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Hybrid Renewable Microgrid Design for a Public University Building: Technical, Economic, Environmental and Educational Assessment

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Abstract. This paper presents the design and assessment of a hybrid electrical and thermal microgrid for a public university building. The project aims to reduce the building's energy expenditure while simultaneously creating a full-scale learning infrastructure for students enrolled in the Renewable Energy Engineering degree.

Several microgrid configurations are evaluated, combining photovoltaic generation (PV), micro-wind power (WT), gas microturbine cogeneration (GM-CHP), battery storage (BES), and hydrogen storage technologies (HES). The methodology integrates technical modelling, economic analysis, and sustainability indicators to compare alternative hybridisation strategies. Results highlight the potential for significant reductions in energy costs and carbon emissions through optimised combinations of distributed generation and storage. In addition, the proposed microgrid provides substantial educational value by enabling access to real operational data, hands-on laboratory activities, and practical training in renewable energy and microgrid systems.

Key words. Microgrid, Renewable Energy, Hybrid Systems, Energy Storage, Cogeneration.

1. Introduction

The decarbonisation of the energy sector and the rapid increase in electricity prices have intensified the interest in distributed generation and microgrids as key enablers of the energy transition. Public buildings, and in particular university campuses, are especially relevant in this context as they typically exhibit large and relatively predictable energy demands and they are subject to public budget constraints.

Microgrids, understood as localised energy systems integrating distributed generation, storage and controllable loads, can operate both grid-connected and islanded, and are increasingly deployed in residential, commercial, industrial and institutional settings. Recent reviews [1], [2] highlight their potential to improve reliability, resilience, power quality and renewable energy utilisation, while enabling advanced energy management strategies and demand-side participation. In university campuses, microgrids have been proposed as "small-scale smart cities", combining renewable generation, energy storage, electric vehicle charging and digital control systems to minimise costs and emissions and to enhance the quality of supply.

Numerous studies have investigated the implementation of microgrids in university campuses, often with a focus on optimal sizing and techno-economic performance. [3] analyse a hybrid microgrid for an Indian university campus combining PV, WT, diesel generation and BES. They compare stand-alone and grid-connected configurations and show that a grid-connected PV–WT system can achieve a substantial reduction in the cost of energy with the optimised configuration reducing the electricity cost to about 20.5% of the current unit price.

[4] study a smart campus microgrid in Greece, consisting of PV generation and BES operated under a zero feed-in scheme. The system is designed to maximise on-site self-consumption while preventing exports to the grid, a strategy motivated by increasing PV penetration and grid congestion.

Beyond the campus context, many studies address the optimal design and techno-economic assessment of hybrid renewable energy systems for remote communities, residential buildings and rural electrification. [5] perform a comprehensive analysis of isolated microgrids combining PV, WT, HES and BES systems, optimised in HOMER. They show that configurations including multi-energy storage systems (BES-HES) can minimise both net present cost (NPC) and cost of energy (COE), while keeping unmet load and excess energy at low levels.

[6] assess microgrid hybrid renewable systems with HES and BES for Canadian residential buildings, exploring both off-grid and grid-connected configurations. Their results confirm that HES is generally more expensive than BES at present, but can confer advantages in long-term storage and emissions reduction.

[7] propose an advanced deep reinforcement learning based energy management system for microgrids with hybrid hydrogen–battery storage, where hydrogen

provides long-duration balancing and batteries handle fast dynamics.

[8] analyse a PV–biomass–BESS microgrid for rural electrification in Colombia. Their results indicate that coordinated operation, prioritising PV and scheduling biomass at peak times, can satisfy demand with overall efficiencies above 90%.

Overall, while existing studies offer valuable insights into optimising campus microgrids they remain focused almost exclusively on technical and economic optimisation, overlooking the pedagogical potential of these systems such as data accessibility, system modularity or relevance to engineering curricula. This study explicitly fills that gap, proposing a hybrid electrical–thermal microgrid where technical performance and academic utility are co-optimised to enhance the learning outcomes of future renewable energy engineers.

2. Base case study description

The university building considered in this work is a public higher-education facility located in Eibar, in the North of Spain that already hosts a 75 kWp rooftop PV installation (without grid sellback option). It offers a degree in Renewable Energy Engineering, closely aligned with topics such as microgrids, renewable generation and energy storage.

The electrical and thermal demand profiles of the building are presented in Fig. 1 and Fig. 2, respectively. The thermal demand, for which no direct measurements were available, was estimated based on recorded fuel oil consumption of the existing boiler. The total useful thermal energy was calculated from the delivered fuel volume using an assumed lower heating value of 43,2 MJ/kg and an overall boiler efficiency of 70%. This energy was then distributed over the year according to the building's operational schedule and outdoor temperature conditions, assuming that the heating system operates during occupied hours when the ambient temperature falls below a defined threshold. A temperature-dependent weighting function was applied to allocate the thermal load on an hourly basis, resulting in a representative demand profile consistent with both climatic conditions and building usage patterns.

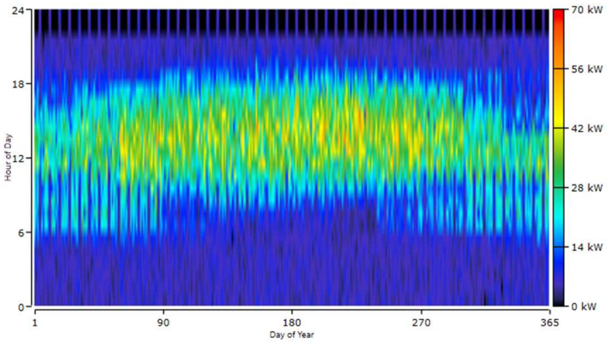

Fig. 1. Electrical demand.

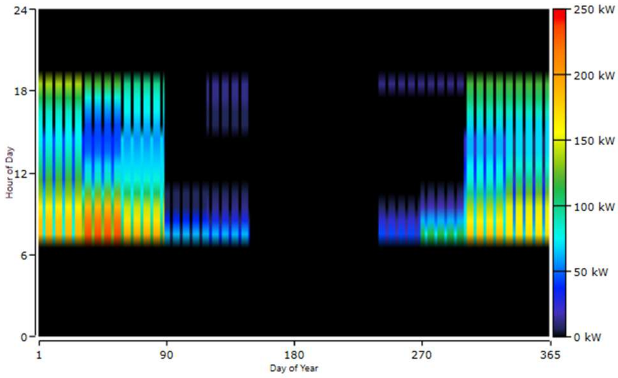

Fig. 2. Thermal demand.

The renewable energy resources available at the site, including solar irradiation and wind potential, are summarised in Table I.

Table I. Natural resources.

Month	Solar		Wind
	Clearness index	Daily radiation (kWh/m²/day)	Average speed (m/s)
Jan	0,438	1,620	6,100
Feb	0,468	2,400	5,960
Mar	0,523	3,770	5,540
Apr	0,515	4,830	5,320
May	0,530	5,800	4,490
Jun	0,543	6,300	4,030
Jul	0,561	6,310	3,840
Aug	0,559	5,550	3,870
Sep	0,550	4,360	4,320
Oct	0,496	2,840	5,300
Nov	0,437	1,750	6,050
Dec	0,413	1,350	6,180

3. Methodology

The methodological framework for this study combines empirical characterisation, multi-technology modelling and comparative performance assessment. First, the university building is defined through its energy behaviour, using historical electrical data and estimated thermal demand. These boundary conditions provide the basis for evaluating a set of hybrid microgrid options that include additional PV capacity, micro-wind generation, a gas microturbine operating in cogeneration mode, battery storage and hydrogen-based storage. Each technology is parameterised using validated manufacturer data and established models, capturing efficiencies, operating limits and—where relevant—electrical-thermal coupling.

All candidate configurations are simulated for 25 years with hourly resolution, using the irradiance, wind speed and load profiles to represent seasonal and diurnal variability. A supervisory rule-based controller manages energy flows by prioritising renewable self-consumption, dispatching cogeneration to follow thermal demand and operating storage systems to minimise imports from the grid. For every configuration, key indicators —CO_2 emissions, Levelized Cost of Energy (LCOE), Net Present Cost (NPC), etc.— are computed, enabling a comparative techno-economic and environmental evaluation.

In parallel with these technical assessments, the methodology incorporates an explicit educational dimension. Microgrid alternatives are not only evaluated for their performance but also for their suitability as a full-scale teaching and research infrastructure for the university's Renewable Energy Engineering degree. Criteria such as data accessibility, system modularity and safe controllability are therefore considered alongside economic and sustainability metrics, ensuring that the selected configuration functions both as a cost-effective energy solution and as a high-value academic demonstrator.

4. Results

A set of simulation scenarios was defined to evaluate different configurations of the microgrid and assess the impact of integrating additional technologies into the existing system. All simulations were carried out over a project lifetime of 25 years. In all cases, electricity export to the grid was not allowed, and any excess generation was curtailed if it could not be locally consumed or stored.

The base case represents the current energy system of the university building. It includes the existing 75 kWp rooftop photovoltaic installation, which is assumed to be fully amortised and therefore excluded from the investment cost calculations. The building remains connected to the electrical grid under a fixed tariff scheme, with an electricity price of 0.12 €/kWh. The thermal demand is entirely supplied by an existing diesel-fired boiler, with a fuel cost of 0.7 €/L.

In Case 1, the photovoltaic capacity is increased beyond the existing installation. Additional PV capacity is considered with a capital cost of 750 €/kW, allowing the optimisation tool to determine the most suitable level of expansion within the defined search space.

Case 2 introduces an electrical energy storage system based on lithium-ion batteries. The system includes battery capacity with a capital cost of 200 €/kWh and an associated converter with a cost of 100 €/kW. This configuration enables energy storage and discharge within the microgrid.

In Case 3, a gas microturbine operating in combined heat and power (CHP) mode is added to the system. The microturbine is fuelled by natural gas with a price of 0.045 €/kWh, and is characterised by a capital cost of 1,800 €/kW and a heat recovery ratio of 50%. The recovered thermal energy is used to partially satisfy the building's thermal demand, reducing the reliance on the existing diesel boiler.

Case 4 combines the technologies introduced in previous scenarios by integrating both the gas microturbine in CHP mode and the battery storage system. The same cost assumptions as in Cases 2 and 3 are applied, enabling increased operational flexibility by coupling dispatchable generation with electrical storage.

In Case 5, a hydrogen-based energy storage system is incorporated. This includes an electrolyser with a capital cost of 900 €/kW, a fuel cell with a capital cost of 1,500 €/kW, and a hydrogen storage tank with a cost of 1,000 €/kg. The system enables the conversion of excess electrical energy into hydrogen and its later reconversion into electricity.

Finally, Case 6 considers the addition of a small-scale wind turbine to the system, with a capital cost of 5,000 €/kW. The wind generation system is evaluated as a complementary renewable energy source alongside the existing photovoltaic installation.

In Table II the simulation results are presented.

Table II. Simulation result.

	Base case	Case 1	Case 3	Caso 4
Total NPC (€)	509.215,00	508.880,1	417.171,9	414.088
LCOE (€)	0,04177	0,04008	0,01764	0,0165
Grid purchase (kWh/yr)-(%)	59.383 – 34,8	57.350 – 32,3	5.088 – 2,89	2.428 – 1,45
PV (kWp)	75	80,9	75	73,2
PV (kWh/yr) -(%)	111.222 – 65,2	120.018 – 67,7	111.237 – 63,3	108.605 – 64,7
Batteries (kWh)	-	-	-	141
Converter (kW)	-	-	-	23,3
GMT (kW)	-	-	20	30
GMT electricity (kWh/yr)-(%)	-	-	59.437 – 33,8	56.757 – 33,8
GMT thermal (kWh/yr)-(%)	-	-	78.367 – 32,8	65.845 – 31,7
Gasoil boiler (kWh/yr)-(%)	187.610 - 100	187.610 - 100	160.345 – 67,2	142.117 – 68,3
Gasoil consumption (L/yr)	26.909	26.909	22.998	20.384
Natural gas consumption (m^3/yr)	-	-	21.891	19.083
Emissions (CO2 kg/yr)	75.176	74.111	104.023	91.335

5. Discussion

The simulation results highlight the impact of integrating different technologies into the microgrid, revealing significant trade-offs between economic performance and environmental impact.

The base case reflects the current configuration of the building, where the existing photovoltaic installation contributes to reducing electricity costs, while the thermal demand is entirely covered by a diesel boiler. As a result, although the system benefits from relatively low electricity costs, it exhibits considerable CO_2 emissions due to the use of diesel for heating.

In Case 1, the expansion of the photovoltaic capacity leads to only marginal improvements in both economic and environmental performance. This behaviour can be explained by the already high penetration of photovoltaic generation in the base case, which limits the additional benefits that can be obtained from further PV installation. As a consequence, the optimisation favours only a slight increase in installed capacity.

Case 2 introduces battery storage; however, the results indicate that this technology is not economically attractive under the current conditions. This is mainly due to the strong temporal correlation between photovoltaic generation and the building's electricity demand, which reduces the need for energy shifting. In addition, the absence of time-of-use electricity pricing and the inability to export excess energy to the grid further limit the potential value of storage. Consequently, battery integration does not significantly improve the overall system performance from an economic perspective. The results further suggest that battery storage would only become economically viable if the flat electricity tariff increased, with profitability emerging from approximately 0.16 €/kWh onwards, or if the building were subject to a time-of-use tariff structure. Nevertheless, although battery storage is not justified on economic grounds under the current assumptions, it remains of clear academic interest, as it would provide a valuable real-scale platform for teaching, experimentation and the analysis of storage operation strategies.

The introduction of a gas microturbine operating in CHP mode in Case 3 results in a substantial reduction in the Net Present Cost. This is primarily due to the lower cost of natural gas compared to grid electricity and diesel, as well as the efficient utilisation of waste heat to meet part of the thermal demand. However, this economic benefit is accompanied by a significant increase in CO_2 emissions. This is explained by the relatively low carbon intensity of the Spanish electricity mix, which makes grid electricity cleaner than locally generated electricity from natural gas. Therefore, the increased reliance on gas-based generation leads to higher overall emissions despite improved efficiency. Furthermore, this configuration represents an academically valuable option, as it provides a suitable real-world framework for the study and analysis of combined heat and power systems.

Case 4 combines the microturbine with battery storage, resulting in a slight additional reduction in costs and a decrease in emissions compared to Case 3. The presence of storage enhances the operational flexibility of the system, allowing for a more efficient use of both the microturbine and the renewable generation. Nevertheless, the system remains largely dependent on natural gas, and therefore emissions remain higher than in the base case.

In Case 5, the integration of a hydrogen-based storage system does not lead to economically favourable results. The high capital cost of the electrolyser, fuel cell and hydrogen storage tank, combined with the relatively low round-trip efficiency of the hydrogen pathway, limits its competitiveness. As a result, this technology is not selected as an optimal solution under the analysed conditions.

Finally, Case 6 considers the addition of small-scale wind generation. The results indicate that this option is not economically justified, mainly due to the high specific investment cost associated with small wind turbines. Furthermore, the existing photovoltaic system already provides a significant share of renewable electricity, reducing the marginal benefit of introducing an additional renewable source. From an academic perspective, this option is also less compelling, since the Renewable Energy Engineering degree already has access to small-scale wind prototypes and wind tunnel facilities for student experimentation and measurement activities.

6. Conclusions and future work

The results of this study demonstrate that the design of a microgrid for a public university building involves a clear trade-off between economic performance, environmental impact and educational value. While several technological configurations were analysed, not all of them proved to be suitable under the specific conditions of the case study.

Among the analysed scenarios, Cases 1 and 4 emerge as the most relevant alternatives. Case 1, based on the expansion of photovoltaic capacity, presents a very low initial investment requirement and maintains low CO_2 emissions. Although the economic improvement compared to the base case is limited, this solution is particularly attractive from both an economic and environmental perspective, as it builds upon an already efficient renewable generation system without introducing additional operational complexity.

Case 4, which combines a gas microturbine operating in CHP mode with battery storage, achieves the lowest Net Present Cost among the analysed scenarios. This configuration integrates multiple technologies, including dispatchable generation and energy storage, making it especially valuable from an academic perspective, as it provides a comprehensive real-scale platform for the study of microgrid operation and control. However, this solution also presents several drawbacks. The initial investment cost is significantly higher, CO_2 emissions are increased compared to the base case and PV-only scenarios, and the overall system complexity leads to higher expected maintenance requirements.

The remaining cases present more limited interest under the analysed conditions. Battery storage alone is not economically viable due to the alignment between photovoltaic generation and electricity demand, as well as the absence of time-of-use pricing and energy export options. Similarly, the hydrogen-based storage system is penalised by its high capital cost and relatively low round-trip efficiency. Finally, the addition of small-scale wind generation is not justified either economically or academically, given both its high specific cost and the existing availability of wind-related laboratory infrastructure within the academic programme.

A key contribution of this work is the explicit consideration of the academic dimension in the design of the microgrid, which is often overlooked in conventional techno-economic studies. In the context of a higher education institution, the microgrid is not only an energy system but also a teaching and research infrastructure. The integration of multiple technologies provides added academic value through access to real operational data, hands-on experimentation opportunities and direct integration into the curriculum. Furthermore, it enables new possibilities for research activities, internships and final-year projects, thereby enhancing the educational impact of the installation.

However, this approach also introduces additional challenges. The integration of multiple technologies increases system complexity, requiring more advanced control strategies and higher maintenance efforts. Moreover, regulatory constraints and administrative barriers may limit the implementation and operation of certain technologies, particularly in grid-connected environments. These aspects must be carefully considered when designing microgrids for educational institutions.

Overall, the study highlights the importance of balancing economic, environmental and academic objectives when designing microgrids for public buildings. Future work should focus on refining the modelling assumptions and exploring additional operational strategies. In particular, the impact of time-of-use electricity tariffs, demand-side management and dynamic control strategies should be analysed in order to better assess the potential value of storage technologies. Furthermore, more detailed modelling of thermal demand and seasonal effects could improve the representation of CHP systems. Finally, the inclusion of advanced control systems and real-time monitoring would enhance the educational value of the proposed microgrid, allowing students to interact with and analyse a real operational system.

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