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Life Cycle GHG emissions assessment of hybrid power systems for off-grid electrification of remote islands

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ABSTRACT

The electricity sector is one of the highest contributors to global warming and air pollution both at an international and a European level. Numerous published studies (e.g., McCallum et al., 2021; Orfanos et al., 2019; Stenzel et al., 2018; Turconi et al., 2013) have been devoted to address the adverse environmental impacts from electricity generation, with specific emphasis on suggesting climate change mitigation measures / strategies for the electricity sector. Among several initiatives targeted to environmental preservation and Greenhouse Gas (GHG) emission reduction, the increase of renewable energy penetration in electricity generation presents a promising, sustainable, and cost-competitive solution, especially for certain remote and rural areas, whose primary supply is based on cost-ineffective diesel power generation.

Motivated by the necessity to scale-up renewable energy technologies in isolated communities (remote islands and areas) for the decarbonization of the electricity sector, this study intends to provide a comprehensive GHG performance assessment, based on the life cycle thinking, of off-grid/stand-alone hybrid renewable energy-based electricity supply systems for application in three isolated Islands, namely, Lesvos, Karpathos and Astypalaia, in the Aegean Sea, Greece. All three Islands are characterized by abundant wind and solar energy potential, but high dependence on diesel fuel and heavy oil imports to cover their local requirements. The main contribution of this paper is that investigates how different autonomous hybrid structures/scenarios, that integrate wind turbines, solar energy conversion units and storage technologies, with back up diesel generators, could reduce the GHG impact for small to medium and large scale isolated, off-grid islands. The suggested life cycle GHG emission calculation methodology follows the ISO 14040-14044 Standards for Life Cycle Assessment (LCA) (International Organization for Standardization, 2004; International Organization for Standardization 14044, 2007). The climate change impact indicator is selected to be quantified, since the GHG reduction targets are of significant focus of the European polices. The adapted methodology connects all resources, material & energy flows involved during the production and use

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of the hybrid generating systems from a ‘cradle-to-gate’ perspective, i.e., from the production and operation of the hybrid systems.

It was found that hybrid wind/PV/diesel/battery power systems that operate under the load following dispatch strategy, i.e., the diesel generator is called upon only to produce the amount of power that is required to meet excessive load demands, exhibit the lowest life cycle GHG emissions, estimated at 0.134 €/kWh, 0.112 €/kWh and 0.268 €/kWh for the Islands of Lesvos, Karpathos and Astypalaia, respectively. For all the investigated Islands, alternatives that emphasize on wind power generation are more efficient than the relevant ones focusing on solar PV power generation. The respective life cycle GHG emissions associated with the wind/diesel/battery power systems are 0.150 €/kWh, 0.163 €/kWh and 0.430 €/kWh for the Islands of Lesvos, Karpathos and Astypalaia, respectively. The results of this study could serve as an environmental basis for the future development and replication of similar hybrid electricity supply systems for off-grid applications towards achieving the isolated Islands’ decarbonization transition.

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