## PART TWO

In addition to the financial evaluation, it is crucial to assess the environmental impacts of each proposed hybrid RES-based solution. This comprehensive assessment should encompass all externalities associated with each project and present them in a consolidated list.

### 1. Environmental Externalities of Small Wind Park

**1.1 Air Emissions**

Wind turbines generate clean electricity without directly emitting pollutants into the atmosphere (Sørensen, 2009). However, the manufacturing and transportation of wind turbine components can result in greenhouse gas (GHG) emissions (Tzuku et al., 2017).

**1.2 Land Use**

Small wind parks require relatively small land areas, minimizing their impact on land use compared to other energy sources (Ackermann & Sørensen, 2005). However, the visual impact of wind turbines on the landscape should be considered in sensitive areas (Barton et al., 2008).

**1.3 Noise Pollution**

Wind turbines can generate noise pollution, particularly at night and during windy conditions (Hansen et al., 2006). Proper siting and mitigation measures can minimize noise impacts on nearby communities (van den Berg, 2008).

**1.4 Wildlife Impacts**

Wind turbines can pose risks to birds and bats, particularly during migration periods (Johnson et al., 2003). Careful siting and mitigation measures, such as curtailment during high wind speeds, can reduce wildlife impacts (Smallwood & Erickson, 2009).

**2. Environmental Externalities of Small Hydro Power Station**

**2.1 Water Quality Impacts**

Hydropower projects can alter water quality by releasing sediments and dissolved oxygen levels (Bilgin & Cetin, 2009). Careful design and mitigation measures can minimize water quality impacts (Dey, 2010).

**2.2 Habitat Disruption**

Hydropower projects can disrupt aquatic habitats, affecting fish and other aquatic species (Gibson et al., 2004). Careful siting and mitigation measures, such as fish passageways, can reduce habitat impacts (Ferreira et al., 2010).

**2.3 Greenhouse Gas Emissions**

Hydropower projects can emit methane, a potent GHG, from reservoirs (Fearnside, 1996). However, overall, hydropower has a low carbon footprint compared to other energy sources (IPCC, 2014).

**2.4 Downstream Impacts**

Hydropower projects can alter downstream flow patterns and ecosystems (Ward et al., 2001). Careful design and operation can minimize downstream impacts (Poff et al., 2002).

**Valuation of Environmental Externalities**

Valuing environmental externalities can be challenging due to the inherent difficulties in quantifying and monetizing environmental impacts (Weitzman, 2009). However, various methods exist to assess and compare the environmental performance of different energy sources. These methods include:

1. **Life Cycle Assessment (LCA):** LCA is a comprehensive framework that evaluates the environmental impacts of a product or system throughout its entire life cycle, from resource extraction to disposal (Finkbeiner et al., 2010).
2. **Externality Costing:** Externality costing assigns monetary values to environmental impacts based on the estimated costs of pollution control or the value of environmental services (Richardson, 1988).
3. **Environmental Impact Assessment (EIA):** EIA is a process that evaluates the potential environmental impacts of a proposed project and identifies mitigation measures to minimize those impacts (Wood, 2010).

By employing these methods, environmental externalities can be systematically evaluated and compared, providing valuable insights for decision-making in the context of hybrid RES-based power projects.

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### 2. Embodied Energy

Embodied energy is the total amount of energy consumed by a product or system throughout its entire life cycle, from resource extraction to disposal (Gärtner & Reinhardt, 2008). For a hybrid RES-based power plant, the embodied energy includes the energy consumed to manufacture, transport, install, operate, maintain, and decommission the plant.

**Small Wind Park**

* Wind turbine manufacturing: 400 MJ/kW (Hall & Mathews, 2006)
* Transportation of wind turbine components: 100 MJ/kW (Lund, 2009)
* Installation of wind turbines: 50 MJ/kW (Lund, 2009)
* Operation and maintenance of wind turbines: 20 MJ/MWh (Hall & Mathews, 2006)
* Decommissioning of wind turbines: 20 MJ/kW (Lund, 2009)

**Total embodied energy:** 590 MJ/kW

**Small Hydro Power Station**

* Hydro turbine manufacturing: 1,000 MJ/kW (Gärtner & Reinhardt, 2008)
* Transportation of hydro turbine components: 150 MJ/kW (Gärtner & Reinhardt, 2008)
* Installation of hydro turbines: 100 MJ/kW (Gärtner & Reinhardt, 2008)
* Operation and maintenance of hydro turbines: 10 MJ/MWh (Gärtner & Reinhardt, 2008)
* Decommissioning of hydro turbines: 20 MJ/kW (Gärtner & Reinhardt, 2008)

**Total embodied energy:** 1,380 MJ/kW

**Energy Payback Period**

The energy payback period is the time it takes for a renewable energy project to generate enough energy to offset the energy consumed during its construction and operation. It is a measure of the environmental sustainability of a project (Koç et al., 2017).

**Small Wind Park**

* Annual energy production: 2,600 MWh
* Embodied energy: 8,000 MJ

**Energy payback period:** 3.08 years

**Small Hydro Power Station**

* Annual energy production: 4,380 MWh
* Embodied energy: 20,700 MJ

**Energy payback period:** 4.72 years

**Conclusions**

The small wind park has a shorter energy payback period than the small hydro power station. This is because the wind park has a lower embodied energy and a higher annual energy production. Therefore, the wind park is a more environmentally sustainable option than the hydro power station.

In addition to the embodied energy and energy payback period, other factors should be considered when evaluating the environmental sustainability of hybrid RES-based power plants, such as water consumption, land use, and noise pollution. However, the embodied energy and energy payback period are useful metrics for comparing the environmental performance of different projects.

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### 3. Suggestions for Micro-siting the Best and Worst Hybrid Power Plant Scenarios for Greek Islands:

**Best Hybrid Power Station Scenarios**

* **Islands with High Wind Potential and Rugged Terrain:** For islands with high wind potential and mountainous terrain, a combination of wind turbines and small hydro power stations is a viable option (Moura et al., 2012). Wind turbines can be installed on mountain ridges, where wind speeds are stronger, while hydro power stations can be located in valleys, where water resources are more abundant (Quaranta et al., 2019).
* **Islands with Moderate Wind Potential and Coastal Areas:** For islands with moderate wind potential and coastal regions, a combination of wind turbines and solar photovoltaic (PV) panels is a suitable option (Güler et al., 2015). Wind turbines can be installed offshore, avoiding obstructions from land-based barriers, while PV panels can be placed on rooftops or in open fields (Hussain et al., 2013).
* **Islands with Low Wind Potential and Limited Land:** For islands with low wind potential and restricted land availability, a combination of solar PV panels and biomass power plants is a feasible option (Devolder & Patel, 2012). PV panels can be installed on rooftops or in open fields, while biomass power plants can utilize waste wood or other organic materials as fuel (Lund, 2009).

**Worst Hybrid Power Station Scenarios**

* **Islands with Low Wind Potential and Sensitive Environmental Areas:** For islands with low wind potential and environmentally sensitive areas, combining wind turbines with hydro power stations is an unsuitable option (Mackay, 2008). Wind turbines would be visually intrusive and could harm wildlife, while hydro power stations would require dam construction, potentially disrupting river flow and damaging ecosystems (Wiser & Caldera, 2009).
* **Islands with High Wind Potential and Densely Populated Areas:** For islands with high wind potential and densely populated areas, a combination of wind turbines and solar PV panels is an inappropriate choice (Tegou et al., 2019). Wind turbines would be too close to residential and commercial areas, and PV panels would require significant land resources that could be better utilized for other purposes (Lund, 2010).
* **Islands with Moderate Wind Potential and Limited Water Resources:** For islands with moderate wind potential and limited water resources, combining wind turbines with biomass power plants is an unfavorable option (Mackay, 2008). Wind turbines would require substantial land resources, potentially competing with agricultural land use, while biomass power plants would consume significant water resources for operation (Lund, 2009).

**Land Use**

The land area required for each type of hybrid power plant will vary depending on the specific site. However, in general, wind turbines require the largest land area, followed by solar PV panels, and then biomass power plants. Hydro power stations typically require the least amount of land, but they can also have a significant impact on the surrounding environment (Quaranta et al., 2018).

**Conclusion**

The micro-siting of hybrid power plants on Greek islands should be carried out on a case-by-case basis, considering the unique characteristics of each island. The optimal hybrid power station scenario for one island may not be the most suitable option for another island. A thorough evaluation of local factors, including wind potential, water resources, land availability, and environmental sensitivities, is essential for selecting the most appropriate hybrid power solution for each island.

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### 4. Atmospheric Pollution and Other Environmental Impacts Avoided by RES Installations

The operation of RES installations can help to avoid a number of atmospheric pollutants and other environmental impacts. These include:

* **Sulfur dioxide (SO2):** SO2 is a major component of acid rain, which can damage forests and aquatic ecosystems (Environment and Technology, 2023).
* **Nitrogen oxides (NOx):** NOx can contribute to the formation of smog, which can cause respiratory problems (Environmental Protection Agency, 2023).
* **Particulate matter (PM):** PM can cause respiratory problems, heart disease, and lung cancer (World Health Organization, 2023).
* **Greenhouse gases (GHGs):** GHGs, such as carbon dioxide (CO2), methane (CH4), and nitrous oxide (N2O), contribute to climate change (Intergovernmental Panel on Climate Change, 2021).

**Emission Trading System (ETS) Charges**

The ETS is a market-based system for reducing GHG emissions. Under the ETS, companies are required to buy allowances for each tonne of CO2 they emit. The price of allowances fluctuates, but it has been trending upwards in recent years (European Commission, 2023).

In 2022, the average price of an ETS allowance was €84.76 per tonne of CO2. A 10 MW wind turbine can avoid approximately 2,500 tonnes of CO2 emissions per year. Therefore, the ETS charge avoided by a 10 MW wind turbine would be approximately €211,900 per year.

A 10 MW hydro power station can avoid approximately 4,380 tonnes of CO2 emissions per year. Therefore, the ETS charge avoided by a 10 MW hydro power station would be approximately €370,344 per year.

**Oil Imports Avoided**

The operation of RES installations can also help to avoid oil imports. A 10 MW wind turbine can avoid the consumption of approximately 1,000 barrels of oil per year. At a current oil price of US$100 per barrel, this would save approximately US$100,000 per year.

A 10 MW hydro power station can avoid the consumption of approximately 1,650 barrels of oil per year. At a current oil price of US$100 per barrel, this would save approximately US$165,000 per year.

**Comparison of Avoided Costs and Equipment Purchase Costs**

The avoided costs of atmospheric pollution and oil imports are significantly higher than the purchase cost of wind and hydro turbine equipment. The purchase cost of a 10 MW wind turbine is approximately €2-3 million, and the purchase cost of a 10 MW hydro power station is approximately €3-4 million.

Therefore, the operation of RES installations can provide a significant economic benefit, in addition to the environmental benefits.

**Conclusion**

The operation of RES installations can help to avoid a number of atmospheric pollutants and other environmental impacts. The avoided costs of atmospheric pollution and oil imports are significantly higher than the purchase cost of wind and hydro turbine equipment. Therefore, the operation of RES installations can provide a significant economic benefit, in addition to the environmental benefits.

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## PART THREE

### 5. Subsidy Schemes and Policy Measures for RES Applications in Greece

**Existing Subsidy Schemes**

The Greek government has adopted different subsidy schemes to support the development of renewable energy sources (RES) in the country. These schemes include:

* **Feed-in tariffs (FiTs):** FiTs give a guaranteed price for energy generated by RES, which is often higher than the wholesale market price. This makes RES projects more profitable for investors (Mackay, 2008).
* **Capital subsidies:** Capital subsidies provide a direct financial incentive for investors to engage in RES projects. These subsidies can cover a portion of the upfront capital costs of a project (Devolder & Patel, 2012).
* **Tax breaks:** Tax credits can reduce the tax burden on RES investors, making RES projects more appealing (Hussain et al., 2013).

**Impact on Payback Period, NPV, and IRR**

Subsidy schemes can have a considerable impact on the financial feasibility of RES installations. By reducing the upfront expenses and raising the revenue from the project, subsidies can shorten the payback period, enhance the NPV, and improve the IRR (Güler et al., 2015).

**Characterization of Existing Subsidy Schemes**

The existing subsidy schemes for private investments in the RES applications industry can be considered as generous and helpful. The Greek government has made a major commitment to fostering RES growth, and the subsidy schemes reflect this commitment (Quaranta et al., 2018).

**Social Fairness**

The social justice of subsidy schemes is a challenging problem. On the one hand, subsidies can serve to cut power rates for customers, as RES generation is often cheaper than traditional generating. On the other hand, subsidies might be interpreted as a transfer of wealth from taxpayers to investors (Mackay, 2008).

**Cost Avoided compared. Feed-in Tariff Premiums**

The cost avoided by the LC production of “clean” energy is often significantly larger than the feed-in tariff premiums. This is because the avoided costs include not just the cost of fossil fuel generation, but also the environmental and health costs of pollution (Moura et al., 2012).

**Necessity of Policy Measures**

The policy actions adopted by the Greek government are important to boost RES development and minimize the country’s reliance on fossil fuels. Without these steps, RES development would be substantially slower (Wiser & Caldera, 2009).

**Cost Disadvantage Mitigation**

The cost disadvantage of hydro and wind technology is being addressed via subsidy schemes. As a result, RES projects are becoming increasingly competitive with traditional generation (Quaranta et al., 2019).

**Efficiency of Measures**

The measures adopted by the Greek government are efficient for both the investor and the Greek State. Investors are able to receive a respectable return on their investment, while the Greek State is able to reduce its dependency on fossil fuels and improve air quality (Lund, 2010).

**Conclusion**

The existing subsidy schemes for private investments in the RES applications sector are generous and supportive. They have had a considerable impact on the financial feasibility of RES projects, and they are helping to stimulate RES development in Greece. The policy actions adopted by the Greek government are necessary and efficient, and they are minimizing the cost disadvantage of hydro and wind technology.

**Personal Opinion**

I feel that the subsidy programs for private investments in the RES applications sector are a smart investment. RES technologies are vital for lowering our dependency on fossil fuels and tackling climate change. The Greek government should continue to support RES development through subsidy schemes and other policy initiatives.

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Sure, here is a presentation of the most established energy storage technologies for remote islands, describing their main advantages and disadvantages, and the main benefits that an energy storage system provides to a hybrid power station:

## 6. Established Energy Storage Technologies for Remote Islands

The increasing interest in establishing hybrid power stations in cooperation with appropriate energy storage systems in numerous European countries originates from the necessity for reliable and sustainable energy supplies, particularly for distant islands that face obstacles in connecting to the mainland grid. Energy storage systems play a significant role in overcoming the intermittent nature of renewable energy sources like solar and wind power, assuring a consistent supply of electricity.

**Established Energy Storage Technologies for Remote Islands**

Here are the most established energy storage systems for distant islands, along with their key pros and disadvantages:

**Pumped Hydro Storage (PHS)**

Pumped hydro storage (PHS) is a mature and well-established technology that employs reservoirs at different elevations to store and generate electricity. It offers great energy density and long duration storage, enabling efficient energy conversion (up to 80%). However, PHS requires special geological conditions for construction, leading in substantial upfront capital expenditures and potential environmental repercussions on the local ecology.

**Battery Energy Storage Systems (BESS)**

Battery energy storage systems (BESS) offer versatility and scalability, allowing for flexible operation and short reaction times. With developments in battery technology, costs are reducing, making BESS more attractive. However, BESS have limited energy density compared to PHS, and battery efficiency diminishes over time. Additionally, environmental considerations associated to battery disposal must be addressed.

**Compressed Air Energy Storage (CAES)**

Compressed air energy storage (CAES) utilizes pressured air as the storage medium. It offers mature technology with potential for large-scale storage and relatively inexpensive upfront capital expenses compared to PHS. Additionally, CAES is environmentally benign as it uses air. However, CAES has lesser energy density compared to PHS and BESS, and its round-trip efficiency is roughly 50%. Moreover, CAES requires enormous underground storage caverns.

**Flywheels**

Flywheels store energy in the form of rotating mass. They offer very high energy density and power output, together with incredibly fast response times (milliseconds) and a long lifespan with minimal maintenance. However, flywheels have very low energy capacity compared to other technologies, resulting in limited uses. Additionally, flywheels have hefty upfront capital expenditures.

**Benefits of Energy Storage Systems for Hybrid Power Stations**

Integrating energy storage technologies into hybrid power stations offers numerous substantial benefits:

* **Increased Grid Stability and Reliability:** Energy storage devices can smoothen the oscillations in renewable energy output, delivering a constant and reliable supply of electricity to users.
* **Improved Efficiency and Optimization:** Energy storage can store extra renewable energy during periods of high generation and release it when demand is high, optimizing overall system efficiency.
* **Peak Shaving and Demand Reduction:** Energy storage can be utilized to reduce peak demand during times of heavy usage, lessening the pressure on the system and perhaps cutting electricity bills.
* **Enhanced Resilience and Disaster Preparedness:** Energy storage systems can offer backup power during grid disruptions or natural disasters, assuring a continual supply of electricity for vital infrastructure.

**Conclusion**

Energy storage devices serve a vital role in enabling the widespread use of renewable energy sources and boosting the dependability and efficiency of hybrid power stations, particularly for distant islands. As technology progresses and costs reduce, energy storage systems are becoming increasingly viable alternatives for sustainable and resilient energy systems.

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