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# Survey on Grid Flexibility Solutions to deal with Unpredictable Renewable Energy Sources and High Penetration of Electric Vehicles on Islands

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***Abstract***: **The evolution of new technologies, including energy storage systems, renewable energy sources, and electric vehicles has changed the distribution system's architecture into an active grid with bidirectional power flow. This paper deals with solutions to increase the grid's flexibility to cope with renewable energy sources' unpredictability, in particular with solutions that deal with such issues in insular situations. Moreover, the concept of a smart island, as well as its challenges and an isolated smart microgrid mode, are discussed in this paper. Furthermore, this review addresses the challenges that electric vehicle implementation has on islands, as well as the numerous types of charging modes provided and vehicle-to-grid integration on islands. Finally, the decarbonization of transportation sectors is examined.**
***Keywords***: electric vehicles, grid flexibility, microgrid, plug-in electric vehicles, renewable energy sources, smart island, vehicle-to-grid

## I. Introduction

Islands have been described as suitable places to develop fresh ideas and solutions that will help accelerate the continent's development. By improving their grid interconnections, geographically close islands provide the opportunity for the establishment of 100% renewable energy systems [1]. For the analysis of a future Barbadian energy system, an open-source model based on the Open Energy Modelling Framework (oemof) using a greenfield modeling method is offered. The model was used to examine 100 % renewable energy system configurations in a scenario analysis. Globally, the outcomes highlight renewable energy's enormous potential, as well as the technical and economic viability of a 100% renewable energy system for Barbados island [2].
In the earlier days, the grid's flexibility was provided by conventional power plants, since they were entirely managed while the load was unpredictable. Presently, unpredictability has shifted to the generation side due to the variety of Renewable Energy Sources (vRES), whereas the opposite has happened to the flexibility agents [1].
Lack of flexibility in an energy system can cause serious problems, especially when demand increases and flexibility becomes limited. Several options to improve energy management tactics and increase grid flexibility have been presented. In the insular context, the Electrical Energy Storage System (EESS) and Smart Energy Systems (SES) are the two main solutions to improve energy system management [1]. In terms of synergies with the transportation sector, electric vehicles (EVs) provide much more opportunities. To achieve the primary goal of electric vehicles, which is to decrease fossil fuel dependency, reduce air pollution, and boost energy security, the energy required to charge EVs must be provided by RES [3].
RES is critical in the energy transition. Nevertheless, because of their great efficiency and environmental characteristics, it's more likely that they'll be employed as demand supplements [4]. Dorotic et al. [5] introduced an island energy system with 100 % vRES and 100 % smart charge vehicles. The outcomes show that a configuration with 22 MW of wind and 30 MW of installed solar capacity provides the smallest amount of total electricity import/export, while a configuration with 40 MW of wind and 6 MW of installed solar capacity is the most cost-effective. The decrease in V2G share increased overall import/export in both cases, however, the transmission peak loads were unaffected.
While the autonomous vehicle revolution has led to the development of robust support systems such as traffic lights and countdown timer detection to enable faster and safer real-world implementation [6], the number of Evs on the road is

steadily increasing in the energy domain. EVs have made significant progress in recent years in terms of lowering energy consumption and electricity costs.

EVs have provided genuine benefits to the transportation system by injecting electrical energy stored in EVs into the grid at the proper moments, such as Vehicle-to-Grid (V2G) [7]. V2G is an aspect that has been developed through time to reduce the significant impact of EVs on smart islands. Nonetheless, integrating RES and EVs will be difficult for the network. Their demand for charging may cause a change in the grid's load, causing the systems' usual operation to be disrupted [8]. In this manner, this survey describes four different ways to charge an EV battery: (1) uncoordinated; (2) coordinated; (3) smart charging; and (4) photovoltaic charging station. In this regard, a mathematical model of PHEV charging types is described, as well as the benefits and drawbacks that each one has. The shift in the economy based on emissions and fossil fuels to a renewable approach addresses the issue of climate change, which will be mentioned in detail at the end of this article.

This paper contributes to the literature in the following ways:

- Existing grid flexibility solutions approaches are summarized.
- Smart Island mode of operation and its challenges are introduced.
- The potential offered by EVs, the difference between many charging modes, and V2G impact on islands are discussed.
- The influence of decarbonization in the transportation sector on islands is investigated.

The remainder of this review is structured as follows: Section II introduces grid flexibility solutions on islands. The concept of a smart island is briefly presented in Section III. Section IV focuses into the specifics of EV charging mode optimization, while Section V verifies V2G integration on islands. The impact of decarbonization on the transportation sector is examined in Section VI, and the literature review is discussed in Section VII. Finally, in Section VIII, some conclusions are made.

## II. Grid Flexibility Solutions on Islands

The European Union's (EU) interest in the island's energy issue is currently at its peak. Many important steps towards the construction of sustainable insular energy systems have been taken in recent years. Islands have been highlighted as an ideal location to demonstrate the technological and economic feasibility of high vRES. Several islands, according to Groppi et al. [1] were already relying on RES, primarily wind, biomass, and hydro.

Concerns about grid flexibility and system adaptability have grown as the percentage of renewable energy in the electric grid has increased. Indeed, the large percentage of vRES in the electric grid presents technological problems for insular electric grids, which are generally antiquated and incapable of handling such instability [1].

Grid flexibility refers to the system's capacity to adjust quickly to unanticipated changes. At each moment, the stability state is translated into the load and power supply requirements. This demand has traditionally been met by adjusting the output of power plants, particularly those with the ability to rapidly ramp up and down, to match the varied and unpredictable electric load. With the introduction of vRES generators, unpredictability has shifted from the demand to the generation side, prompting flexibility agents to relocate to the demand side in response. Nonetheless, current systems give flexibility by regulating power plant output. With vRES, this has resulted in a decrease in consumption, resulting in the loss of clean energy [1]. Two trends are tackling the challenge of grid flexibility on islands: 1. Electrical Energy Storage Systems (EESS); and (2) Smart Energy Systems (SES), which will be detailed in the following subchapters.

### A. Electrical Energy Storage Systems

EESS includes all solutions that can absorb and supply electricity from and to the grid. EESS incorporates Pumped Hydro Energy Storage (PHES), different types of Battery Energy Storage System (BESS), including distributed ones, hybrid systems with underwater compressed air energy storage (UWCAES), thermal storage, and hydrogen energy storage (HES) systems [1]. Fig. 1 presents the structure of a hybrid energy system on an island.

In the literature, many studies have been discussed involving several EESS for energy systems on geographical islands. The influence of alternative PHES configurations on scheduling expenses and vRES curtailment in the Gran Canary island was investigated by Fernandez-Munoz et al. [9] by using a power system generation scheduling based on the next-day forecast. The results show that new configurations can still make a difference by lowering scheduling costs and increasing integrated vRES. In the Azores archipelago, Barbaro et al. [10] developed an optimized design for Faial's energy system, maximizing RES penetration. On top of the traditional generators and 4.25 MW of Wind Turbine Generator (WTG) already in place, the best configuration included 5.5 MW of geothermal generators and 6.2 MWh of BESS capacity. Wang et al. [11] examined the UWCAES system for the energy system of the South China Sea island. According to the studies, a round-trip efficiency of 58.9% can be reached.

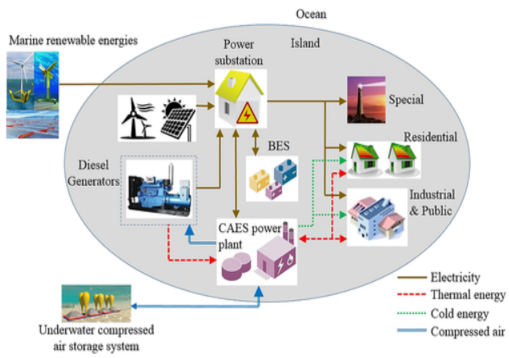


**Figure. 1**: Energy system structure on an island [11]

Khosravi et al. [12] investigated a novel system that combined ocean thermal energy conversion (OTEC) and photovoltaic (PV) with a HES system. The energy system's total energy efficiency was 3.32%, while the OTEC system's overall energy efficiency without the HES was 2.75%. The hybrid system's exergy efficiency was 18.35%, with a Pay Back Period of roughly 8 years. The cost of electricity was 0.168 \$/kWh, which is 40% less than the previous system's cost of 0.28 \$/kWh.

In summary, BESS is a viable solution for small-to-medium-scale systems. PHES, on the other hand, has proven to be a viable option for larger islands or those with unique geographical characteristics. It has particularly advantages for larger systems with available natural reservoirs (vRES penetration rate is increased by 1.93–37 %). For the case of Barbados island, Harewood et al. [2] mentioned that PHES can lower the expenses of a 100 % renewable setup while also lowering the resource consumption required for batteries. Higher costs of RES, reduced oil prices, or a drop in demand have only a minor impact on the value of PHES. As a result, while striving for 100 % RES, the results show that PHES is a no-brainer for the design of energy systems in Barbados. The benefits of hydrogen include its abundance, low pollutant emissions, reduced greenhouse gas emissions, and low noise pollution [13].

### B. Smart Energy Systems

SES access the integration of various energy sectors, namely: (1) the thermal sector using Thermal Energy Storages (TES); (2) the transportation sector employing many energy sectors; and (3) the water production and management sector.

Several searches have been reviewed in the literature regarding methods that increase grid flexibility by coupling the power sector to other energy-consuming sectors such as transport, building, thermal, water production, and management by employing Demand Side Management (DSM) strategies. Marcinkowski et al. [14] compared the effects of BESS and TES for the Danish Sams island and the Scottish Orkney Islands. It has been demonstrated that coupling the power and thermal sectors through heat pumps (HPs) and TES has a bigger impact on the global energy system. Indeed, the TES/HP scenario reduces total annual costs by 2.2 and 3.1% in Sams and Orkney islands, respectively, but the BESS scenario increases total yearly costs by 2.7 and 11%. Dominkovi'c et al. [15] investigated the integration of vRES into a Caribbean island's energy system by employing an energy planning approach aimed at integrating energy sectors such as (1) the cooling sector using ice storage, (2) the transportation sector using smart charging or V2G, and (3) the water production sector using a Reverse Osmosis (RO) desalination plant. The results showed that vRES supplied 84.6% of total electricity demand with a 1% restriction, a 17% peak growth, and a 30% reduction in energy supply. When carbon costs were factored in, the yearly economic cost of the entire energy system was 2.5% lower than the reference. Swingler et al. [16] compared solutions for long-duration energy storage for Prince Edward Island's electricity system powered by RES. The authors used HOMER to compare lithium battery technology, which is efficient but expensive, to a less efficient but less expensive TES combined with a steam turbine. Both systems were sized to be able to achieve a 100 % RES electricity share. Although both storage solutions produce equivalent amounts of unutilized renewable energy, the battery technology produces greater electrical curtailment at the source, which may be advantageous in the context of flexible charging of EVs. Corsini et al. [17] investigated the use of a grid-connected RO desalination plant on the Italian island of Ventotene. The outcomes demonstrated that the RO reduced the summer peak load by 29.5 % by exploiting the excess energy produced during wintertime. The solution was to optimize the operation based on economic factors, which resulted in the production of 48.5 % of the freshwater demand while only utilizing 18.3% of the total vRES production.

Concerning the transportation sector, Krajacic et al. [18] conducted a study on four separate islands: Mljet, Croatia; Porto Santo, Madeira; Terceira, Azores; and Malta adopting hydrogen solutions for transportation. Several scenarios are modeled to analyze the impact of the hydrogen vector on island electric networks' ability to host vRES. The results show that hydrogen as an energy vector is a technically realistic alternative to fossil fuels, and can assure energy supply security while also increasing the use of local RES. In the case of smaller islands, hydrogen technology will enable them to become 100% renewable in terms of electricity and transportation, whereas in the case of larger islands, such as Malta, hydrogen could make a significant contribution to reducing the use of fossil fuels, particularly if it is used as a transportation fuel.

Different energy carriers and technologies capable of meeting the grid's needs can be employed to increase the grid's flexibility and, as a result: raise the grid's capacity to absorb a bigger proportion of vRES, lessen the requirement for vRES curtailment, and control peak load.

In Fig. 3, the potential of EVs has been examined, as well as the distinctions between planned charging and V2G. Hydrogen's potential in the transportation sector has been explored, whether pure or combined with natural gas, and biogas, as well as the possibilities afforded by desalination facilities and seasonal water storage. A summary of the research regarding grid flexibility solutions is provided in Table 1.

In terms of reducing excess power output, vREs, and increasing the grid capacity of hosting vRES, all of the investigated methods showed promising outcomes. Power-to-heat systems are an intriguing alternative. The employment of HPs, in particular, has a two-fold influence on-grid energy management and building energy efficiency. All of the aforementioned technologies allow the grid to use electricity for sectors other than power, resulting in many load curves and the ability to move a portion of those loads. It is important to highlight that powering other industries and services always increases electricity consumption while lowering global primary energy demand. Nonetheless, the flexibility of the suggested technologies allows load shifting and management to decrease peak values, so as not to negatively affect the island grid [1].

## III. An Overview of Smart Islands

Smart Island (SI) is an area separated from the main electrical grid. An SI can incorporate infrastructure management alternatives and meet local demand using RES [19]. A plat-

*Table 1*: Summary of the research regarding grid flexibility solutions.

| Reference | EESS | SES | Type of solution | Location | Results |
|---|---|---|---|---|---|
| [9] | Yes | No | PHES | Gran Canary island | Cheaper scheduling and enhancing integrated vRES. |
| [10] | Yes | No | BESS | Faial island | Small system configuration with batteries. |
| [11] | Yes | No | UWCAES | South China Sea island | Parameters relevant for UWCAES's round-trip efficiency. |
| [12] | Yes | No | HES | Lavan island, Iran | Environmentally beneficial, and will aid in the viability and practicality of RES. |
| [14] | Yes | Yes | BESS and TES | Danish Sams and Scottish Orkney islands | TES/HP Reduces costs, total fuel consumption, and CO2 emissions. BEES has import/export reduction, However, the downside is that costs will increase. |
| [15] | No | Yes | Transportation, cooling, and water production sector | Caribbean island's | Reduction on energy supply. |
| [16] | No | Yes | TES | Prince Edward Island's | The notion of a thermal storage turbine has been proved to be competitive with lithium-ion battery technology. |
| [17] | No | Yes | Water production sector | Italian island of Ventotene | Summer peak load was cut by 29.5%. % by exploiting the excess energy production during the wintertime. |
| [18] | No | Yes | Transportation sector | Mljet, Porto Santo, Terceira, and Malta | The inclusion of the hydrogen energy vector in scenarios with limited penetration enabled the grid to host a 4–6% increase in RES penetration. |

form for charging and discharging EVs without the usage of a common grid has been established within the smart islands. An illustration of the SI can be demonstrated in Fig. 2.

**Figure. 2**: The illustrative representation of the SI [19].

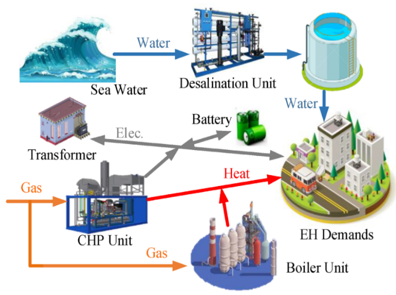


**Figure. 3**: Illustration of the studied EH [19].

## A. *Smart Island Problems*

The demand supplement problem is one of the smart island's main issues due to its isolation feature. However, this issue is possible to overcome by deploying RES. Mohamed et al. [19] examined a multi-objective method based on deep adversarial learning to handle microgrid's optimal energy management. The goal was to use an effective scenario-based method to reduce the total cost, pollutant emissions, and uncertainty factors.

The SI typically addresses a great number of obstacles due to its diverse load demands, which include electrical, thermal, gas, and water since it cannot be supplied only through transportation and microgrid systems. As described by authors in [19, 20], one option to overcome this problem is to use Energy Hubs (EH). The EH is a multi-carrier energy system with distinct units of production and multiple sources, including EV, renewable generations, combined cooling, heat, and power (CCHP), and seawater desalination (SWD), which may meet load requirements by utilizing efficient methods. An illustration of EH can be seen in Fig. 3, presenting the EH's energy layers and their corresponding generation/conversion units.

According to the literature research, EH is a system whose components are equipped with communication equipment such as smart meters and communication cables, allowing customers to regulate their energy consumption [21]. Wasilewski et al. [22] presented the problems, possibilities, and benefits of integrating EHs with distributed generating sources in an islanded mode of operation are examined, to serve many types of demand loads while also boosting the power grid's efficiency.

EHs can benefit from advantages such as optimal use of installed capacity and environmental potential by accepting to provide other demands in addition to typical necessities such as electricity, cooling, and heating [13]. EH can increase its flexibility by converting energy into the necessary product and storing it in a different form, such as electrical or thermal energy.

EHs with high renewable energy penetration and waste heat recovery capability are well suited to meet the needs of the water desalination process. The seawater can be desalinated by a desalination unit designed to supply the water demand of the EH [19]. Kafaei et al. [13] offered a stochastic model for the day-ahead operation of an EH equipped with a SWD as a huge load, EVs, and a hydrogen electrolyzer in a smart commercial building on Qeshm Island, Iran. The EH uses an SWD as a flexible load with RO technology and an Organic Rankine Cycle (ORC) as a new technique for generating electrical power from thermal energy to improve the efficiency of the system.

### *B. Centralized, Decentralized, and Distributed Approaches*

SI can be managed on three different bases: (1) centralized, (2) decentralized; and (3) distributed. Nonetheless, centralized techniques are not yet economically viable, and this will be an issue if the smart island agents are operated independently. Furthermore, units in isolated areas must respond quickly to load fluctuations, which is impossible to achieve with centralized operations. The necessity of integrating the central units occurs also in decentralized techniques, which corresponds to a big issue as well. A distributed technique is used to overcome this problem [19]. The main benefit of distributed methods is their decentralization, which reduces the chance of a system's core being attacked and destroyed. Fig. 4 compares the structure of the centralized, decentralized, and distributed frameworks.

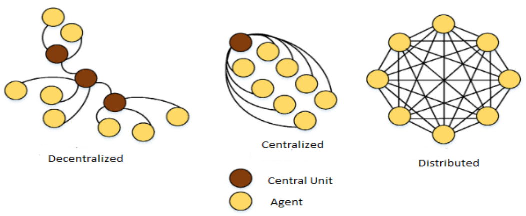


**Figure. 4**: Centralized, decentralized, and distributed structures [19].

Distributed techniques are methods by which energy management schemes and optimal operation are achieved through agent-to-agent energy and data transactions. In this regard, Liu et al. [23] attempted to examine the optimal energy management for multi-microgrids using a novel distributed-based method known as the "double-phase method". In an energy market, the method in which agents exchange their desired energy price until a saddle point is reached and the agents are satisfied.
On another hand, Qiu et al. [24] provided an adaptive robust decentralized-distributed optimization approach for dealing with the effective distributed scheduling of multi-microgrid systems with a variety of structures, uncertainties, and transverse communication failures. Nikmehr et al. [25] studied a new hybrid method that blends centralized and distributed methodologies but still requires a central coordinator. Fernandez-Munoz et al. [9] employed a primal-dual method of multipliers, which has been demonstrated to have a better performance than the multiplier method with alternating directions. In this situation, distributed solutions outperformed centralized approaches when it came to processing time and resilience.

### *C. Smart Grids and Microgrids on Islands*

The field of power systems has been witnessing the appearance of new terminology like smart grid and microgrid, which have separate meanings. Although the definitions of those terms are still developing, the smart grid is generally referred to as the integration of advanced computing technologies and communications with the power grid. The purpose of a smart grid is to offer a safe, reliable, and adaptable grid operation that can handle a significant number of renewables and other resources while maintaining system reliability and cost-effectiveness [26].
On another hand, the microgrid (MC) is thought to be the most practical solution for a small island. In small electric grids, an MC is an autonomous electric system with distributed energy sources and electrical loads. AN MC can be operated in a grid-connected mode or islanded mode, which will provide greater advantages [19] [27].
For the case of islanded mode, energy management is one of the most significant issues in MC. To boost the use of RES and alleviate the carbon dioxide issue, a major change in the energy system is needed. The operation of the SI was analyzed in [20]. The Smart island is depicted as an isolated smart microgrid integrated with EV-based smart transportation systems and EH. As an example of a study case, the point estimate method (PEM) is employed to deal with EVs uncertainties due to the significant uncertainty effects on the smart island operating problem.

## IV. Charging Optimization modes for Electric Vehicles

With over 1 million fully electric vehicles in use around the world, the international electric vehicle market is exploding [28]. The Biden Administration in the United States wants to decarbonize the road vehicle fleet by 2050. By 2030, the United Kingdom intends to prohibit the sale of new conventional vehicles and the EU wants at least 30 million zero-emission vehicles on its roads, up from the 1.8 million it had at the end of 2019 [29].
There are four primary types of EVs: (1) Purely Electric; (2) Hybrids without grid connection; (3) Plug-In Electric Vehicle (PHEV); (4) Fuel Cell, among which PHEVs will be the ones employed in this chapter. PHEVs are vehicles that have properties extremely similar to hybrids, but their batteries can be recharged via a grid connection [30].
The normal demand of an EV per charge is between 10 and 100 kWh. Therefore, the accumulated charging of EVs will affect the performance and stability of the network. Due to the high initial cost of Evs, charging takes place at home or work, during evenings or nights. Consequently, isolated grid overloaded may occur during the early stages of EV adoption. The impact of EVs on isolated electric grids is one of the main problems in the electrification of the transportation sector. Since an EV might increase the charging station demand, distribution transformers can quickly become overloaded, causing several issues [28].
Grid operators have several alternatives for minimizing the impact of vehicle charging on their networks. These alternatives, together known as charge management, entail the operators imposing demand charges, time-of-use rates, and dynamic pricing, all of which are widely used today due to their application to bigger, industrial clients [31]. Additional charge management alternatives are emerging as a result of recent technological advancements. If charge management is not used, the increased loads provided by charging can cause a shift in an island's daily load profile and an increase in demand peak as the number of EVs grows [28]. The high demand from Evs reflected in the modeling results and charging patterns, poses a problem for a future sustainable energy

system [2].
To mitigate these difficulties, a diverse range of charging modes are investigated. In this survey four operating modes were analyzed: uncoordinated, coordinated, smart charging, and charging utilizing photovoltaic for EV, which will be discussed further in this section.

### *A. Uncoordinated Charging*

The grid's reliability and security may be jeopardized if a large number of EVs are charged with uncontrolled charging. PHEVs are believed to leave in the morning and return about 6:00 PM, according to [32, 33, 34]. To simulate this scenario, a probability distribution function (PDF) with a uniformly distributed feature is defined by:

$$f(ts) = (1/b - a) * a \leq ts \leq b, a = 18, b = 19 \quad (1)$$

where $ts$ is the charging start time of the PHEV; a, and b are a constant for specifying the shape of a logarithmic spiral.

### *B. Coordinated Charging*

Coordinated charging is the most suitable for EV adoption in its early stages. It is also ideal for areas where EV adoption is minimal. PHEV owners tend to charge their vehicles during low-demand hours, or off-peak hours, according to [32, 33, 34]. The charging time is longer than usual, particularly after 9:00 p.m. when the cost is low. The second charging pattern is modeled by the probability density function and can be characterized by:

$$f(ts) = (1/b - a) * a \leq ts \leq b, a = 21, b = 24 \quad (2)$$

Unidirectional chargers with adjustable timings can be used to perform coordinated charging since they can be programmed to charge the vehicle at a specific time, as indicated by Gay et al. [28]. This strategy can eliminate the need for additional production capacity and the daily demand profile is minimized. Optimization charging periods can assist in lowering daily electricity costs, while coordinated charging can support flattening the load curve.
Aslani et al. [35] developed a novel probabilistic optimization challenge for determining the capacity of sub-systems of hydrogen-based MGs, including EVs, RES, and Hydrogen vehicles (HVs) in many weather conditions. To describe stochastic behaviors and solve the suggested probabilistic optimization problem, the Monte Carlo simulation (MCS) and Flower Pollination Algorithm (FPA) are utilized. This research investigates several Iranian climates based on historical data, as well as several coordinated/uncoordinated charging modes for EVs and HVs. The outcomes of the suggested probabilistic method vs existing deterministic methods revealed that ignoring the probabilistic behaviors in MGs leads to significant inaccuracy. The negative consequences of ignoring the uncertainty of MGs were found to be enhanced in the uncoordinated charging mode of EVs.

### *C. Smart Charging*

Bidirectional chargers, which permit the transfer of power and communication between the EV and the grid and vice versa, will be able to supply significant amounts of power to the grid at increasing penetration rates [36, 37]. This technology is sometimes referred to as Smart Charging (SC) in the literature.
SC allows grid operators to schedule charge profiles for economic or technical reasons. For example, SC comprises EV load control, which may be programmed using different methods to accomplish a given objective, such as the reduction of energy costs, or lowering greenhouse gas emissions [38]. SC's only drawback is its high complexity and cost.
To adopt SC technology, it is necessary to have access to the charging device data. The connection data between the EV and the charging device is then shared with the charging station operator, but it is only shared with the EV user's permission [39].
Excess energy from vRES can be stored and used at a later time. According to studies, SC can help the grid operator match supply and demand in energy systems with a high penetration of wind and solar [40]. According to Dabbaghjamanesh et al. [32], the fundamental purpose of the SC system is to optimize the schedule of the charging pattern of PHEVs. The EV charging takes place when PHEV owners and utilities share a mutual interest. When there is excess production capacity and the cost of electricity is cheap, the EV begins charging. A normal probability density function is considered in [34] by:

$$\begin{aligned} &f(ts) = (1/(\psi * \sqrt{2 * \pi}))* \\ &e^{-1/2*(ts-\mu/\sigma)^2}, \mu = 1, \psi = 3 \end{aligned} \quad (3)$$

where $\psi$ is the covariance, $\mu$ is the mean value of the signal strength data set, and $\sigma$ is the standard deviation. Equation (4) represents the probability distribution function of the vehicle's daily driving miles.

$$\begin{aligned} &f(m) = (1/(m * \psi * \sqrt{2 * \pi}))* \\ &e^{(-\ln(m)-\mu^2)/2*\psi^2)}, m > 0 \end{aligned} \quad (4)$$

where $m$ is the number of observations in a sample set with type H1 (where the signal source is an adversary).
According to Calise et al. [8], SC vehicles enable battery charging and discharging, to reduce energy import/export and production from traditional power plants. In this work, the results reveal a rise in SC on Evs and a decrease in hydrogen-powered vehicles.
Pfeifer et al. [41] studied the islands of Lastovo, Vis, Mljet, and Korkula suggesting that the interconnections between a group of islands can incorporate the production of RES that are locally accessible. Aside from that, EVs are connected to the grid through V2G and SC systems, making them viable energy storage systems. According to the results, the connectivity improved the percentage of electricity from RES and decreased the total amount of power produced in excess. Simultaneously, the V2G allowed for the utilization of cross-sector synergies.
Therefore, islands and distant places can benefit from interconnection, although this is not always the case. According to Neves et al. [42], 71 % of small islands that are not connected to the mainland grid will not do so due to financial or technological constraints. Ramos-Real et al. [43] assessed numerous scenarios for possible reconnection Tenerife–La Gomera and concluded that connecting small energy

systems with the grid is not always technically feasible or cost-effective.

### *D. Charging using Photovoltaic*

A solar photovoltaic (PV) based charging station (CS) is one of many RES that is simple to use and offers a viable charging option. PV charging station aims to maximize the use of energy from the photovoltaic array to charge Evs.
In the literature, many authors have focused their efforts on developing a renewable energy charging station. Among these are [44, 45, 46]. The most frequent arrangement for connecting the PV array to the charging station in all recorded literature is through a dc-dc boost converter utilized for maximum power point tracking (MPPT) [47]. Nevertheless, the boost converter adds an extra power step, lowering the charging station's efficiency. Bhatti et al. [48] provided a method for managing energy in real-time for EV charging by employing PV on the island of Uligamo. A decentralized coordinated method is required by the charging algorithm to optimize the power flow inside the microgrid. The outcomes suggest that charging Evs employing a PV-based microgrid is more cost-effective than an autonomous charging generator. The load on the microgrid is significantly reduced as a result of this method. Fig. 5 shows the proposed microgrid system located on this island.

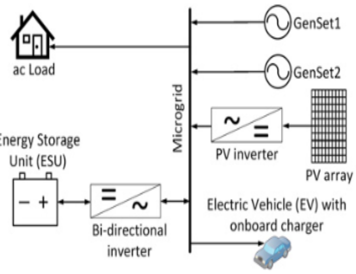


**Figure. 5**: Microgrid system [41].

Despite the numerous advantages of adopting a PV array for EV charging, variations in solar irradiation have an impact on charging station operation. The effects of irradiance fluctuations on EV charging were discussed by Islam et al. [49]. If the charging station is operated in only island mode (IM) or grid-connected mode (GCM), the effect of irradiance variation becomes worse. In this way, Verma et al. [4] refers that the charging station is designed to work in both islanded and GCMs, depending on the availability of PV array generation and charging demand. Furthermore, the controller is designed to allow for seamless mode switching between an IM and a GCM, allowing the charging station to minimize the effect of irradiance variation while maximizing the use of a PV array.
In order to help the impact caused by the variation of solar irradiation, the charging station must have a storage battery [50]. An energy storage battery can be employed to optimize PV production management and smooth electricity consumption during peak periods [51]. Battery systems are critical for residents on small islands, as they can reduce electric bills, increase reliability, and provide protection, particularly during power outages caused by natural hazards.

## V. Implementation of V2G

An EV battery is considered insufficient for operation when it reaches 70% to 80% of its original storage capacity. V2G services can be used in this instance [28]. V2G has several advantages, features, cost-effectiveness, and technological requirements.
The literature discusses the viability of using EV batteries in large-scale stationary applications. Hein et al. [52] conducted a comparison of EV batteries used in V2G services, old EV batteries for stationary applications, and new EV batteries for stationary applications in a study. They concluded that, in the long run, battery re-use would be unprofitable due to battery capacity decline and corresponding value decline. On another hand, Cready et al. [53] investigated eight potential stationary applications for old EV batteries and discovered that half of them were economically viable. According to these authors, the battery can be employed in stationary applications after modest refurbishing. Storage for renewable energy installations, spinning reserve, and localized voltage/frequency management are some of the stationary applications. According to Heymans et al. [54], stationary used EV battery packs also can relieve the strain on the electricity grid by shifting power from peak to off-peak hours, an application that is not suited to the batteries while they are installed in EV.
Similarly, many authors in the literature have covered the concept of V2G and the impact of EV penetration. Beer et al. [55] investigated the impact of EVs on the main grid and their utility as a technology for boosting renewable energy output. The authors concentrated on evaluating the implications of EVs on the power grid, and they benefited from the EVs' storing capability to service the microgrid system and satisfy its demand. Mehrjerdi et al. [56] and Rassaei et al. [57] endeavored to provide details about the V2G technology's problems, benefits, uncertainty management, and economic aspects. EVs as mobile devices for storing energy integrated with RES were examined using stochastic analysis by Khodayar et al. [58]. This type of stochastic assessment is used to mimic the behavior of EVs, particularly in smart cities. Tabatabaee et al. [59] pursued the same goal, where they attempted to model the uncertainty of high EV penetration using V2G mode of operation.

### *A. V2G and V2H Penetration's Impact on Islands*

While natural hazards can affect all economic sectors, damage to transportation assets accounts for a significant portion of economic losses. Infrastructure, rather than vehicles, will be harmed by road transport damage. However, since EVs are essential for evacuation, emergency response, and recovery following natural hazards, any significant changes to an island's transportation infrastructure should be carefully evaluated [28].
Extreme circumstances can cause harm to electricity systems resulting in power loss for a large number of customers and significant periods of outage. Under these conditions, vehicle-to-home (V2H) and vehicle-to-grid (V2G) can be implemented. V2H refers to when an EV can be used to directly power a house, while V2G is when an EV injects energy back into the grid and can support it as a mobile energy

storage [60]. In this situation, the EV develops a grid balance where during peak hours the energy stored in the battery is discharged and during off-peak times it is recharged [39]. Shin et al. [61] optimized the V2H system so that the duration of V2H sustains residential load without suffering a significant load decrease during island mode.

Nevertheless, if the restoration process continues, the portion of the energy used by EVs may contribute to limiting the stored energy without the need for local power production. A strategy for supplying power in an emergency based on isolated EV charging systems is proposed in [19]. EVs can transport electricity to the island system by recharging batteries with secure energy sources. In this article, the genetic algorithm (GA) is utilized to ensure that the isolated system remains operational throughout the outage while minimizing the loss of total load.

### *B. Charging with V2G*

The frequent changes between energy injection into the grid and consumption might limit the usable life of an EV by increasing the rate of battery degradation in V2G services [39]. However, only services that require enormous amounts of energy resulting in a deep battery discharge can significantly reduce battery life.

According to studies made by [36, 62, 63], offering ancillary services such as voltage and frequency regulation has no substantial impact on battery life and will be beneficial to EV owners with reasonable price structures. However, services that need a lot of energy, such as spinning reserve, and peak shaving, cause the batteries to have a lot of depth of discharge, which reduces battery life.

Lee et al. [64] examine Hawaii's energy transition, stressing the interconnection of battery storage, renewable energy, and V2G as two of the major components of the smart grid in the upcoming years. For the case of São Miguel island, in Açores, Ioakimidis et al. [65] simulated the impact of plug-in hybrid electric vehicle technology. They identified this island as a remote island with significant RES. However, due to this island's reliance on fossil fuels, it has significant import expenses. The authors use The Integrated MARKAL-EFOM System (TIMES) to examine grid to EV (G2V) charging schemes for several scenarios of EVs with variable PHEV penetration levels. They concluded that 32% of the island's vehicle fleet may be realized. Moreover, the findings indicate that PHEV integration into the local grid system is a possibility since it has the ability to contribute significant value to the energy mix while simultaneously lowering the environmental impact of their strong fossil-fuel consumption by enabling more vRES to be brought onto the grid.

The deployment of EVs in Barbados, a Caribbean island, to aid in the integration of RES with PV was studied by Taibi et al. [66]. Two EV operation modes were evaluated in this study: scheduled charging and V2G, where V2G has shown to be the most cost-effective choice. For the island of Korcula discussed in detail in Dorotic et al. [5], Evs was shown to enhance the total amount of electricity traded with the mainland without having an impact on exchanged peak power. Similarly, in terms of primary energy demand reduction, Meschede et al. [67] achieved comparable and even better results, by demonstrating that V2G has the cheapest annual cost.

Colmenar-Santos et al. [68] examined the economics of V2G adoption in the Canary Islands using time-of-use rates for residential EV owners. They concluded that V2G would benefit both the grid operator and the EV owner, with the potential for a 50% decrease in mobility energy expenditures. Amjad et al. [31] employed Smart charging on EVs and V2G to reduce a major portion of the hydrogen vehicles. They discovered that SC raise 15% of the overall transportation demand in this case. On the opposite, hydrogen vehicles encountered a 45% decline in their utilization. Aside from that, to handle the increasing percentage of EVs that require charging and will be employed as power storage devices, the capacity of the grid for battery connection must be extended to 3000 MW.

This means that EVs are better suited to V2G services that demand quick response and reactive power but don't require a lot of depth-of-discharge at the moment. However there is not yet enough knowledge to know how much energy storage costs based on EVs compared to possibilities, for example, static battery choices, compressed air storage, and PHES mentioned before. When applied to the electricity grids of small islands, each option would have a different impact [28].

## VI. Decarbonization of Transportation Sectors on Islands

The transition to EVs should occur in tandem with increased renewable generation to support the decarbonization of transportation sectors. The combination of EVs and RES reduces the reliance on fossil fuels and polluting emissions. Nonetheless, it should be emphasized that lower emission levels increase the total planning cost [69]. Many EV proprietors are encouraged to reduce the amount of energy consumed in energy emissions and invest in RES to balance their household and EV usage [28].

To counter their substantial reliance importation of fossil fuels for power generation, islands require alternative green energy scenarios. Groppi et al. [70] created scenarios for small islands that featured battery storage and hydrogen. In this article, the authors presented the decarbonization of the electricity and road transport sectors in an environmentally sustainable way, with HOMER software. Pico and Faial islands in the Azores were studied by Alves et al. [71] to outline possible paths that could lead to 100% renewable energy systems. The results suggest that Pico Island can achieve the primary goal when compared to other islands with independent power systems. On the other hand, Faial Island only gets to 70%. Regardless, the islands' connection allows both islands to have a 100% renewable energy system [72].

A modest family-sized internal combustion engine automobile emits equivalent greenhouse gas emissions unless the EV gets a range of 5.93km/kWh. Fig. 6 compares the emissions of several types of internal combustion engine vehicles.

The carbon intensity of the grid, as well as effective electric vehicle emissions, reduces as non-carbon derived power penetration rises. The way an EV is driven, or the 'mode' in which it is driven, has a significant impact on emissions [3]. EVs won't make sense from an emissions perspective until power generation has been decarbonized by 20%, and their

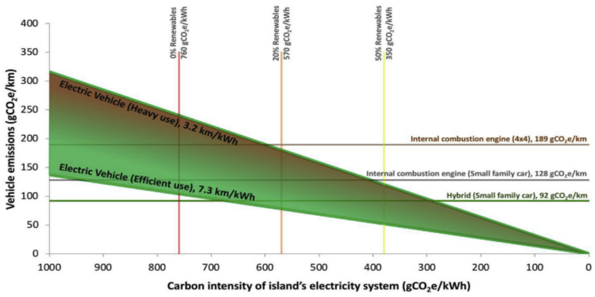


**Figure. 6**: Emissions from various vehicle types and the impact of the carbon intensity of an island energy system's electricity supply [3].

transportation systems won't be considered decarbonized until renewable penetration has reached 50%. This backs up the prior argument that to accelerate the decarbonization of transportation systems, EVs must be accompanied by renewable energy-sourced electricity.

## VII. Discussion

Islands have been identified as an excellent location to present the technological and economic viability of vRES. As the percentage of renewable energy in the electric grid has increased, concerns regarding grid flexibility and system adaptability have grown. Several solutions were suggested, with the most widely employed technology in islands being battery energy systems and pumped hydro energy storage. However, in terms of the transportation sector, EVs offer far greater prospects. The growing influence of EVs and RES makes it possible to minimize global pollution.

On islands, a microgrid system combined with EH is the most practical answer to smart island challenges. Furthermore, the microgrid system is managed through distributed optimization.

Four charging modes are mentioned to reduce the problems that EV penetration imposes on isolated electrical networks. An overview of the functionality, advantages and disadvantages of the four charging modes covered previously can be found in table 2 from Chavez et al. [34]. The best charging technique is determined by the goal to be achieved and the system parameters. For example, uncoordinated charging is better for cost reduction whereas coordinated charging is the best option for reducing the system's cost and emissions at the same time [27]. Nevertheless, they put the main grid at risk and if EV charging is uncontrolled, more storage is needed [2]. Even though SC has a low cost and encourages the use of fewer hydrogen vehicles, charging using a solar panel is the most practical and least polluting method. The disadvantage is that PV charging relies on solar irradiation variation, so there will be no night production. In this way, EVs will need to be assisted with a storage battery.

## VIII. Conclusions

This survey proposes ways to improve the grid's flexibility to cope with vRES in insular regions. Therefore, finding alternative methods to improve energy management methods and increase grid flexibility is even more important for small islands. In circumstances of off-grid or grid-connected architecture, the usage of EESS has proven to be a viable solution. The same may be true for SESs.

Small islands are a privileged market for EVs due to restricted road grids, high fuel expenses, and a necessity for direct grid storage choices. It has been demonstrated that such technology may be used to provide grid flexibility services and support grid balance management in islands without disrupting transportation operations. Nonetheless, incorporating EVs into their grids will be difficult. Their charging demand may disturb the systems' normal operation. Several solutions have been developed with the conclusion that battery energy systems, pumped hydro energy storage, and EV charging using PV are the most often employed technologies on islands.

This study focused on the idea of a smart island platform for charging and discharging EVs without using the traditional grid, as well as the obstacles they faced. Aside from that, it also discussed how to reduce the significant impact of EVs on an island, being V2G a good solution. However, V2G isn't particularly viable because there haven't been enough advancements in battery technology to make this mode of operation viable. Small islands offer a lot of potential for a prospering battery reuse industry, which may help lower EV ownership costs while also supporting local economies. The outcome is determined by the size of the island and the charging mode.

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*Table 2*: Summary of Operation Modes

| Operating Modes | Functionality | Advantages/Disadvantages |
|---|---|---|
| Uncoordinated | PHEV leave their home in the morning and return around 6:00 PM | Can compromise the grid's security and reliability |
| Coordinated | The charging time is longer than usual, particularly after 9:00 p.m | Can eliminate the need for additional production capacity and the daily demand profile is minimized |
| Smart Charging | The EV battery starts charging when there is overproduction capacity and the cost of electricity is cheap | Reduces greenhouse gas emissions and hydrogen vehicles but is highly complex and costly |
| Photovoltaic | Maximize the use of energy from the photovoltaic array to charge Evs | Simple and a viable charging option. However, variations in solar irradiation have an impact on PV charging station operation |


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