long lifespan but store less energy. Superconducting magnets and flywheels offer high power and almost unlimited lifespans but can be costly and have limited capacity. The choice depends on energy requirements, response speed, lifespan, and budget.

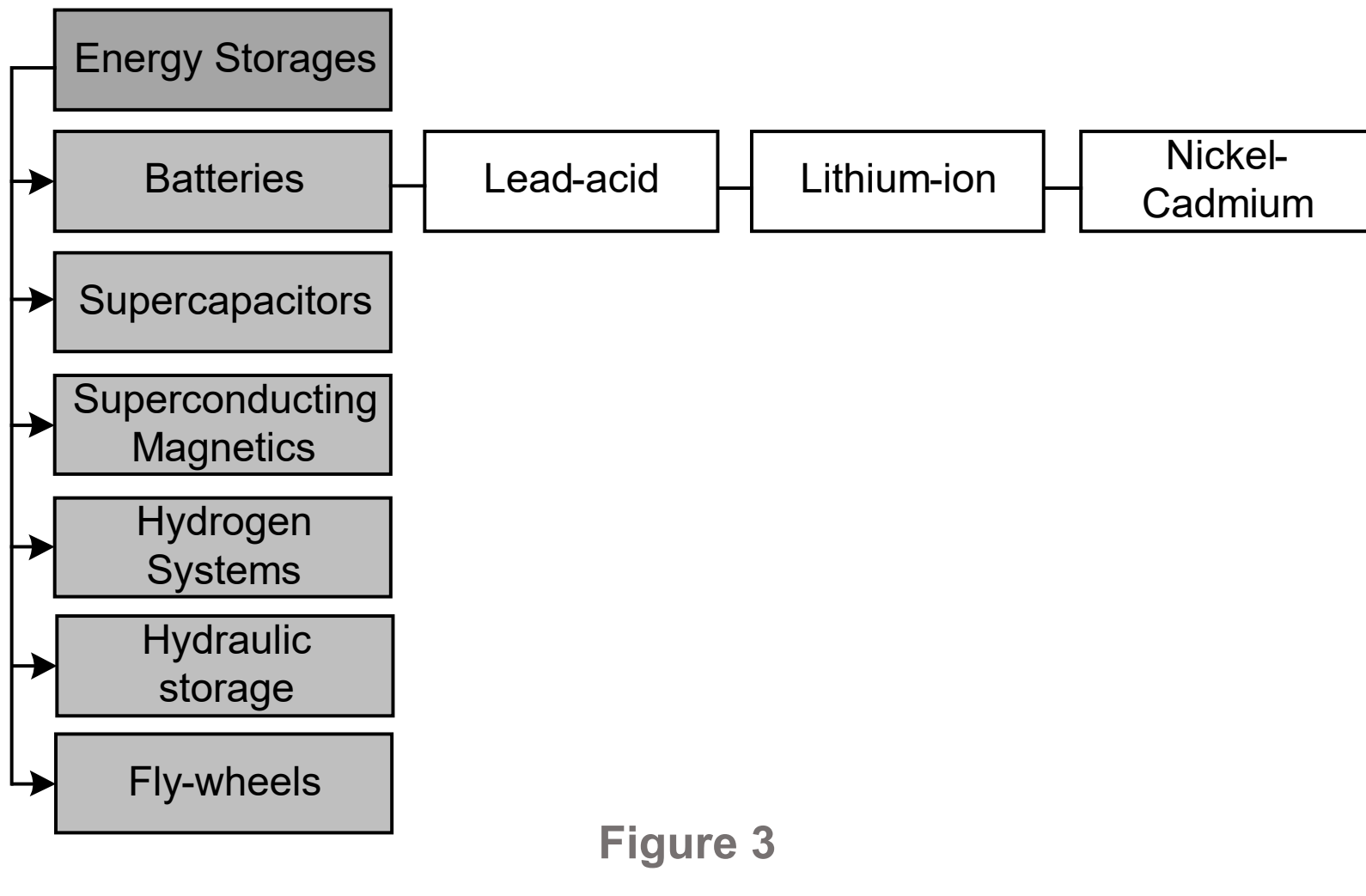


Figure 3

Categorizing loads by their energy carrier such as electrical or thermal nature, their type of power consumption like AC or DC operation, and variability involves understanding their energy usage patterns and operational needs. Loads may operate steadily or vary over time. This understanding is essential for designing and optimizing energy systems to enhance efficiency and reliability.

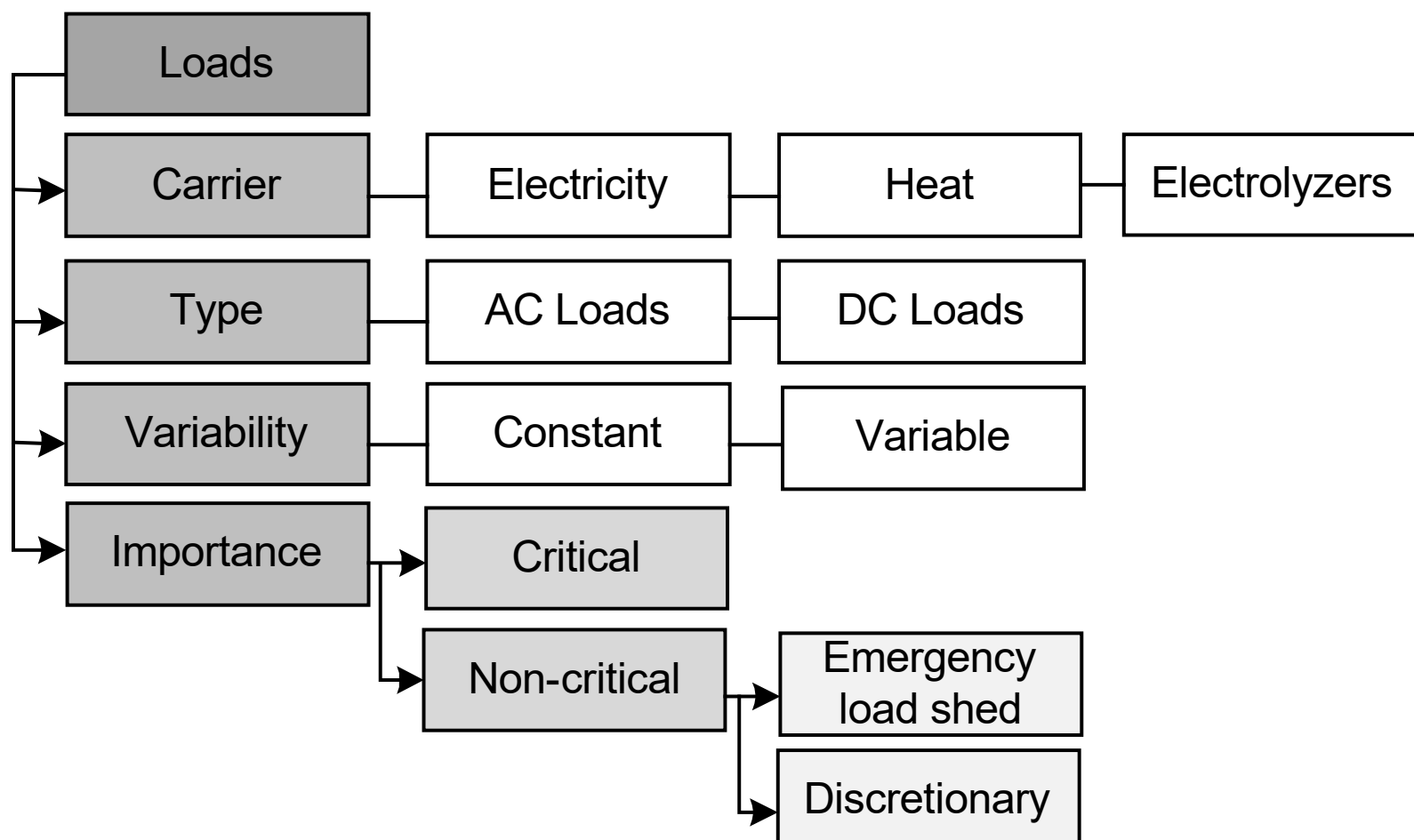


Figure 4

Various techniques are used in MGs sizing and energy managing. There is considerable interest in using multi-criteria methods to find optimal solutions for both MG design and synergic management. This highlights the need for comprehensive strategies that address multiple facets of MG operation. Generally, mathematical optimization offers precise solutions but needs help with scalability. Meta-heuristic algorithms provide efficient solutions but do not guarantee optimality.

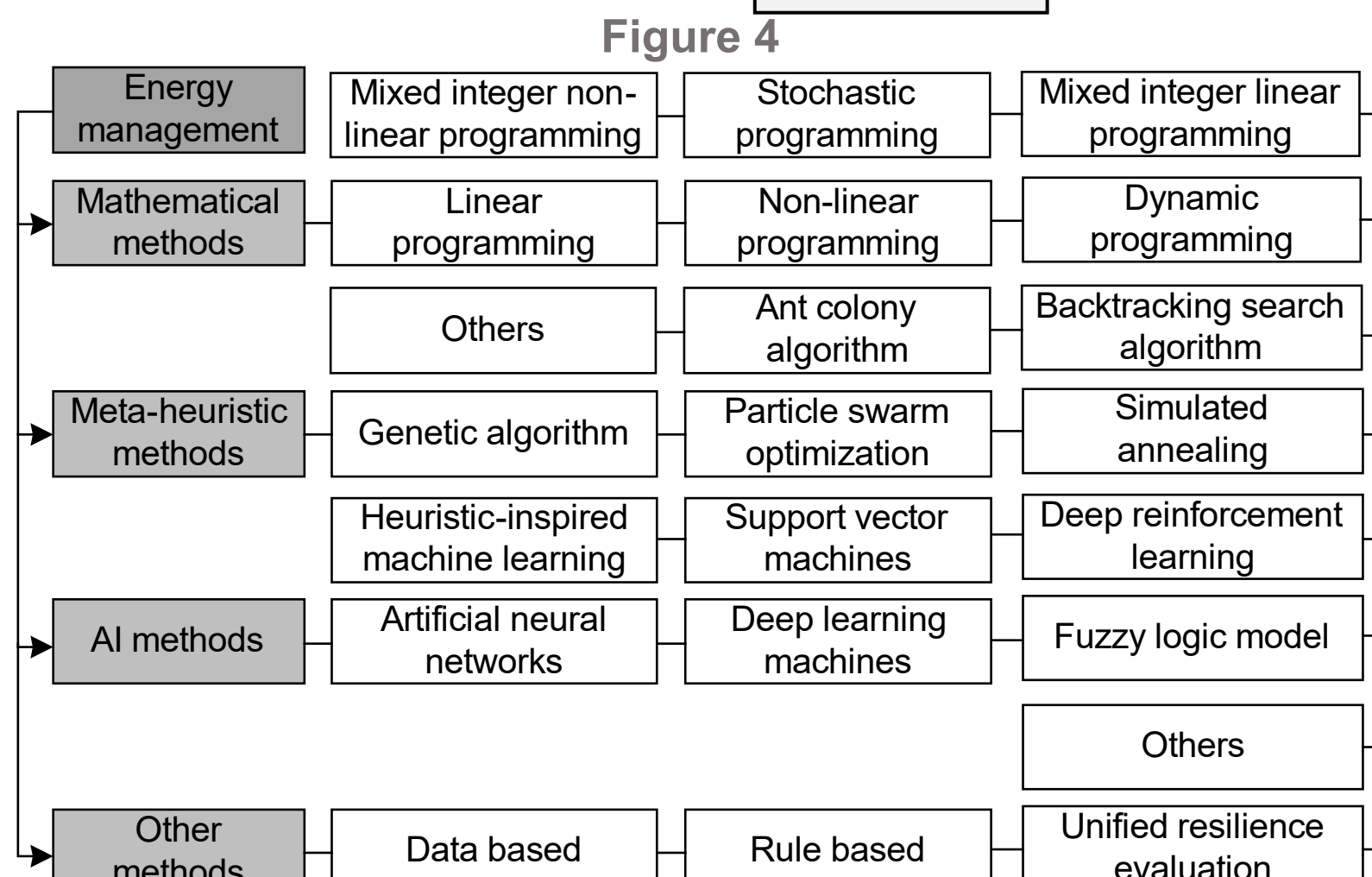


Figure 5

The literature on MGs explores a wide range of objectives. These can be studied both individually and collectively, sometimes focusing on a single objective, and other times on multiple objectives. Many studies aim to provide solutions to specific parts of the issue, often limited by simplified assumptions like focusing on a single goal or using deterministic inputs. Such objectives can include technical, power quality, economic, or environmental goals. However, this approach frequently overlooks other important objectives and aspects.

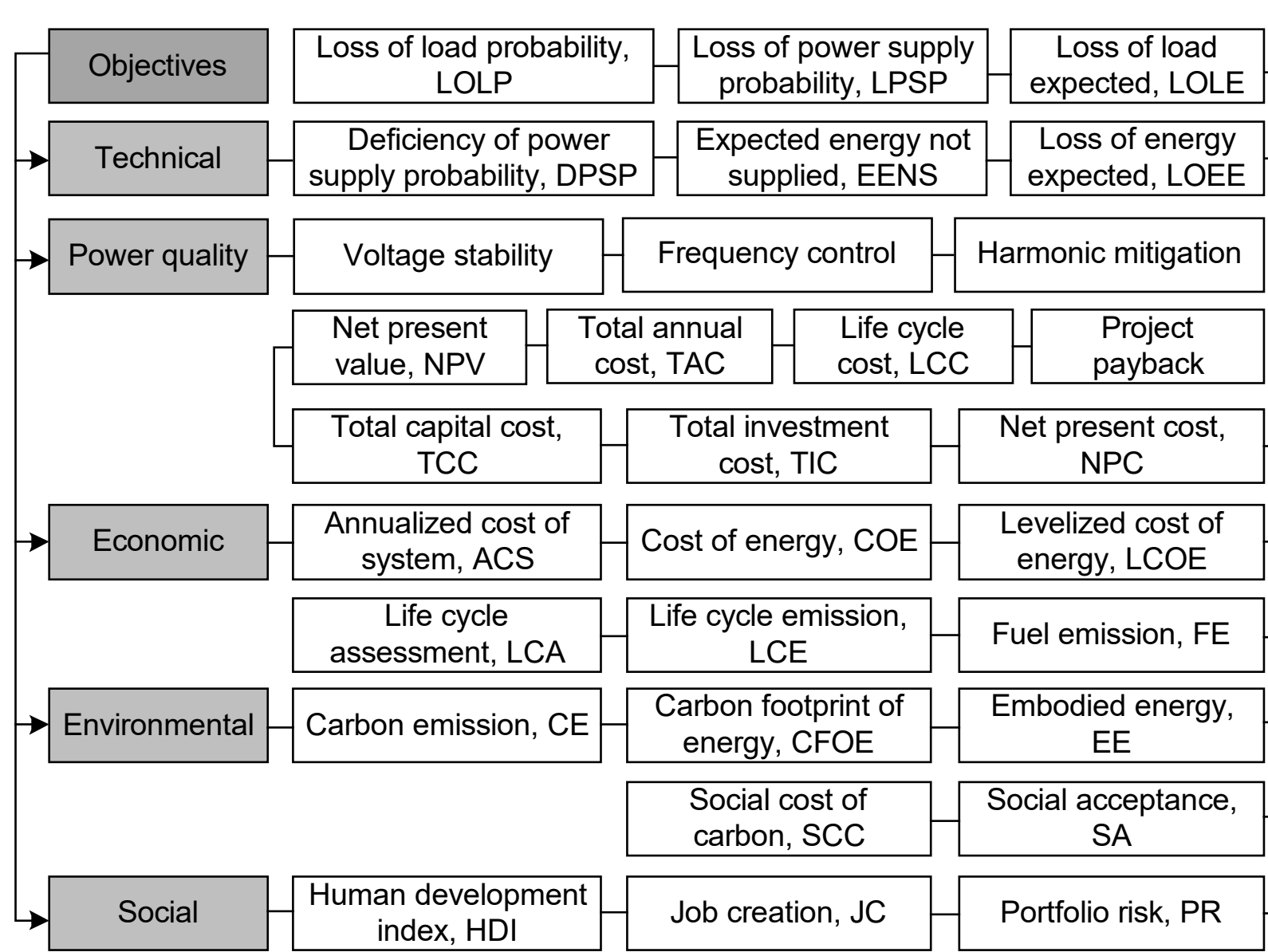


Figure 6

Constraints include limits on production, consumption, and infrastructure capacity and ensure efficient, stable, and cost-effective operation while meeting goals.

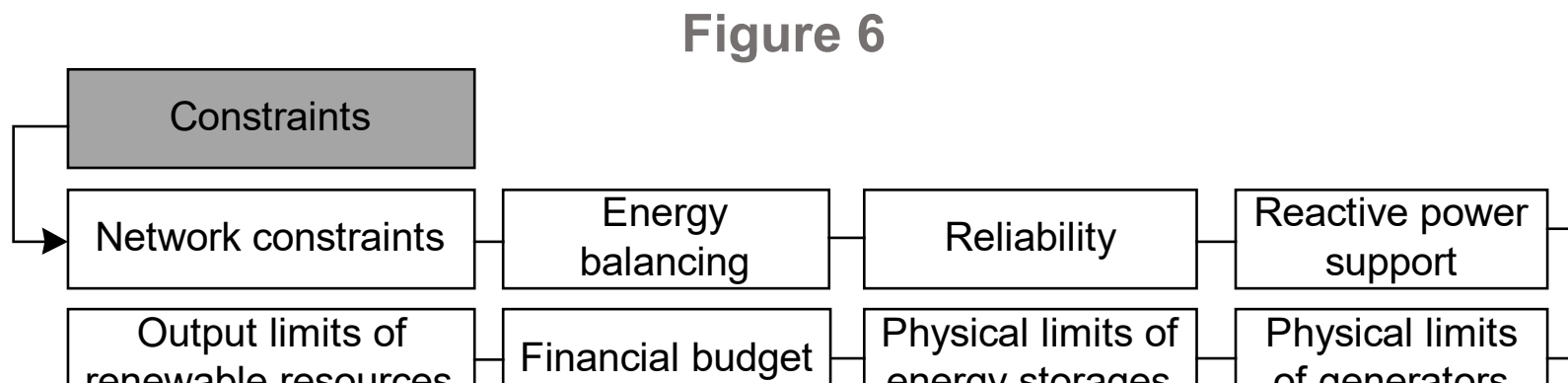


Figure 7

3. Case Study, Optimal Framework Selection

This study examines the feasibility of introducing a microgrid (MG) to meet the community's specific energy needs and improve electricity supply resilience, focusing on economic efficiency. The proposed MG is an on-grid, AC-coupled radial grid based on the existing energy consumption pattern for a medium-scale, mainly residential application (Figure 1). Given the region's ample solar and wind resources, the MG aims to leverage these renewable sources (Figure 2). To ensure continuous power supply during low renewable generation periods, lead-acid batteries are selected for their cost-effectiveness despite high initial costs (Figure 3). All load carriers in the rural area demand are AC power electricity, exhibit variable characteristics, are non-critical, and designated for residential use (Figure 4).

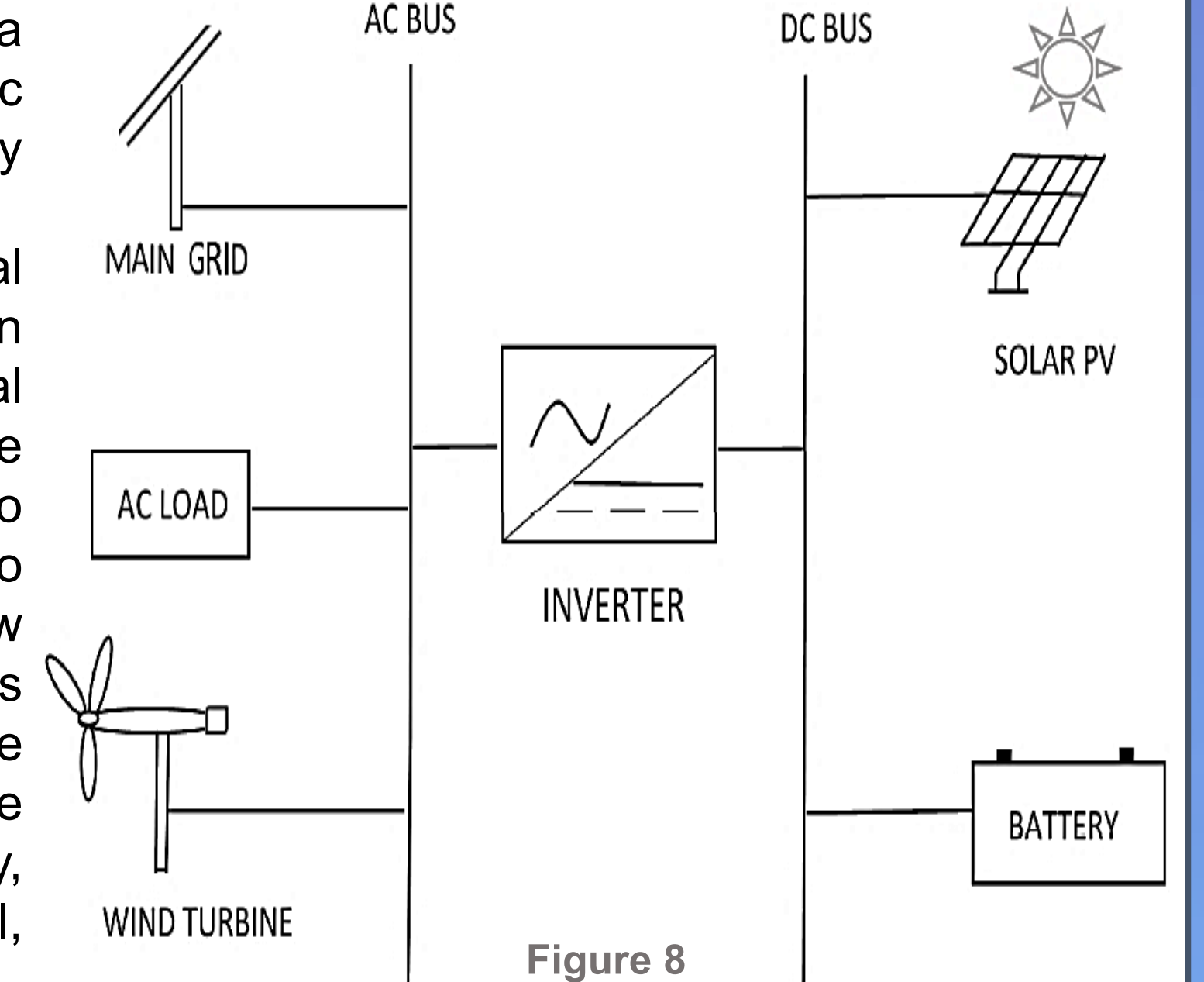


Figure 8

The goal is to design the system by sizing equipment based on geographical conditions and load demands, using heuristic optimization algorithms like PSO for its high exploration capability. An EMS, implemented through the PSO algorithm, achieves optimal performance at each time step with a rule-based system under a look-up table (Figure 5). The EMS information determines the optimal equipment sizing. Reliability is assessed using the deficiency of the power supply probability (DPSP) metric (Figure 6), and the system's total capital cost (TCC) is calculated over the project's lifespan (Figure 6). The algorithm aims to minimize TCC while keeping DPSP below a specified threshold to meet economic and reliability requirements (Figure 7).

Table I shows the optimal sizes of components and the related costs considering two different DPSP levels. It presents that the storage volume has been dramatically downsized by increasing DPSP from 0% to 10%. This reduction significantly decreases the system TCC, which is slightly dependent on the main grid. Compared to the first scenario, the second scenario shows a reduced renewable unit production and storage transaction volume while increasing network participation. The analysis of these scenarios can be used to obtain the optimal design. Table II summarizes the MG components energy values for both scenarios on a typical day using optimal sizes according to Table I.

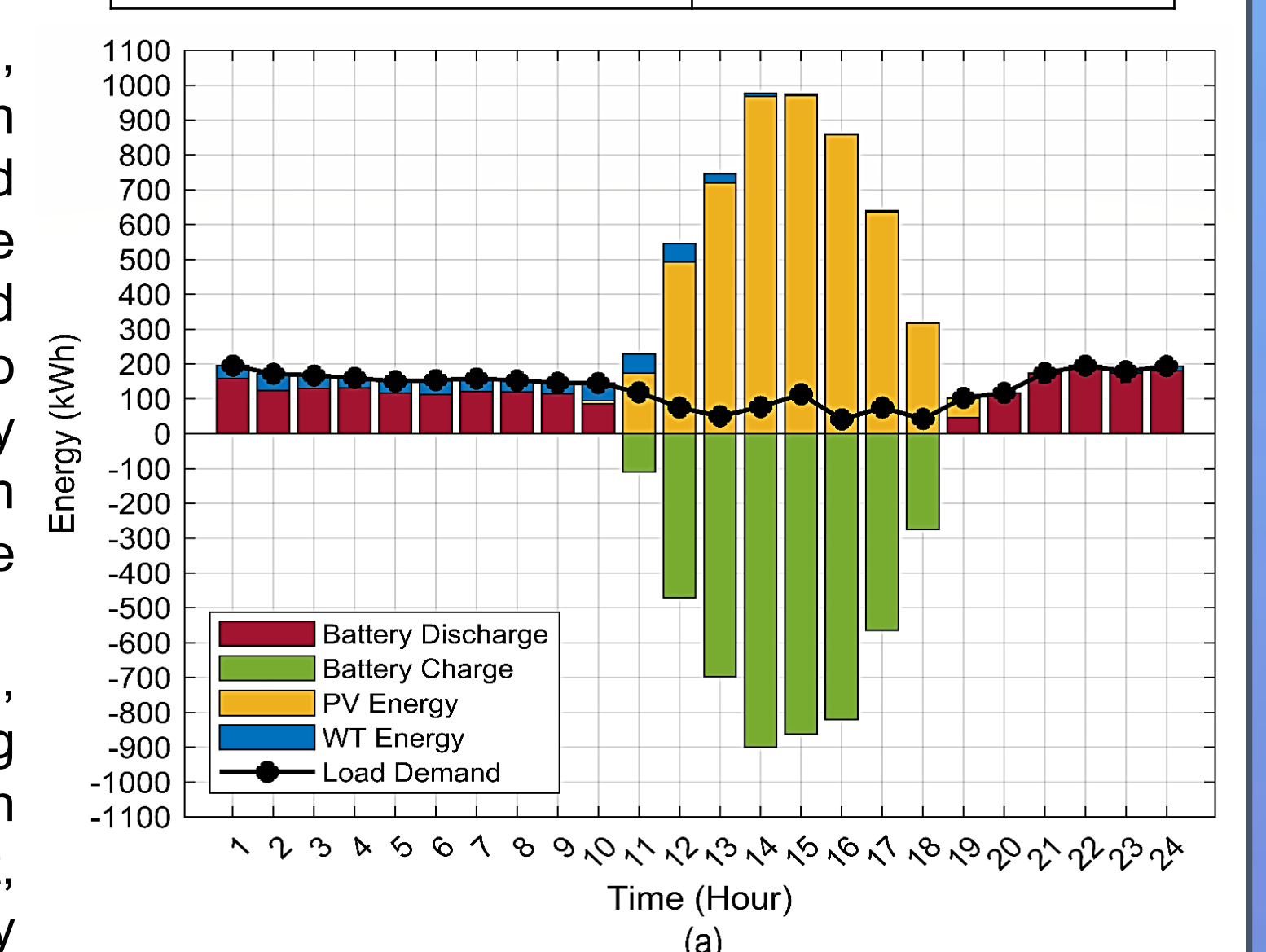
Scen.	1	2
DPSP (%)	0	0.1
A_{PV} (m ²)	17554	12912
A_{WT} (m ²)	2927	2366
$N_{Battery}$ (#)	46368	8528
MG Cost ($\times 10^6$ \$)	17.434	6.964
Grid Purchase ($\times 10^6$ \$)	0	0.754
TTC ($\times 10^6$ \$)	17.434	7.718

Scen.	1	2
PV (kWh)	5198.95	3824.14
WT (kWh)	558.86	451.75
Battery_Ch (kWh)	4697.64	3310.12
Battery_Disch (kWh)	2093.82	1334.30
Grid Supply (kWh)	0.00	853.93
Energy Demand (kWh)	3154	

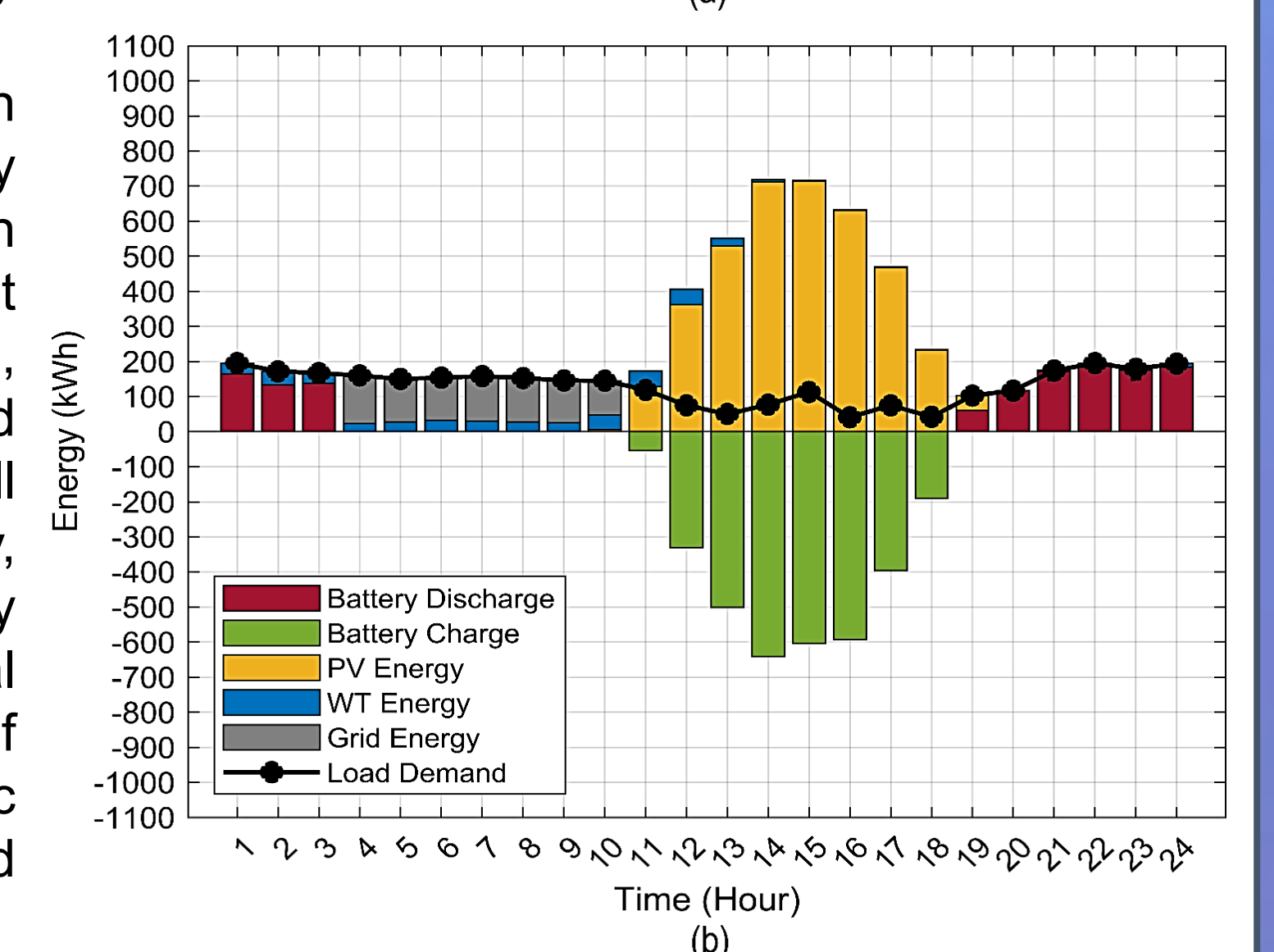
According to Table I, in the second scenario, compared to the first one, there is a reduction in the energy output of PVs and WTs, as indicated in Table II. However, with a significant decrease in the size of the storage unit, energy input and output to/from the battery have decreased. To better understand the scenarios, the hourly energy balance on a typical day is presented in Figure 9, for the first scenario, (a), and the second scenario, (b).

By dynamically adjusting system variables, PSO aims to minimize TCC while keeping DPSP below a set threshold. This approach enables efficient energy resource management, supporting sustainable and resilient energy solutions in response to evolving demands.

Further research and development in optimization techniques can significantly enhance energy management practices in MGs, promoting a sustainable and resilient energy future. Exploring advanced algorithms, integrating real-time data analytics, and leveraging innovative storage technologies will be crucial in achieving these goals. Additionally, collaboration between researchers, industry stakeholders, and policymakers will play a vital role in advancing the implementation of optimized MG systems, ensuring economic viability, environmental sustainability, and energy security for communities worldwide.



(a)



(b)

Figure 9

4. Conclusions

This research article has explored MG structures from various perspectives, mainly focusing on aspects of designing a MG. Following this examination, a comprehensive analysis of the differences between these structures was conducted, presenting the brief advantages and disadvantages of each. With an understanding of these structures, the most suitable framework for a case study was proposed. The targeted MG is situated in a specific location where, considering the geographical conditions, type, and magnitude of demand, the optimal arrangement of the MG, EMS, and optimization algorithm for elements sizing, along with technical and economic constraints and objectives, were investigated. While the extensive scope of the topics presented in the initial sections was not fully addressed in the MG study, future research endeavors will delve into extensive quantitative analyses of the targeted MG, further advancing our understanding in the field. Additionally, obtaining the global optimal design will be an exciting outcome in future works.

References:

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