University of Piraeus

Department of Industrial Management & Technology

An integrated analysis of Hybrid Energy Systems for decarbonization of off-grid Islands based on life cycle thinking

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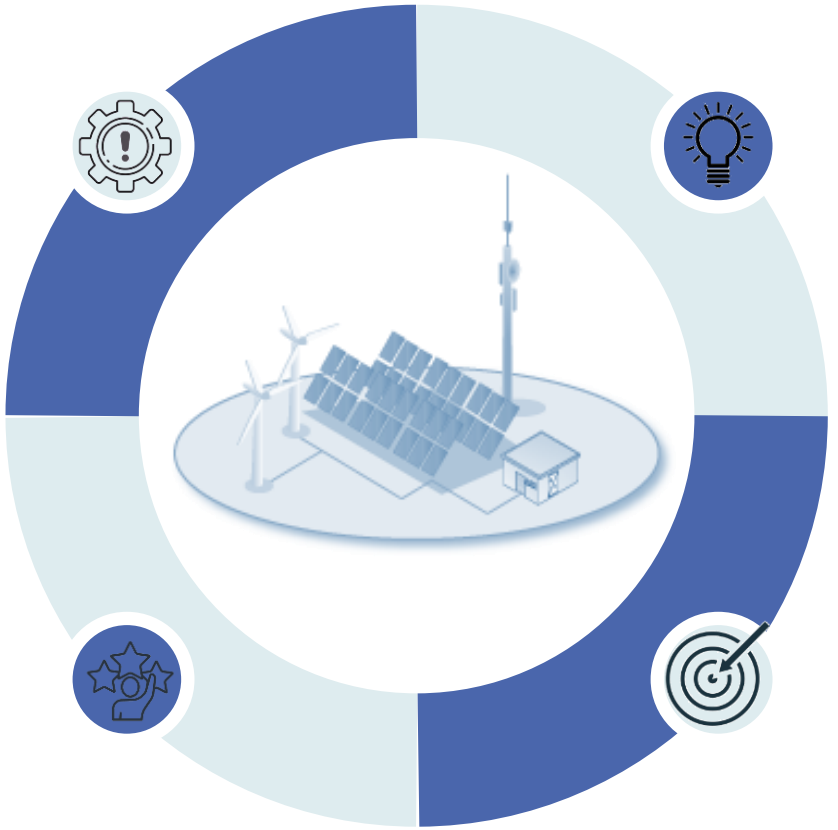
Introduction

Issue

The electric power generation industry is one of the largest contributors to climate change at a European level, due to its large dependence on conventional fossil fuels (lignite, oil, and natural gas)

Motivation

Necessity to scale-up renewable energy technologies in isolated communities (remote islands and areas) for the decarbonization of the electricity sector



Solution

- Deployment of hybrid power systems that integrate wind turbine, photovoltaic (PV) solar technology, and/or diesel generators, with or without storage energy systems, could be a promising, cost-competitive solution for off-grid Islands

Objective

- Optimal design and an economic and an environmental performance assessment of an autonomous hybrid electricity supply system for application in the isolated Lesvos Island, in the North-eastern Aegean Sea, Greece.

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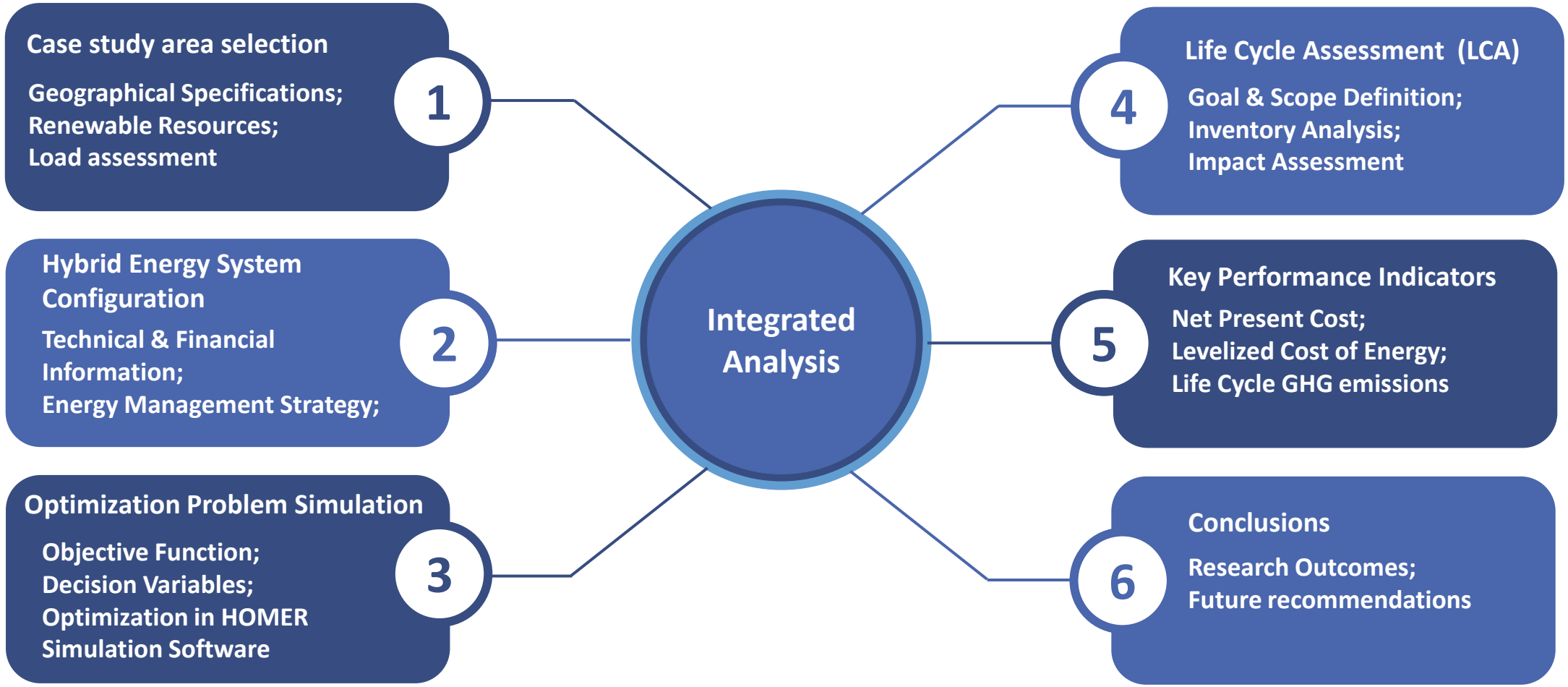
Methodological framework of the present study



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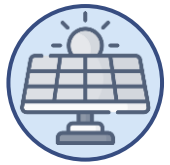
Study Area & Local Data Description

Lesvos Island: Representative case study for investigating future perspectives of large autonomous electricity generation systems in remote Greek Islands

- The 3rd largest island in Greece / Located in North-Eastern Aegean Sea;
- Lesvos has an autonomous electrical system; it relies highly on diesel electricity generation plants;
- Annual electricity demand 300.27 GWh

21 % RES penetration



Annual daily average of the solar global radiation 4.62 kWh/m^2/day

Annual average wind speed 6.68 m/s

Levelized Cost of Energy (LCOE) 0.161 €/kWh (Ref. year 2023)

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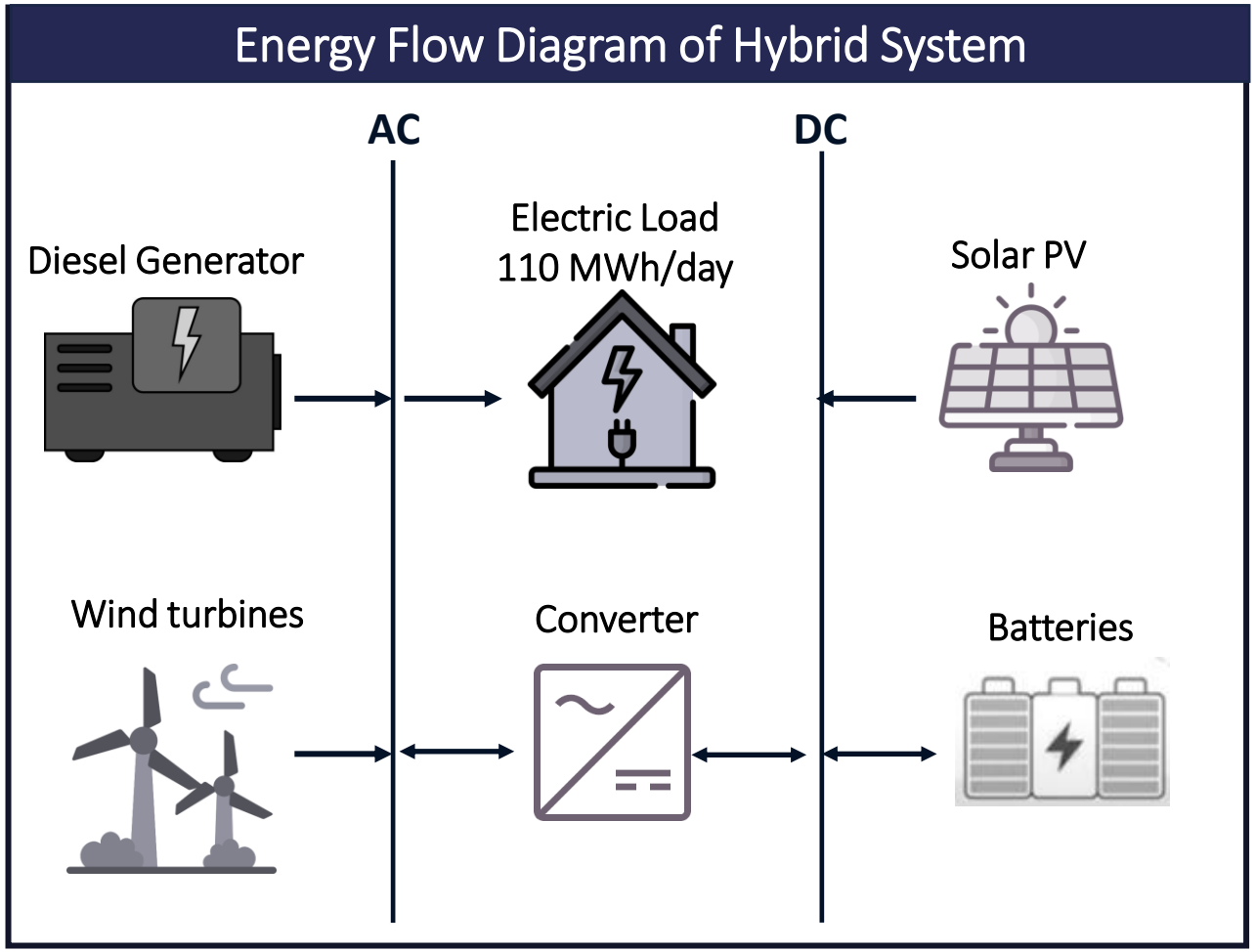
Hybrid Energy System Development

1. Solar PV arrays, wind turbines & diesel generators are considered as energy resources

2. Converter & batteries are considered to maintain the energy flow between DC and AC electrical components and energy storage, respectively.

3. Load Following Dispatch Strategy:
   - Never charge battery with the diesel generator;
   - Charging Batteries is left to RES;
   - High-RES penetration systems



Each component has been selected considering Greek market availability, satisfactory performance, and reliability aspects as well as retail price.

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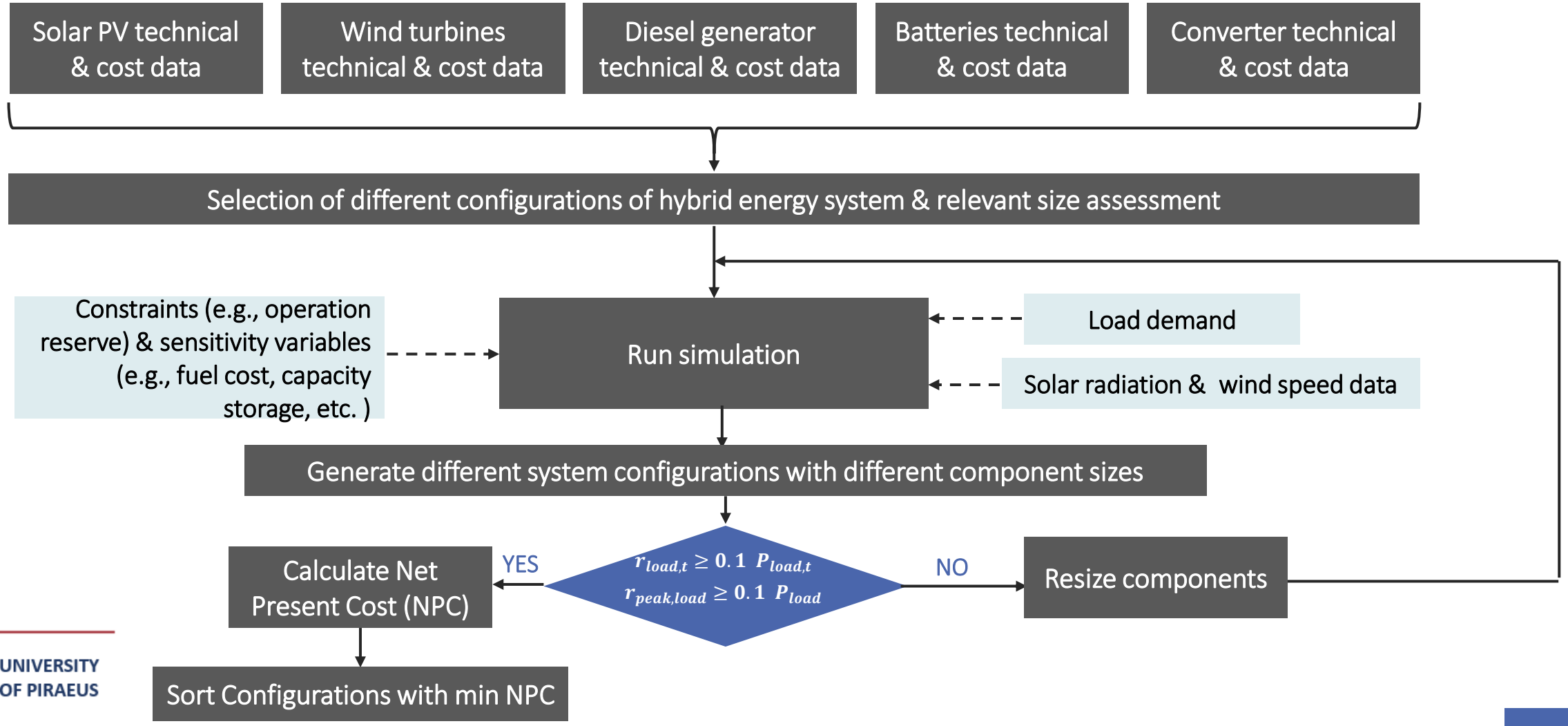
Optimal Design and Economic Performance Assessment

Application of Hybrid Optimization Model for Electric Renewables (HOMER) Simulation Software to evaluate the technical and economic feasibility of different design options and display all possible system configurations in ascending Net Present Cost (NPC) order



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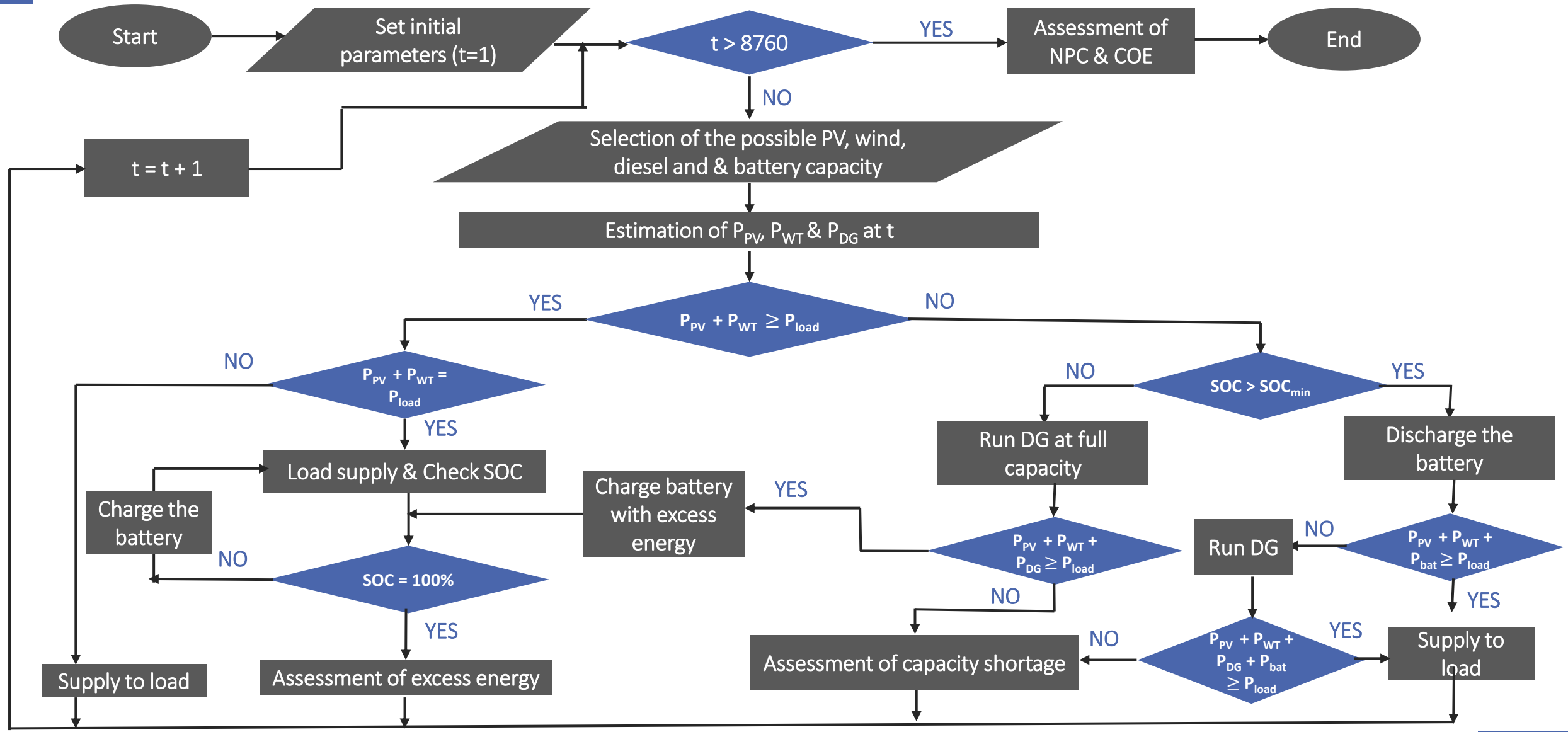
Flow Chart of Load Following Dispatch Strategy

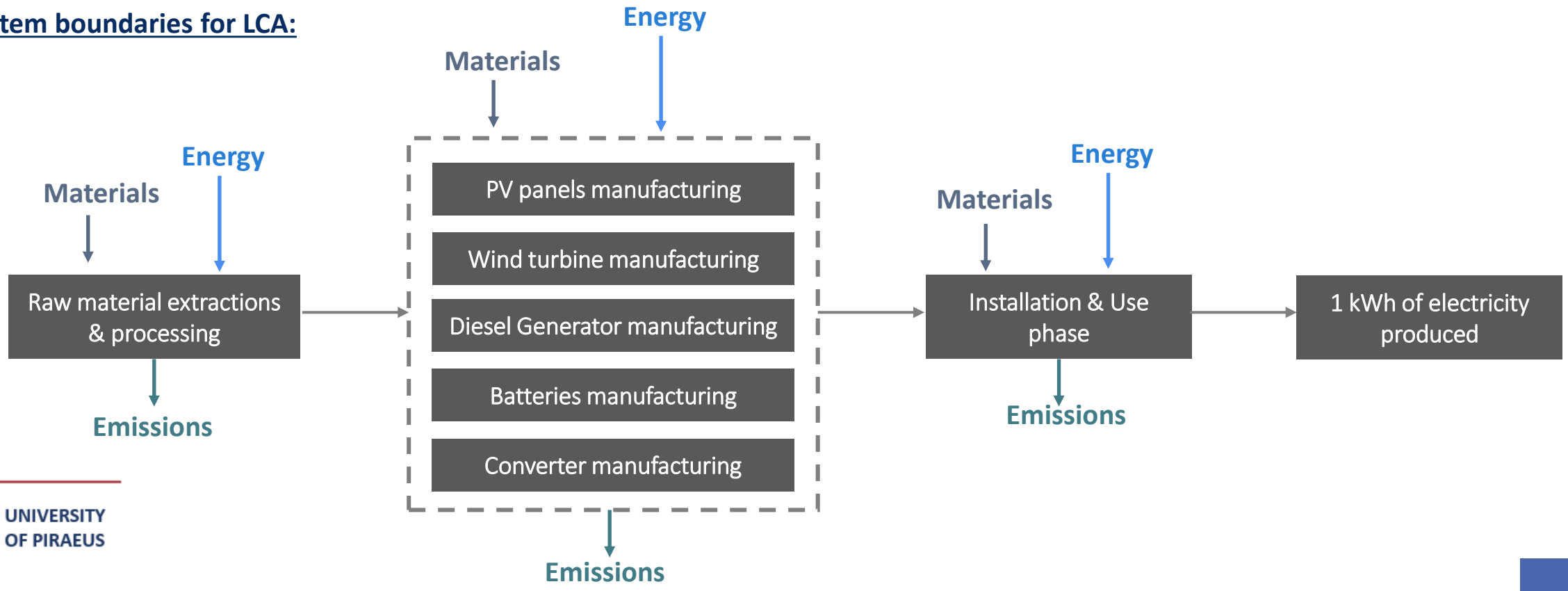


Life Cycle Assessment (LCA) of optimal hybrid power system

LCA is an environmental system analysis tool based on ISO 14040-14044 Standards that "provides" a systematic framework to identify, quantify, interpret and evaluate the environmental impacts of a product, function or service from original sources to final disposal.

By applying LCA in the electricity sector, energy providers can gain invaluable insights into the environmental implications of the relevant power generation technologies, facilitating strategic planning towards electricity sector decarbonization

System boundaries for LCA:



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Integrated Analysis Results

System simulations were performed assuming an annual interest rate of 8% and project lifetime of 25 years

Energy Modelling

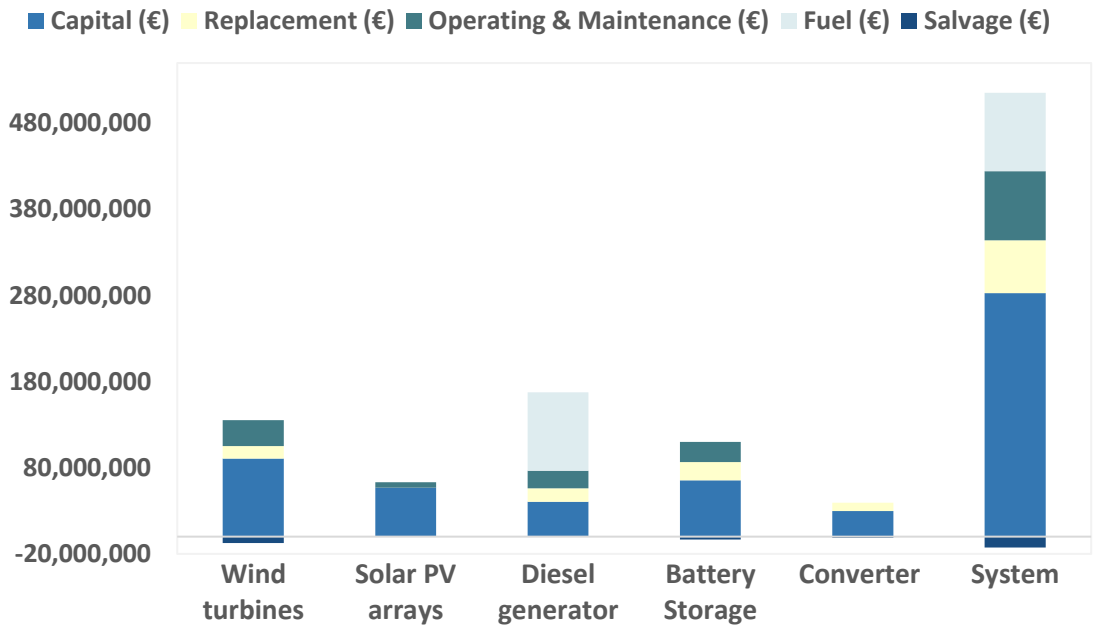
- 66.98 MW of PV arrays & 72.80 MW of wind turbines;
- 80 MW sized diesel generators;
- 250 MWh battery energy storage;
- 89.8 % share of RES
- 6.6% diesel contribution

Economic Analysis

- NPC: 502,459,400 €
- COE: 0.153 €/kWh
- The major chunk of the total NPC accounts for the diesel generator, due to its high fuel and O&M cost

LCA Modelling

- The estimated total GWP100 for 1 kWh of electricity generated using the IMPACT World+ Method amounts to 116 gCO_{2eq} / kWh;
- Diesel generators are the most important contributors to the GHG impact, followed by the batteries.
- Lower GHG emissions, about 1154 gr-CO2eq/kWh, compared to conventional stand-alone diesel power generation units.



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Conclusions

- Many options for the configuration of hybrid system → Depend on load, available resources and costs
- Hybrid wind/PV/diesel/battery power systems offer market entry strategies for technologies that are not currently cost competitive with diesel-only based power generation systems.
- The LCOE value for the proposed hybrid system is estimated at 0.153 €/kWh for the Lesvos Island. For the most adverse scenario (the diesel oil price and the electricity demand are increased by 20% & the solar global radiation and the wind speed are increased by 20%, the LCOE is increased at 0.190 €/kWh.
- The perspectives of the existing local autonomous systems of Greek Islands for sustainable improvement are very promising (> 89.8 % RES contribution into the already existing power system in case of Lesvos)
- From an environmental perspective, the proposed hybrid system results to lower GHG emissions, about 1154 gr-CO_{2eq}/kWh, compared to conventional stand-alone diesel power generation units
- Further research effort to address the design & optimization of an autonomous hybrid power system capable of meeting the electricity and thermal energy requirements of off-grid islands simultaneously.

Thank you for your attention!

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