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Modelling electric vehicles uptake on the Greek islands

Eleni Zafeiratou *, Catalina Spataru

UCL Energy Institute, Central House14 Upper Woburn Place, London, WC1H 0NN, United Kingdom

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ABSTRACT

For decades, the Greek islands have been facing challenges in terms of quality of power supply, increased carbon dioxide equivalent (CO_{2eq}) emissions, and costs due to their reliance on oil-fired generation subsidised by the Greek state. In light of the recent reforms to decarbonise the islands' region while enhancing their local grids, this study investigates the impact of electromobility considering an autonomous electricity system supported by storage versus an interconnected one. Two Electric Vehicles (EVs) deployment scenarios coupled with several charging strategies have been modelled using the PLEXOS energy systems model. The results highlight that the Vehicle-to-Grid (V2G) scenarios demonstrate the most evident benefits for the islands' electricity systems, performing adequately under both the Autonomous and Interconnection scenarios concerning the economic and environmental impact. Such scenarios have the potential to reduce emissions by 8.5% while dropping costs up to 20% by 2040, when combined with the required renewables expansion plan. From the security of supply perspective, the results demonstrate improvements under the interconnected context accompanied by thermal generation restrictions without however eliminating power shortages recorded already in a non-EV case. The analysis also showcases an escalated impact on power shortages and curtailments during the maximum week, particularly when combined with an ambitious EV deployment. Yet, V2G may increase renewables share up to 7% in 2040. In this context, EVs could mobilise the additional deployment of 600 MW renewables by 2040 if interconnections with the mainland are realised. Assuming islands continue operating as autonomous electricity systems, the additional capacity to accommodate may reach 720 MW.

1. Introduction

The Greek government has considered electromobility one of the top priorities for decarbonising the transport sector, particularly in the Aegean sea, where tourism activities instigate a higher carbon footprint than the mainland [1]. Greece targets one of every three new vehicles to be electric by 2030 in parallel with the installation of 10,000 public chargers [2]. Electric Vehicles (EVs) currently account for approximately 1,120, with 334 public chargers installed with increasing trends [3,4]. From these, 31 are located on the 'Greek Non-Interconnected Islands (NIIs)' region. At the same time the 'Hellenic Distribution Network Operator (HEDNO)' has announced a plan to install at least one electric charger on every island with peak demand higher than 1 MW [3]. On islands such as Crete, the number of chargers will soon reach 35, whereas, for Rhodes and medium-sized islands, the target is to reach at least ten chargers per island by early 2023 [5].

A flagship project proposing an electromobility transformation is taking place on the island of Astypalea in Greece, as 1,500 'Internal Combustion Engine Vehicles (ICEVs)' will be replaced with electric ones, accompanied by solar and wind energy. Under the European initiative 'Clean Energy for European Union (EU) Islands', the Greek government accounted that two more islands, Symi and Megisti, will be converted into smart islands in conjunction with mini-grids, storage units and EVs [6]. Concerning other regions, on the Balearic islands, significant subsidies have been streamed towards the uptake of electromobility, which has resulted in the largest per capita network of charging points in Spain [7,8]. In the global context, Barbados has among the highest EV use per capita, while the Dominican Republic is rolling out hundreds of public charging stations [9].

Currently, the majority of the Greek islands in the Aegean Sea remain non-interconnected, comprising 29 autonomous electrical systems, out of which 19 have been included in the present analysis representing 98.7% of the total population and 97.2% of the total electricity generation produced on the NIIs (Fig. 1). These systems rely on 1,750 MW of

Abbreviations: NIIs, Non-Interconnected Islands; EVs, Electric Vehicles; V2G, Vehicle to Grid; ICEV, Internal Combustion Engine Vehicles; BESS, Battery Energy Storage Systems; RES, Renewable Energy Sources; IPTO, Independent Power Transmission Operator; G2V, Grid to Vehicle.

* Corresponding author at: Ms Eleni Zafeiratou, Bartlett, UCL Energy Institute: University College London Energy Institute, United Kingdom.
E-mail addresses: e.zafeiratou@ucl.ac.uk (E. Zafeiratou), c.spataru@ucl.ac.uk (C. Spataru).

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oil-fired capacity and 444 MW of renewable energy sources (RES) to cover their electricity demand [10,11]. Hence, the introduction of EVs can only be realised if the required infrastructure investments are in place to allow higher RES integration, which will constitute electromobility a cleaner and cheaper option than ICEVs. Such projects concern submarine High Voltage (HV) transmission extensions as proposed by the Independent Power Transmission Operator (IPTO) [12] or utility-scale energy storage systems.

1.1. Background

The impact of scenarios for the charging of EVs on the electricity system is addressed in several ways in the literature of speciality. Studies have proved that different charging strategies may have a considerable effect on the system's performance considering techno-economic aspects and balancing the grid. Nonetheless, a number of studies assess scenarios only with one charging pattern. Nunes et al. [13] proved that if solar PVs provide a large fraction of Portugal's electricity system by 2050, EVs could offer an opportunity to use that excess electricity by charging during morning hours, a case that could have high applicability to the Greek islands. However, such an approach will require changing the charging culture and probably conflict with the drivers' daily routines and commitments. Hodge et al. [14] indicate that the adoption of vehicle-to-grid (V2G) bidirectional charging will have a limited impact on the increase of wind energy in California's power system as the area has already reached its maximum penetration; hence, it will contribute to decommissioning conventional stations kept in reserve. Foley et al. [15] proposed a scenario coinciding with peak electricity consumption and an off-peak charging, assuming drivers will charge their EVs later to take advantage of cheaper electricity or use smart metering to fill in the night valley.

Modelling EVs through scenario analysis also reveals insights into users' behavioural approaches. The most common and resourceful modelling approach is to compare a wide range of charging scenarios. Mullan et al. [16] investigated the impact of electromobility, assuming a 10% share of EVs in the total fleet of Western Australia, a geographically isolated area that resembles a geographical island. It showed multiple benefits if off-peak charging is applied in the short term, while it increases the utilisation of the existing transmission capacity combined with higher efficiency in the base-load generation. At the same time, long-term benefits are foreseen related to prohibiting unnecessary investments. Hui Sun et al. [17], using a mixed logit model, predicted how certain factors impact EV users' choices in relation to regular charging. The authors showed that the likelihood of regular charging after the last trip increases for commercial users while decreases for private users. Besides, commercial users tend not to charge their EVs at night, while private users charge immediately. Ying et al. [18] used the Monte Carlo simulation to analyse EV charging patterns. The results prove that the most efficient scenario is the smart option which diminishes the user cost and, in parallel, moderates load changes and V2G.

The peculiarities of deploying EVs in isolated power systems are assessed by simulating different EV penetration levels. Kadurek et al. [19] show that if charging rates exceed a certain level, they could impact daily demand patterns while putting the system's security of supply at risk. As such, smart charging hand in hand with RES growth could contribute to ensuring the required storage and backup power in such systems. Similarly, according to Pina et al. [20], RES integration is doubled on the Flores island in the Azores when adopting a flexible charging behaviour. The benefits of electromobility for the system's reliability on Azores islands are also explored by Silva and Ferrão [21] through a range of scenarios combining renewables with EVs and energy efficiency measures. The results highlight that EVs deployment will reduce the consumption of fossil fuels in the transport sector while increasing the need for higher electricity generation capacity on the islands. A case study for Tenerife island shows that fast charging and discharging, backed by smart control systems, could flatten the demand curve [22]. The benefits of renewables development supported by EVs for Galapagos islands are investigated by Clairand et al. [23]. The authors highlight that EVs would improve the local system's operation despite significant regulatory and economic constraints related to up-front investments in local energy systems, both from an environmental and economic point of view. Da Silva et al. [24] showcases an emissions reduction of 47% once EVs are introduced on São Miguel's island when combined with high renewables integration and energy efficiency measures, yet, the V2G option is not judged economically profitable. V2G in isolated power systems was also covered by Joa et al. [25], demonstrating that EVs could contribute to voltage control when connected to the system in case of sudden changes in dispatched load. Overall, the literature indicates that electromobility can significantly diminish excess renewable energy produced in an island electric system while reducing costs.

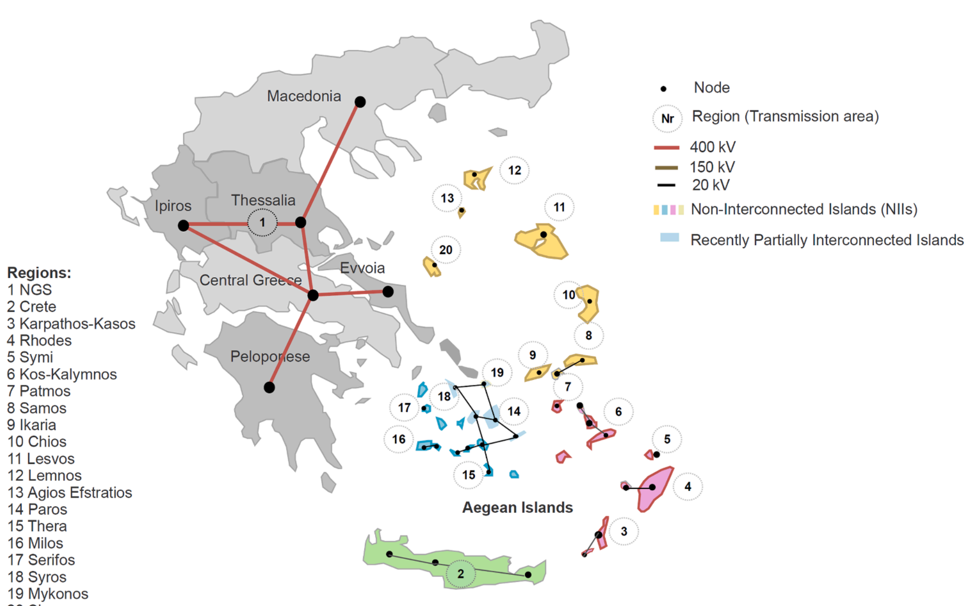

Fig. 1. Representation of the Greek NIIs and the mainland in the model.

1.2. Contribution and paper structure

The Greek islands' electricity system undergoes massive transformations with new transmission extensions installed between the islands and the mainland. At the same time, utility-scale Battery Energy Storage Systems (BESS) are being investigated, allowing the maximum penetration of renewables while providing a smooth power supply with reduced generation costs. In light of these reforms, this paper proposes for the first time a wide range of charging scenarios for the Greek islands. Despite the strong political will to accelerate EVs deployment, there has been a lack of published research regarding the endurance of the current system configuration to welcome additional loads via charging. Such methods are applied using PLEXOS, a software tool for energy planning, simulating and optimising electricity and gas markets developed by Energy Exemplar [26]. PLEXOS is commercially available and free for academic purposes. In this respect, the model developed for the Greek islands could be adapted and replicated in other regions worldwide, subject to access to relevant data.

The remaining of this paper includes the methodological approach (section 2), the background information considered in the two scenarios proposing an autonomous versus an interconnected future for the Greek islands, the deployment scenarios and the charging profiles. The third section provides the modelling results and discussions along the following key dimensions: security of supply, economic and environmental impact in terms of carbon dioxide equivalent (CO_2eq) emissions reduction. The main conclusions are summarised in section 4.

2. Methodology

2.1. Modelling approach

2.1.1. Electricity system

The Greek electricity system in PLEXOS model is defined by six (6) electrical nodes on the mainland and 46 electrical nodes in the islands region. Nodes are the primary connection locations for transmission lines, generators, and other components such as purchasers in PLEXOS, forming in the current analysis 20 transmission regions (R).

To model EVs' impact on the 19 Greek island electrical systems, we encompassed EV deployment projections for two milestone years, 2030 and 2040. The model ran between 2020 and 2040 with an annual timestep via the 'Long Term (LT)' cost-optimisation module as described in Eq. (1) [27,28]. The LT module optimises the necessary investments concerning generation, storage and transmission capacity on each transmission region (R) that operates independently or interconnected. The LT utilised a quarterly load duration curve with 12 time slices and an hourly resolution. The model applies transmission extensions interconnecting the Greek islands with the mainland according to the plans published by the IPTO [12,29–32]. New generation capacity and storage deployment are also calculated endogenously in PLEXOS, following scenario analysis considering data for existing applications and assumptions for future installations as well as the specificities of each electrical system [1,33,34]. As extracted from the LT investment phase, the results were introduced in the 'Short-Term (ST)' dispatch simulation module using hourly resolution, where EV simulations were executed.

The ST emulations were performed for a weekly representative horizon per milestone year, considering the average (AVG) loads (23 to 29 May). In the context of measuring the reliability impact on extreme loads usually recorded during the summer and particularly in August when high tourism volumes visit the Greek islands, the maximum (MAX) week (10-16 August) has been simulated. In order to select the representative weeks, the approach adopted by Hatziargyriou (2012) and HEDNO (2019b, 2020a) was applied by considering hourly data for 2016 alongside 4-year monthly data (2012-2015) on each electrical region. The ST module uses full chronological optimisation with an hourly time step and rounded relaxation. Cost optimisation obtains the least-cost dispatch of each power plant; considering the merit order, when the supply meets a given demand profile. RES generation is based on stochastic optimisation based on five years (2012-2016) of historical data by the National Aeronautics and Space Administration [37]. Conventional sources also consider data regarding fixed, variable and built costs as specified in [34,38–44]. Carbon costs per energy unit produced are extracted from the EU Reference Scenario [45]

Renewable and conventional technologies are subject to constraints. According to Directives 2010/75/EU and 2015/2193/EU [28,46], oil-fired power generation is hampered to 1,500 and 500 hours respectively from 2020, while from 2030 onwards, the maximum operational hours decrease to 500 horizontally. On the other hand, unless energy storage systems are deployed, integration of new RES in the autonomous state is limited by the constraint that installed RES capacity for a year (y) is less than or equal to 30% of the forecasted annual peak demand for a year (y+1) [47]. In parallel, a set of constraints was inserted in the model, which ensures that the committed reserved capacity is always higher than a specific forecasting error rate (ERi), reflecting hourly RES intermittency multiplied by the forecasted hourly RES production [48].

Minimise:

$$\sum_{y,g} DF_y * \left(BC_g * GB_{g,y}\right) + \sum_{y} DF_y * FO\&M * P\max_g * \left(Units_g + \sum_{i \le y} GB\ Units_{g,i}\right) + \sum_{t} DF_y * GL_{g,t} * (\mathrm{HR * Fuel\ Price\ +\ VO\&M}). + \sum_{t} DF_{t\in y} * L_t * (\mathrm{VOLL} * \mathrm{USE}_t) \tag{1}$$

Where:

'g' is the generator; 't' is the dispatch period; 'DF' is the discount factor [DFy = 1/(1 + D)y where 'D' is the discount rate]; 'y' is the ultimate year of the projection horizon considered in the model; 'BCg' is the overnight build cost of the generator 'g' or transmission line; 'GBg' is the number of generating units build in the year' i' for generator 'g'; 'FO&M' are the fixed operations and maintenance costs of generator 'g' including also abatement costs; 'Pmax' is the maximum generating capacity of each unit of the generator 'g'; 'Units' is the number of installed generating units of generator 'g'; 'GB Units' is the number of built generating units of generator 'g'; 'GL' is the dispatch level of generating unit 'g' in period 't'; 'HR' is the heat rate; 'VO&M' are the variable operations & maintenance costs including also emissions and abatement costs; 'Lt' is the duration of dispatch period 't'; 'VOLL' is the value of lost load (unserved energy price = 3000€/MWh [30]); 'USE' is the unserved energy

2.1.2. Electric vehicle (EV) charging loads

EV charging loads were emulated using the 'Purchaser Function' in PLEXOS, which requests additional power above the native and pump/utility battery storage demand recorded Eq (2). The model's electricity price is configured, considering the dispatch merit order, including the additional loads.

$$\mathrm{Load}_{R,t} = \mathrm{NL}_{R,t} + \mathrm{PL}_{R,t} + \mathrm{BL}_{R,t} + \mathrm{PL}_{S,\ R,t} \tag{2}$$

Where:

'Native Load (NL)' is the actual consumers demand per region 'R' for each time unit 't'; 'Pump load (PL)' is the load requested to pump water in hydropower systems; 'Battery Load (BL)' is the charging load from utility-scale batteries; 'Purchaser Load (PL)' is used to simulate EVs charging load for certain time zones during the day for each deployment scenario (S).

In this study, the vehicle batteries were emulated as one single large unit per island. The actual capacity of EV batteries on each electrical region (BSEV)[1] was configured as described in Eq (3), considering the

[1] The BSEV per island included in Appendix A.

size of a typical EV battery (BSEVt) corresponding to a Fiat 500e for 2030 and a Volkswagen ID.3 Pro S for 2040 [49–51]. The actual load for each island (EVL) was calculated by pondering the percentage (%) of EVs charging at a specific time (t) multiplied by the capacity of the charger (C_c) per deployment scenario (S) [Eq (4)].

$$BSEV_{S,R,y} = \text{Number } EVs_{S,R,y} * BSEVt_y \quad (3)$$

$$EVL_{S,R,y,t} = \text{Number } EV_{S,R,y,t} * (\% \text{ EV connected}_{S,y,t}) * Cc_{S,y} \quad (4)$$

The input assumptions used to describe the types of EVs and the charging infrastructure in the modelling exercise are included in Table 1. A minimum state of charge (SoC) at 20% was considered to avoid the fast ageing of batteries. Efficiency for charging and discharging (η_{conv}) has been set at 88% [52]. The charging and discharging rates are estimated considering the average driving distance set on each island per day and the EV's average consumption, as well as the pattern to represent drivers' daily habits in terms of the hour of departure and arrival [53,54].

2.2. The deployment of EVs on the Greek Islands

In order to measure the impact of electromobility on the Greek islands, it was assumed an analogous EV deployment with the mainland from 2020 to 2040. A regression analysis was applied between the GDP growth rate [58] and new sales to project future passenger vehicles registrations in Greece. Also, an annual scrap rate[2] of 40,000 vehicles/year was assumed [59]. The original 2017 figures and historical registrations for each island were provided by the Hellenic Statistical Authority [60]. Balanced growth of passengers cars is expected across all islands due to the absence of regional historical figures.

Two EV deployment scenarios were included as there is still uncertainty in the EV adoption pace in remote regions such as the Greek islands (Figure 2).

I **Scenario 1 (S1)** supposes slow growth in line with the MERGE EU project figures, which were published back in 2010, assuming EV penetration of 4% in 2030 and extrapolated to almost 20% in 2040 (approximately 125 thousand EVs) [35,61].

II **Scenario 2 (S2)** supposes the achievement of the target of 24% integration of EVs into the passenger vehicles market by 2030, according to the 'Greek National Climate and Energy Plan (NECP)' published in 2019 [1]. In 2040, the figures are extrapolated to 82% share, translating into 517 thousand EVs deployed on the Greek islands.

Table 1
EVs modelling input assumptions [49–51,55–57].

Modelling Input Assumptions	Unit	Year	
		2030	2040
Average Distance per weekday	Km[1]	20-37	
Average Distance per weekend	km	16-30	
Average Consumption	kWh/100km	17,11	
BSEVt	kWh	24	77
EV range	km	150	450
Electric Charger - residential (C_c)	kW	3,7	7
Electric Charger - public (C_c)	kW	22	43

[1] Subject to the size of the island as indicated in [55].

[2] Concerning cars whose materials are discarded, reused or recycled.

2.3. EV Charging Profiles

2.3.1. Grid-to-vehicle (G2V)

Overall, the scenarios are emulated in two different states: A) the Autonomous-Batteries considering the deployment of 1.38 GW BESS as a result of optimisation analysis in PLEXOS, in a context without generation restrictions in oil-fired steam and gas turbines, and B) the Interconnection building 13 GW of submarine interconnection capacity in a framework applying generation restrictions according to Directives 2010/75/EU and 2015/2193/EU [28,46].

Firstly, a baseline was set with a non-EV scenario for 2030 without EV loads. One of the most critical requirements in simulating EVs is to ensure that the car has sufficient energy to complete the next day's trip. As long as this prerequisite is met, the power system operator can optimise the timing of charging and discharging, the intensity of the loads (or the generation dispatched for bidirectional use) and the speed at which these operations are executed. Hereafter, seven Grid-to-Vehicle (G2V) charging patterns were introduced. Each charging profile was developed to capture the impacts of controlled and unconstrained charging patterns, as described in Table 2.

Regarding the weekly driving distance per island, the specificities of the typical EV are taken as an example, and the requirement to have the car sufficiently charged early in the morning. In this context, the recharging must take place twice a week. Alternatively, an opportunistic approach assumes that daily charging occurs, requesting lower demand loads. Opportunistic, Unscheduled daily charging assumes more cars (batches of 30% to 40%) charging simultaneously than the rest of the Scheduled scenarios, assuming cars charge for two hours in batches of 20% of the total EV car fleet. Daily Morning charging supposes that most active users will schedule to plugin their car during the first hour they arrive at work and before they leave but less during lunchtime. The Public charging profile is combined with a Scheduled one assuming that 40% are charging their cars at home during the night and the rest, 60%, with public chargers during the evening (inspired by the analysis conducted in [62]). By 2040, faster chargers will become available and affordable. However, fast charging comes with a cost as, notwithstanding the lower number of EVs connected simultaneously to the grid, there is a tradeoff related to the chargers increased capacity affecting the loads.

The charging profiles presenting the EV loads for S1 and S2 are illustrated in Figure 3 and Figure 4. The time duration of all biweekly charging profiles is anticipated to shift during the day. In 2030, assuming that EVs are charged with slow chargers at home or work, there is a requirement for six hours of charging to reach a 95% SoC. On a daily basis, this is diminished to two hours. With fast chargers in public spaces, one-hour charging is sufficient. By 2040, biweekly charging at home requires only two hours, with the requested load rising steeply. Despite the increase in EVs deployment, the charging timespan is shortened to 20 min for Public charging.

2.3.2. Tourism

The impact on local grids from 'imported' electric vehicles belonging to or used by the tourists during summertime is investigated. Rental car companies listed were recorded and their available fleet [63]. That load was extracted from the AVG week and added during the MAX load week. Furthermore, imported EVs that travel with ferries were included alongside the local fleet during that week. Tourists were divided between those arriving by plane and ferry [64]. It was assumed that 60% possess a car with three passengers per vehicle from those arriving by ferry to the islands [54,64]. The final number of additional EVs due to Tourism activities is illustrated in Fig. 5, showcasing such a scenario's extensive impact.

The hybrid-controlled charging pattern assumed that 30% of the hotels would have chargers available for their customers and 70% would charge with public ones. By 2040, the number of hotels that can offer night charging could increase to 60%, considering learnings from the

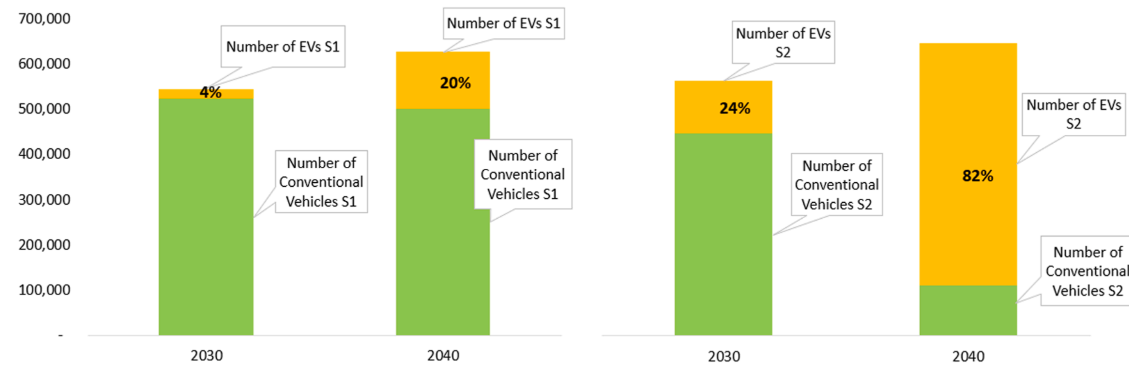

Fig. 2. EV deployment scenarios S1 and S2 versus ICEVs.

Table 2
G2V charging scenarios description.

N	Category	Charging Profile Scenario	Timeframe		% of EVs connected to the grid simultaneously (hourly)	
			2030	2040	2030	2040
I.a	**Controlled**	Scheduled	00:00-7:00	00:00-7:00	100%	50%
I.b		Scheduled (daily)	00:00-7:00	00:00-7:00	20-40%	20%
II.a	**Uncontrolled**	Unscheduled	18:00-01:00	18:00-22:00	100%	50-100%
II.b		Unscheduled (daily)	18:00-22:00	18:00-21:00	30-70%	20-40%
II.c		Public Charging[1]	18:00-20:00	18:00-20:00	30%	30%
			00:00-7:00	00:00-7:00	40%	20%
III.a	**Morning**	Morning	10:00-16:00	10:00-15:00	100%	50%
III.b		Morning (daily)	10:00-16:00	10:00-15:00	20-40%	20%

[1] Biweekly night charging for the number of vehicles which have access to private chargers.

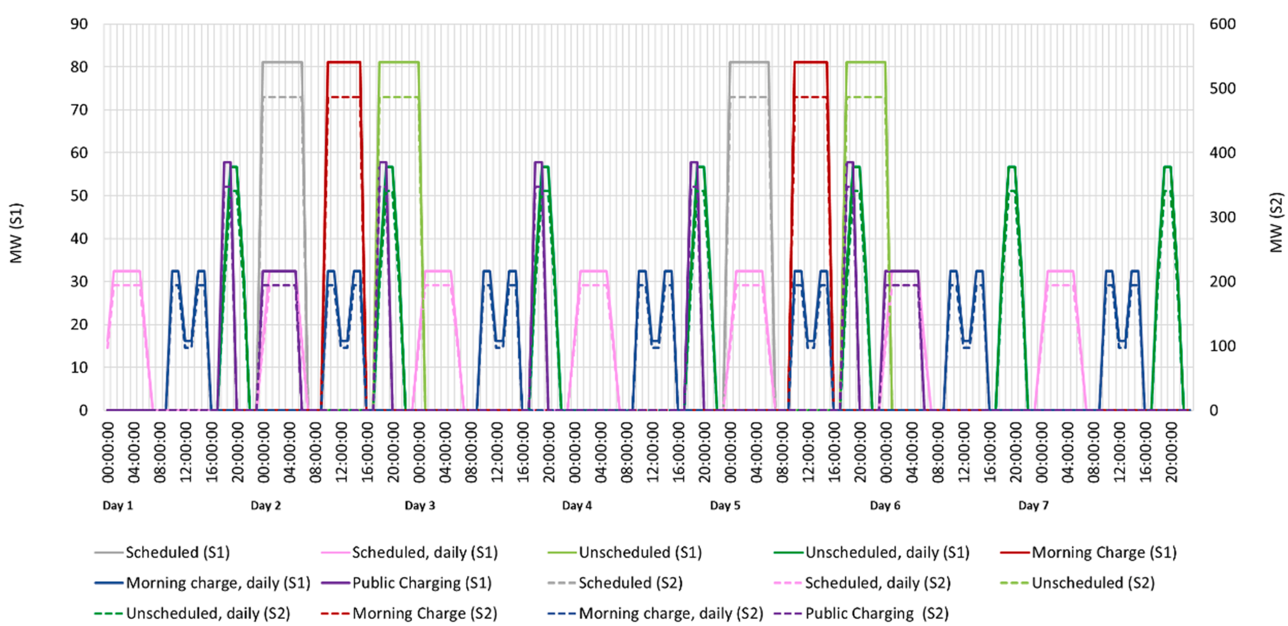

Fig. 3. Charging profiles 2030 - S1 and S2.

United States[3] [65]. The charging times have been proposed bearing in mind typical patterns of tourists activities [66,67] (Table 3). The Tourism scenario is combined with the Public charging option to test the system's impact under a critical pattern. The charging profiles for the two scenarios, S1 and S2, are illustrated in Figure 6 and Figure 7.

[3] https://www.plugshare.com/map/hotels.

2.3.3. *Vehicle to grid (V2G)*

RES curtailment, concerning reduced energy from the generator to the grid, would be limited to 8% - 13% instead of 10-23% on an island case study if they were coupled with V2G smart charging technology [68]. The V2G concept allows dispatching power to adjust EV charging and discharging levels to flatten peak demand, fill load valleys and provide ancillary services to assist in the real-time balancing of the network. Furthermore, smart charging could support distribution system operators to mitigate congestion and help users manage their energy consumption and increase their rates of renewable power

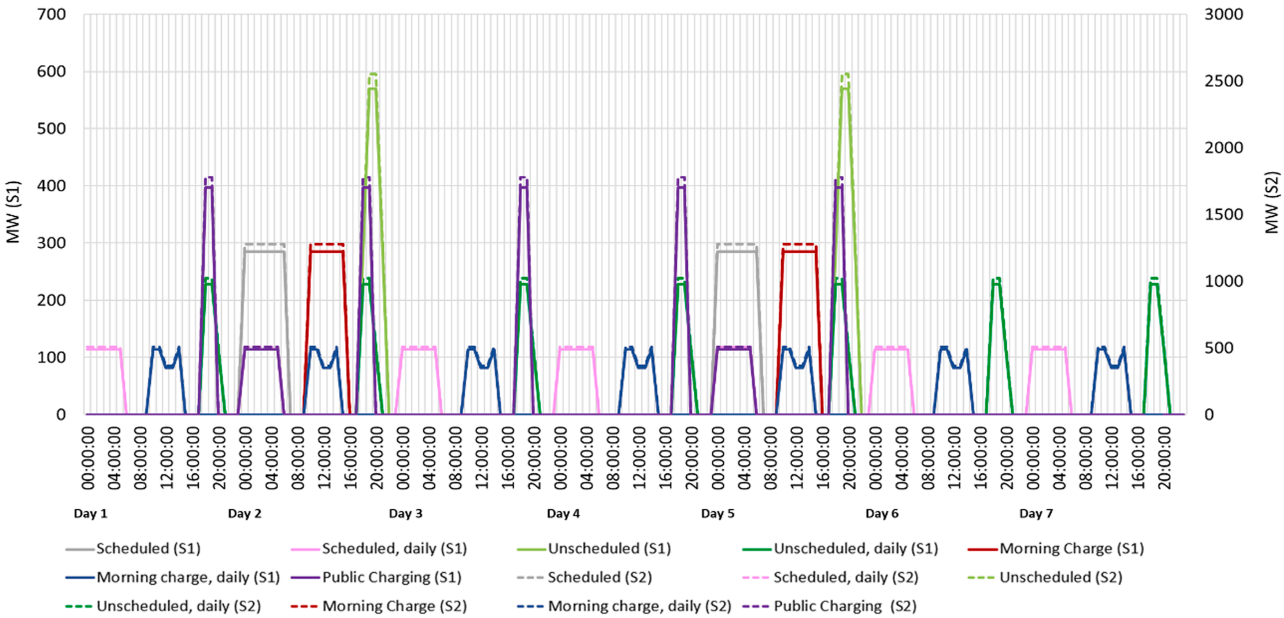

Fig. 4. Charging profiles in 2040 - S1 and S2.

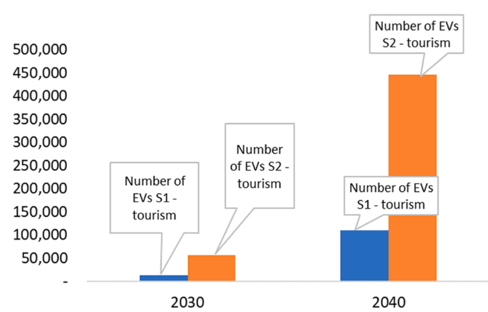

Fig. 5. Number of additional EVs due to tourism activities.

self-consumption [68]. The downside of bidirectional charging is the wear on the vehicle's battery and the transformers and power quality degradation.

In PLEXOS, electricity evicted from vehicles to the grid was imitated using the storage function. Two storage objects were linked to the generator representing the EVs (Fig. 8). The head storage imitates the vehicle's battery, providing power to the car. In contrast, the tail storage represents a virtual pool from which the head storage can pump electricity and charge the EV's battery. The discharging of the car takes place through an hourly 'natural outflow (NOut)' function in Eq (5), representing the energy consumed throughout the day, assuming a timespan between 09:00 to 18:00. In order to keep the balance between the two storages, the same positive natural inflow is entering the tail storage. When the car is not connected to the grid, the power generator capacity and the pumping loads are set to zero. Herein, two charging scenarios were included, the **V2G** (Unconstrained) and the **V2G-restricted,** as indicated in Table 4.

$$\mathrm{NOut}_{S,\ R,t} = \text{Daily Distance}_{R} * \text{ Average Consumption EV}_{R} * \frac{\text{Number of EVs}_{S,R}}{\text{Hours out of plug}} \tag{5}$$

EV discharging entails variable costs which contribute to configuring the merit dispatch order on each island's electrical system. The EVs' cost of electricity is set in the PLEXOS model as described in Eq (6) [69]. For providing an incentive to EV owners to contribute through pooled EV groups to the electricity market, a markup equal to 10% of the cost of electricity C_{el} was considered in the model.

$$C_{V2G} = C_{el}^{EV} / \eta_{conv} + C_{deg} \tag{6}$$

Where:

C_{el}^{EV} is the cost of electricity for discharging the car during the valley and off-valley hours; η_{conv} is the discharging efficiency of the EV battery; C_{deg} is the car's degradation cost relevant to the V2G operation, calculated according to Eq (7).

$$C_{deg} = C_{bat} / (E_C * BSEVt * DoD) \tag{7}$$

Where:

C_{bat} is the cost of the EV car battery, including the replacement labour cost; E_c is the battery's lifetime in cycles (Table 5); DoD is the depth of discharge.

All G2V charging options, as well as the Tourism scenario and V2G strategies in 2030 and 2040, simulated for the autonomous and interconnected state of the Greek islands are illustrated in Fig. 9.

Table 3
Charging patterns in Tourism scenario.

N	Category	Charging/Discharging profiles	Timeframe		% of EVs connected to the grid simultaneously (hourly)	
			2030	2040	2030	2040
IIV	**Tourism**	Timeframe of charging	00:00-07:00 10:00-13:00,16:00-19:00	00:00-07:00 10:00-13:00,16:00-19:00	10% in hotels 4-8% in public chargers	10% in hotels 2.8% in public chargers
		Timeframe of discharging	7:00-10:00, 19:00-00:00	7:00-10:00, 19:00-00:00	Driving or parked - not plugged in	

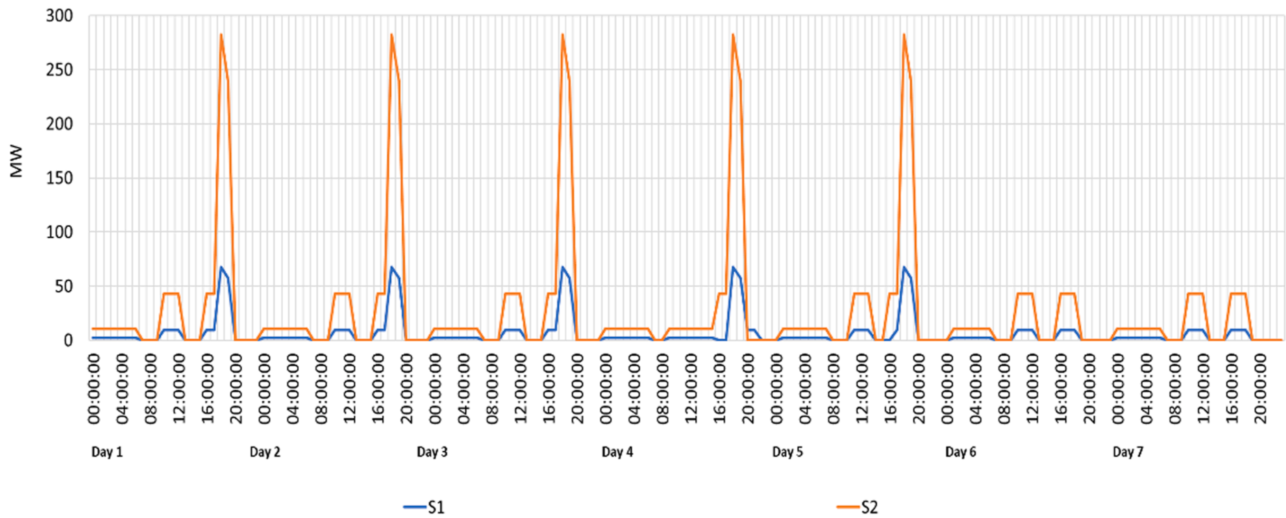

Fig. 6. Charging profiles in 2030 (Tourism) - S1 and S2.

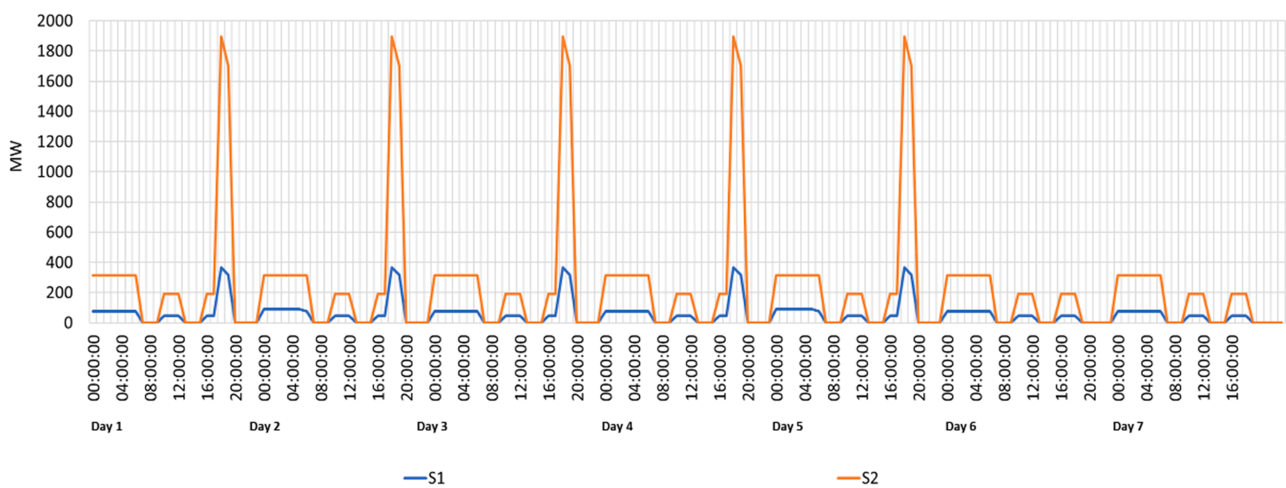

Fig. 7. Charging profiles in 2040 (Tourism) - S1 and S2.

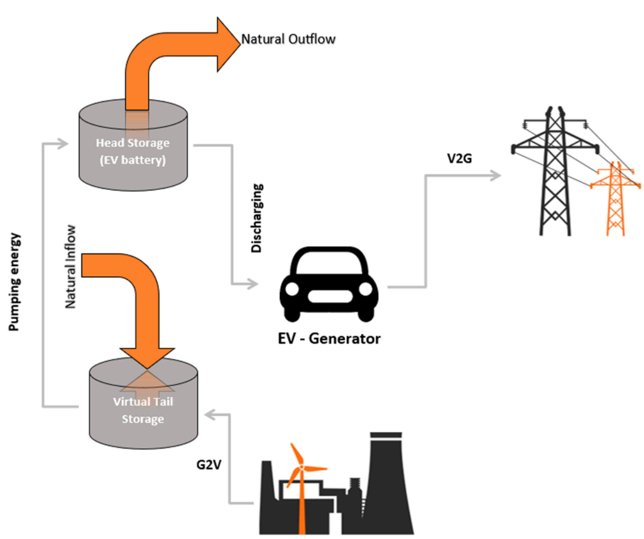

Fig. 8. V2G schematic applied in PLEXOS model.

3. Results and discussions

3.1. Security of supply impact

3.1.1. Load profiles

The mean daily demand profiles concerning the average (AVG) week in 2030 and 2040, under the autonomous context, are illustrated in Fig. 10. The Unscheduled daily scenario fills the nighttime valley during which utility-scale batteries are charging, whose power is used in the evenings to cover EV demand. Under a more ambitious (S2) scenario, the trends are intensified, resulting in sizable spikes mainly deriving from the biweekly Morning, Unscheduled charging and Public charging scenarios. Consequently, the benefits of V2G and Scheduled daily charging, where EV owners choose to plug in their vehicles at home, become most prevalent under such an ambitious context. Differences between the V2G and V2G-restricted options are mainly related to the fact that cars are not allowed to be charged and discharged during evening peaks, which, beyond the noticeable impact on the grid, also generate higher energy quantities early in the morning. V2G generation is dispatched considering demand requirements, committed thermal units, and the available power produced by renewable energy, particularly wind, following the dispatch merit order.

Uncertainty in the power system increases by 2040 as more renewables and EVs are deployed on the islands. The charging options

Table 4
V2G and G2V Charging Profile.

N	Charging Profile Scenario	V2G and G2V Time frame		Discharging (off the grid)
V.a	V2G	00:00-08:00	18:00-23:00	9:00-17:00
V.b	V2G - restricted	02:00-08:00		9:00-17:00

Table 5
EVs specifications considered in the V2G analysis [52,70].

Indicator	Value
Reference cost	145 €/MWh (2030) 125 €/MWh (2040)
η_{conv}	88%
DoD	80%
E_c	0.01% degradation per cycle[1]

[1] Assuming two cycles per week for 52 weeks, per year, in 12 years, the car will have lost approximately 12.5% without V2G operation. Under a V2G scenario the lifetime of a battery can be reduced to 7-8 years.

stressing the system the most are Morning and Public scenarios and, in general, the biweekly scenarios that cause overloading while putting transformers at risk, leading to sharp demand load spikes. Under the Autonomous-Batteries scenario, the V2G restricted pattern creates a relatively smooth profile while contributing with power injections. V2G generation increases during specific timeframes as onshore wind and solar deployment are not aligned with the demand requirements, while no interchange between off-shore wind farms developed in the region and the islands takes place.

Under the interconnection case, similar trends are observed (Fig. 11). In the absence of storage to regulate demand and supply discrepancies, EV charging impacts loads directly, especially under the biweekly profiles. The charging load is partially covered by increasing imports from the mainland and local renewable generation. However, V2G and daily Scheduled charging options demonstrate a feasible path by smoothening the daily demand profiles. V2G injection to the grid is considerably higher in this context (320 MW versus 46 MW in the autonomous), especially during evening peaks. This shows a larger margin for V2G systems deployment since flexible local thermal generation is shut down.

When considering the MAX week representing loads usually encountered over the summer, more gas turbines are already committed in the autonomous context due to the comparatively higher demand. Therefore, lower levels of V2G generation will be dispatched. On the contrary, the interconnected system exceeds 1900 MW due to the absence of local thermal generators. Overall, daily off-peak Scheduled charging patterns demonstrate satisfactory results. However, the effect of EVs is escalated considering Unscheduled, Tourism and Public charging, which takes place with fast chargers over a short period in bulk. These recording demand spikes stress the system as there is a lack of sufficient flexible units to cover up to 2.4 GW additional load.

3.1.2. *System balancing and reliability*

Despite the undeniable benefits of electrifying mobility providing a sustainable energy mix, EVs add uncertainty to the grid, subject to charging and discharging timing, quantity, location, and connection. Thus, the importance of an integrated energy plan considering the future requirements and opportunities emerging from the use of EVs is undeniable. For this section, the impact of EVs deployment on the MAX week was visualised due to the considerable strain added to the system over periods recording the annual peaks.

According to Fig. 12, the Autonomous-Batteries scenario triggers limited power shortages under the Unscheduled daily or biweekly charging profiles as well as under the Public and the Morning charging options. During the 2030 AVG week, the Unscheduled profile will not satisfy 0.4% of the demand required under S1, while this figure is amplified to 0.65% under the S2-ambitious scenario. During the 2030 MAX week, peak-charging scenarios range at low levels between 0.1% and 0.2% under both S1 and S2. The V2G restricted scenario will also experience power cuts equal to 0.5% of the total demand due to increased charging loads before the morning departure. By 2040, power shortages will increase both in terms of frequency and duration. Under S1, during the AVG week, the impact is limited. Nevertheless, under an ambitious scenario (S2) where EVs add up to 2400 MW/hour in the system, unserved energy will skyrocket to almost 6% in peak charging scenarios, e.g., Public charging, Unscheduled patterns. Furthermore, over the MAX week representing the summer months, the unserved demand in the Tourism scenario is going as high as 2% under S1 and 3.6% under S2, proving that relevant investments in power generation and transmission capacity should occur concurrently with EVs deployment.

The islands' electrical system (R), most volatile to power shortages under the autonomous state, are mainly located in the Dodecanese complex, including Kos-Kalymnos, Rhodes, Kasos-Karpathos and Symi, exposing the fragility of these remote electrical systems. A rapid scale-up of transport electrification by 2040 will also create significant power shortages of up to 4.5% on islands such as Crete, Paros and Syros as highly touristic destinations.

Assuming an interconnected islands network, the most affected islands are Crete, the Dodecanese region, and Thera in the Cycladic region. During the AVG week of 2030, assuming a moderate growth of EVs (S1), a reduction in power shortage across all scenarios is recorded compared to the non-EV case recording unserved demand due to generation restrictions. However, under the ambitious S2 scenario, most charging profiles evidence power shortages as high as 4% of the total demand. Exceptions remain the Scheduled daily options and the V2G scenarios that enhance local flexibility, allowing them to inject energy into the system during late evening hours when power shortages are usually recorded. Over the MAX week in S1, most charging profiles range at the same levels as a non-EV scenario, close to 6%. This is not the case in the S2 scenario, where the Morning scenario cannot satisfy 9% of the demand. The Tourism impact becomes even higher under the Interconnection scenario where imported EVs belonging to tourists cause significant amounts of unserved energy ranging between 5% (S1) and 7% (S2) in 2030 while exceeding 9% in 2040. Those scenarios that reduce unserved demand are mainly the V2G scenarios that bring down power shortages by 30-100% compared to a non-EV case.

Options favouring Scheduled daily charging also succeed in avoiding curtailments while filling valleys and contributing to peak shaving in the Autonomous-Batteries scenario. Over the 2030 AVG week, the Scheduled and Daily Morning scenarios record values similar to the baseline, non-EV profile, while the Public, Unscheduled and biweekly Morning profiles increase up to 2.5% (Fig. 13). Considering the S2 case, these incidents are amplified. Particularly, 3.5% of energy spillage is recorded assuming Public charging under a moderate load profile. The Unscheduled daily scenario records the highest values at 3% over the MAX week, anticipated due to a misalignment between demand loads and wind energy generated during the night when fully charged batteries cannot absorb it. Such phenomena result in more charging and discharging full cycles that deteriorate battery lifetime. In parallel, they restrict utility BESS installed on islands to discharge up to the minimum SoC, usually between 18:00 and 21:00. In 2040, the Unscheduled scenario continues to be the least efficient scenario, with 4.5% of curtailed energy recorded during the AVG week, considerably higher than a non-

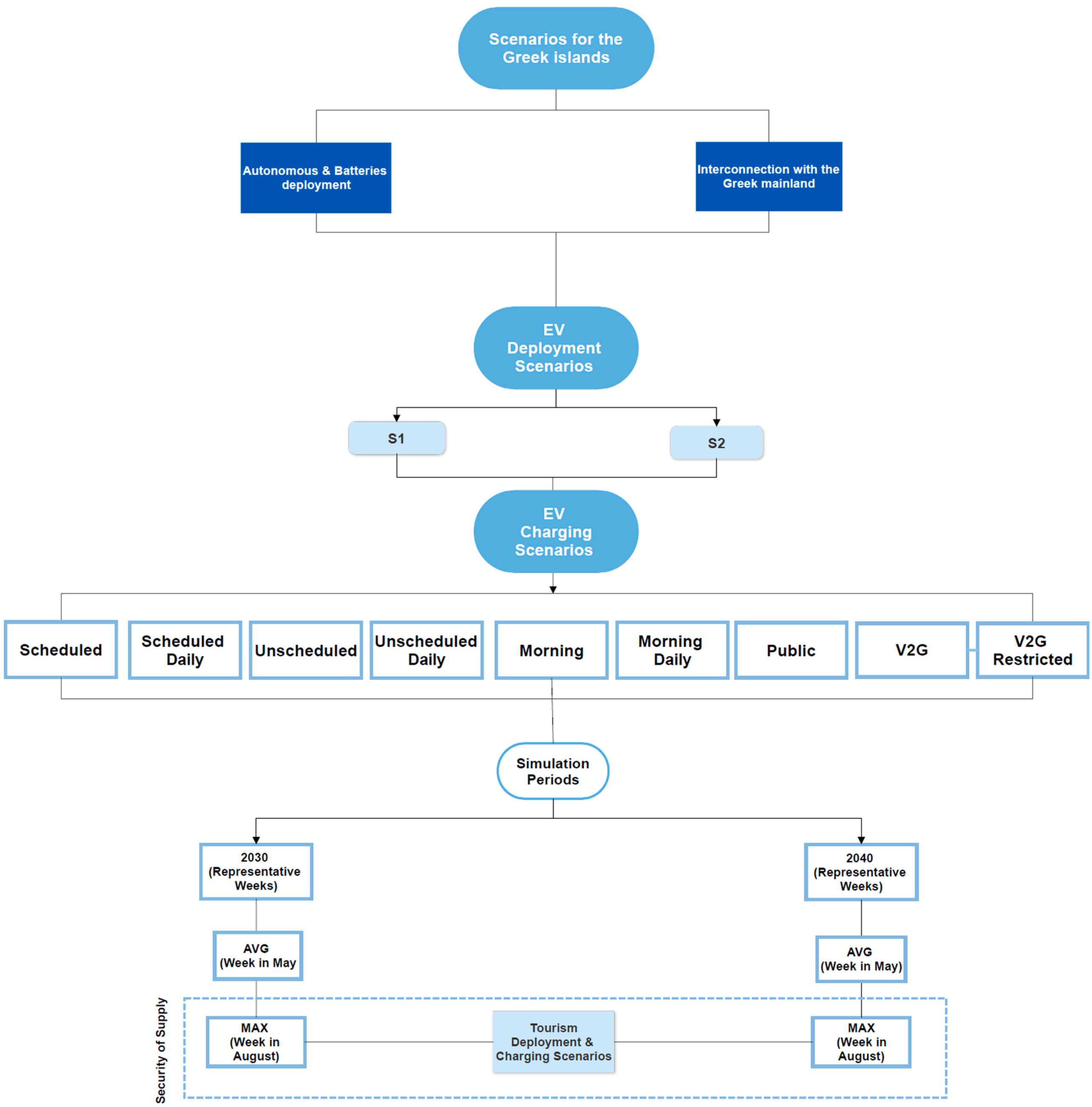

Fig. 9. Overview of EVs scenarios developed.

EV scenario curtailing approximately 0.9% of the total RES generation. In the MAX week, the Tourism scenario records values exceeding 4% under both S1 and S2.

In the Interconnection scenario, curtailed energy is relatively lower than in the autonomous case considering no EVs deployment, as it allows power flows exchange among the islands and the mainland. While there is a limited impact on the grid during the AVG week, in the MAX, curtailed energy increases across all the scenarios, with the highest figures of almost 4.2%, recorded in the Morning daily and Tourism scenarios. This is because EV charging during morning hours fails to smoothen the demand curve while shifting hydro storage generation from evening hours to 14:00 to 16:00 to serve the requested loads. Curtailed energy occurs mainly on islands operating hydro pump stations due to constraints, forcing them to inject energy during valleys while shifting the pumping schedule to accommodate EV charging requirements. In 2040, there is a significant increase in curtailed power, especially during the MAX week under the peak charging scenarios, underlining the negative impact of uncontrolled charging loads on the grid. The Tourism Scenario reaches as high as 5% in S1, whereas in S2, it exceeds 8%, exposing the severe impact of such a trajectory. Assuming submarine transmission extensions occur, the V2G and Scheduled daily patterns eliminate curtailments, while in a more ambitious (S2) scenario, only the V2G restricted pattern keeps the curtailed values below 2%.

3.1.3. Renewables integration

Electric vehicles will play a role in supporting renewables development if optimally placed during the day, considering seasonality trends in demand and RES generation. In the autonomous case, renewables generation is relatively low under a baseline non-EV scenario as new RES are limited by the constraints discussed in section 2.1.1. Therefore, there is an inevitable decrease in RES share when EVs are introduced in

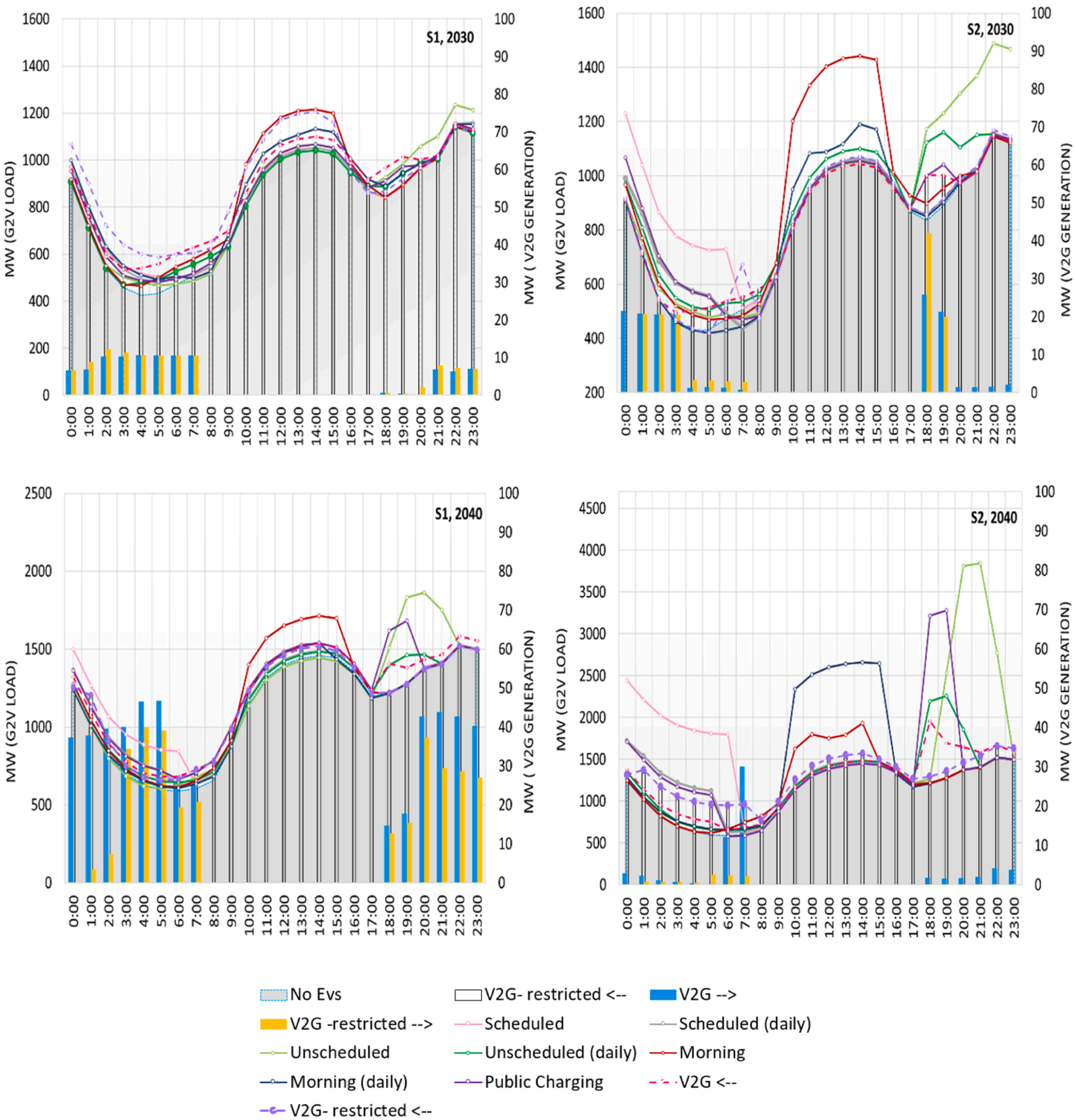

Fig. 10. Representative daily EV load profiles (Autonomous-Batteries scenario).

2030, reflecting thermal generation dispatch as the only alternative (Fig. 14). Almost all G2V scenarios require a higher thermal capacity to meet demand. This is indicated in the Unscheduled scenario creating a deficit in RES generation of 13%, while in the Morning scenario, the reduction reaches 19%. Presuming that an ambitious EVs (S2) scenario is in place, the only patterns to increase RES share are the V2G scenarios by increasing the charging and discharging cycles of battery storage while forcing higher capacity factors in hydro pump stations. In 2040, during the AVG week, Morning daily, and V2G scenarios, RES share increases in the generation mix between 4% and 6% as there is approximately a twofold growth in renewables installed with ample margins for operational optimisation. In particular, the results show curtailment elimination of solar, whereas hydropower dispatch increases during morning hours. The rest of the scenarios continue recording reduction in renewables participation in the electricity mix.

Considering the MAX week, such phenomena are intensified with RES share reduction to 31% under S2 Public charging and 28% under Tourism. Only patterns such as the Scheduled daily and V2G-restricted succeed in containing EVs impact on the electricity mix by limiting RES reduction share to 8% and 14%, respectively.

In the Interconnection scenario, in 2030, considering average generation loads, the V2G scenarios prevail across both a moderate and an aggressive EV deployment case (Fig. 15). Assuming all interconnections are realised by 2040, V2G scenarios optimise local capacity only under S1 with up to a 7% RES increase, while daily Morning charging sustains its satisfactory performance. In an ambitious S2 scenario, all patterns will trigger significant additional imports topped up with local thermal generation, reducing the participation of RES in the energy mix. In contrast with the Autonomous-Batteries case, results on the MAX week in 2040 demonstrate better performance across most scenarios due to

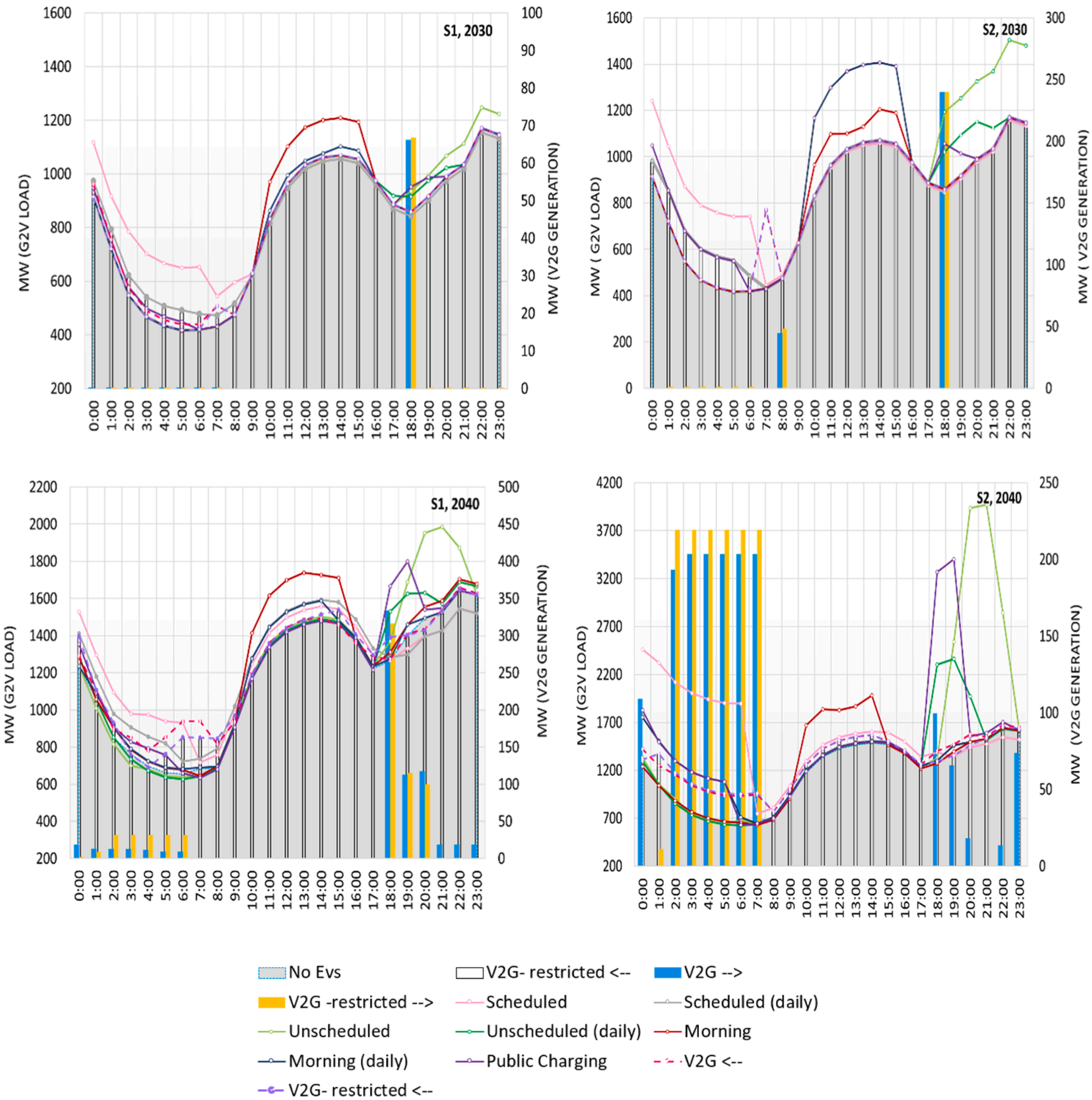

Fig. 11. Representative daily EV load profiles (Interconnected scenario).

higher solar irradiation and wind speeds. Notably, the V2G-restricted scenario increases RES participation in the mix by 5%.

Even though general trends are observed, certain specificities are also related to wind and solar stochasticity in modelling but also geographical variations. For example, under the S2 Scenario, Crete records lower RES reduction during evening peaks than the S1 case, demonstrating marginally higher wind speeds over that week, considering the stochastic dimension included in the modelling analysis regulated in PLEXOS. Overall, the results prove that EVs can mobilise more stochastic and dispatchable renewable energy projects, as indicated in Table 6. Furthermore, as renewables generation is highly seasonal, there is not always one optimum solution across the year. Therefore, beyond the undeniable better performance of the V2G scenarios, the outcomes showcase that Morning daily charging could support the injection of more solar power over weeks that the demand is relatively low but the irradiation relatively higher. Unscheduled, Public and Morning biweekly options increase further the use of oil-fired units due to the incapacity of the available RES to cover the demand.

3.2. Economic impact

The integration of EVs shows that the highest generation costs are usually recorded in scenarios charging during evening hours (e.g., Unscheduled & Public) when the system is experiencing its second daily peak. In 2030, in the AVG week, improved performance is observed in the Scheduled daily and V2G-restricted scenarios for both the autonomous S1 and S2 cases, which succeeded to decrease generation costs by up to 6% while dispatching electricity at competitive prices (Fig. 16). Generation costs in 2040 are similarly affected by the type and quantity of thermal generation committed. However, due to renewables increase, there is a higher margin for cost reduction, particularly considering the bidirectional charging (V2G) balancing the demand and supply

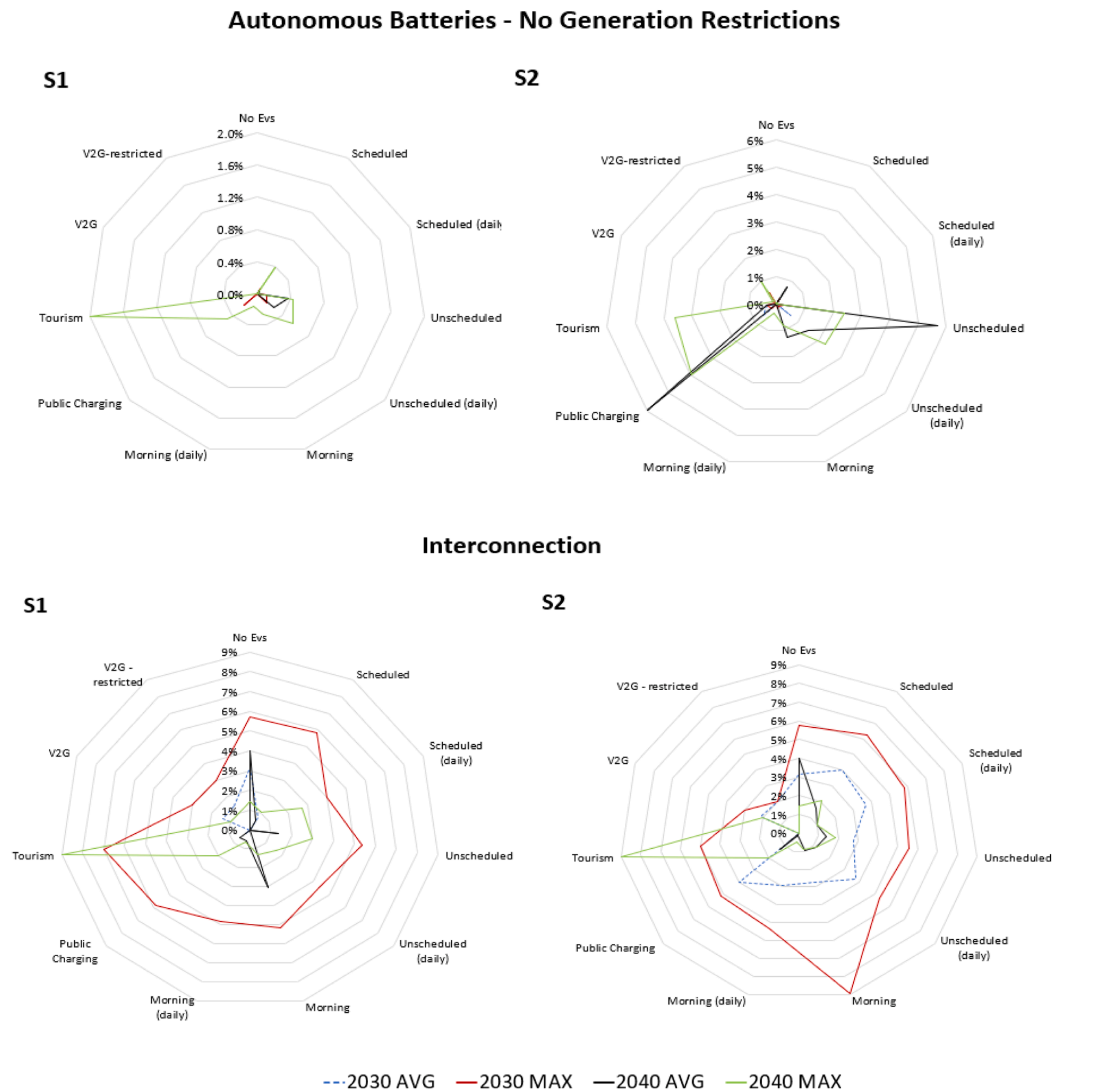

Fig. 12. Unserved energy as % of the total demand under EV charging scenarios.

effectively, with reductions up to 20% under S1 while limited to 15.3% under S2. Overall, it is evidenced that prices are marginally reduced between 2030 and 2040 in the Autonomous-Batteries baseline non-EV scenario due to the increase in RES penetration. However, as oil fuel prices are assumed to follow an increasing trend according to the World Energy Outlook [44], the benefits of RES in terms of price reductions are constrained.

On the other hand, in the Interconnection scenario, generation costs in the non-EV case diminish by 50 €/MWh between 2030 and 2040. It assumes the retirement of approximately 80% of the existing local capacity by 2030 and 92% by 2040. Therefore, EV charging is less dependable on thermal generation than the Autonomous-Batteries scenario. In 2030, under S1, most scenarios drop costs up to 31% in the Scheduled daily pattern. In S2, the costs reduction is sustained and improved for certain scenarios, with the V2G-restricted recording the highest reduction (Fig. 17). Such a scenario highlights the increased RES penetration on the Greek islands following their interconnection and the extensive impact of imports from the mainland, which effectively replaces additional demand. In 2040, considering the AVG week and a moderate EV deployment scenario (S1), a cost reduction is observed across all scenarios except for the Unscheduled and the Public charging, which record an increase of up to 20%, forcing the start-up of the remaining oil-fired gas turbines complementing imports from the mainland. The V2G scenarios and daily Scheduled show potential for price reductions across all scenarios but are limited compared to 2030, ranging between 6 and 12%. Scheduled daily succeeds a 12% reduction. The relatively reduced effect by 2040 is attributed to imports from the mainland when all infrastructure projects are realised. Under a more aggressive S2 case in 2040, the results are similar to S1, with a marginal additional increase of 1 to 3% in the peak charging options exposing

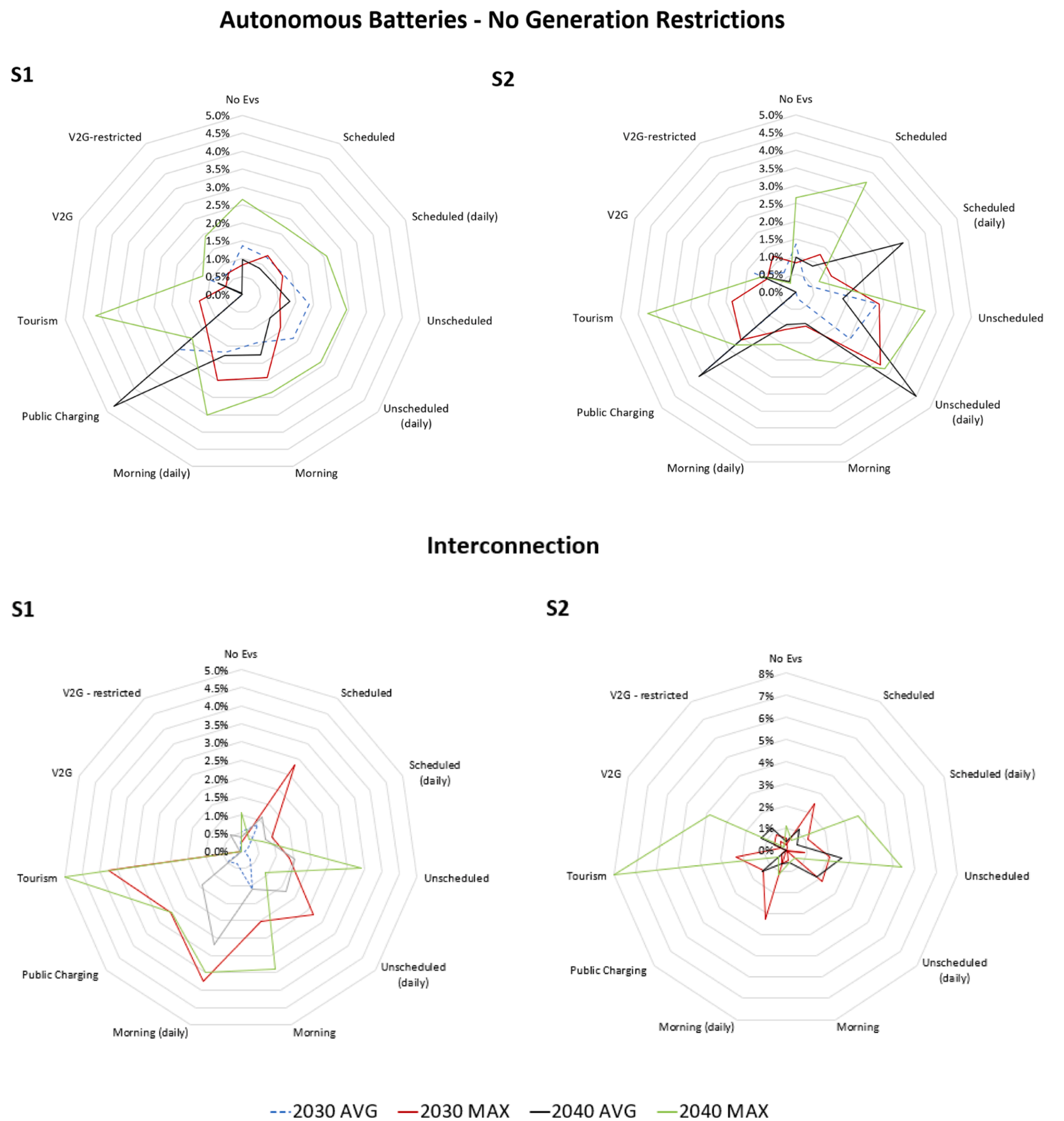

Fig. 13. Curtailed energy as % of the total demand under EV charging scenarios.

their unsuitability as principal charging strategies for the Greek islands.

Compared to a non-EV scenario, cost-reduction up to 12% is observed through the MAX generation load weeks concerning mainly the V2G and Scheduled daily scenarios in the autonomous case. This is anticipated as, alongside high demand, there is a large margin for replacing expensive thermal generation due to the increased performance of renewable systems. In the Interconnection scenario, a reduction is evidenced, however, limited compared to the Autonomous-Batteries case due to a relatively smaller margin for improvement as the majority of the existing thermal units have been retired.

3.3. Environmental impact

The electrification of the transport sector is only meaningful from an environmental point of view when the system's electricity mix consists of low-carbon intensity fuels, which will eventually reduce the carbon emissions from transport uses. Also, the results indicate discrepancies between RES generation figures, electricity generation costs and emissions due to the complexity of the islands' electricity system operation, dependent on the technology-specific costs and emissions intensity, import quantities and the available generation and storage capacity on each island.

According to Fig. 18, considering energy autonomy in 2030 in the AVG week, there is a relative increase in CO_{2eq} emissions across most scenarios, even in a moderate S1 case going as high as 7% for the Morning daily charging, compared to a non-EV scenario. The V2G restricted charging strategy demonstrates an exception as it reduces emissions by 5.5% by reinjecting energy into the grid. Under S2, the

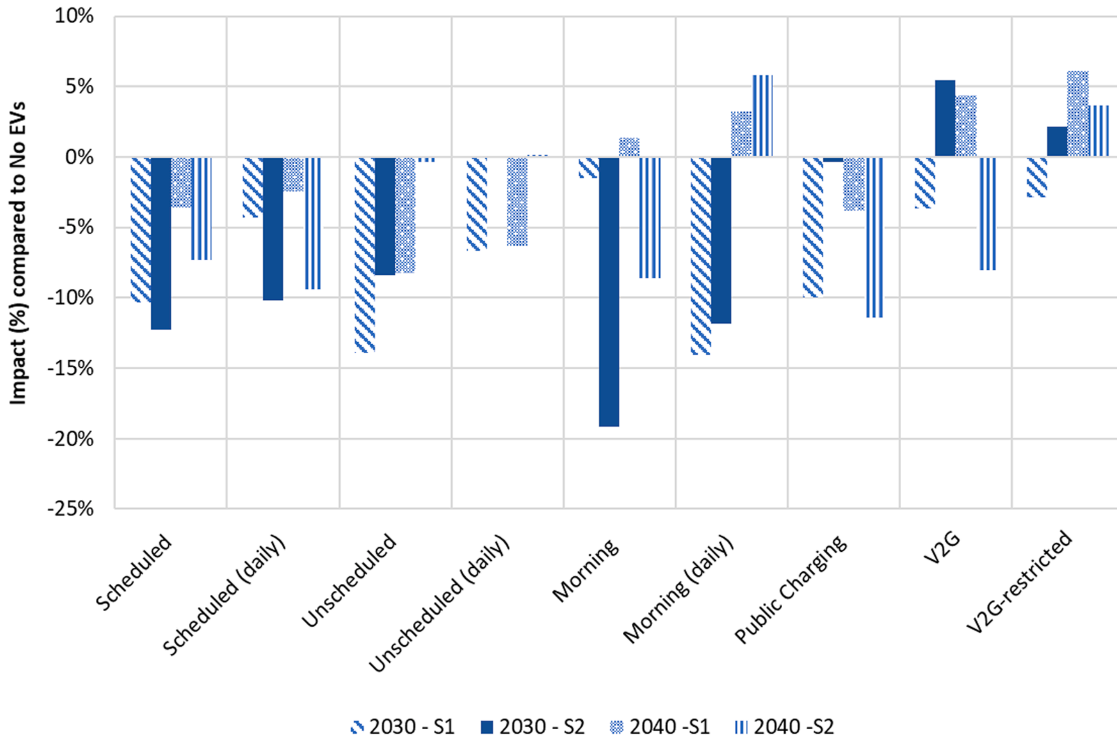

Fig. 14. EV charging scenarios impact on RES integration vs No-EVs baseline case - Autonomous-Batteries scenario.

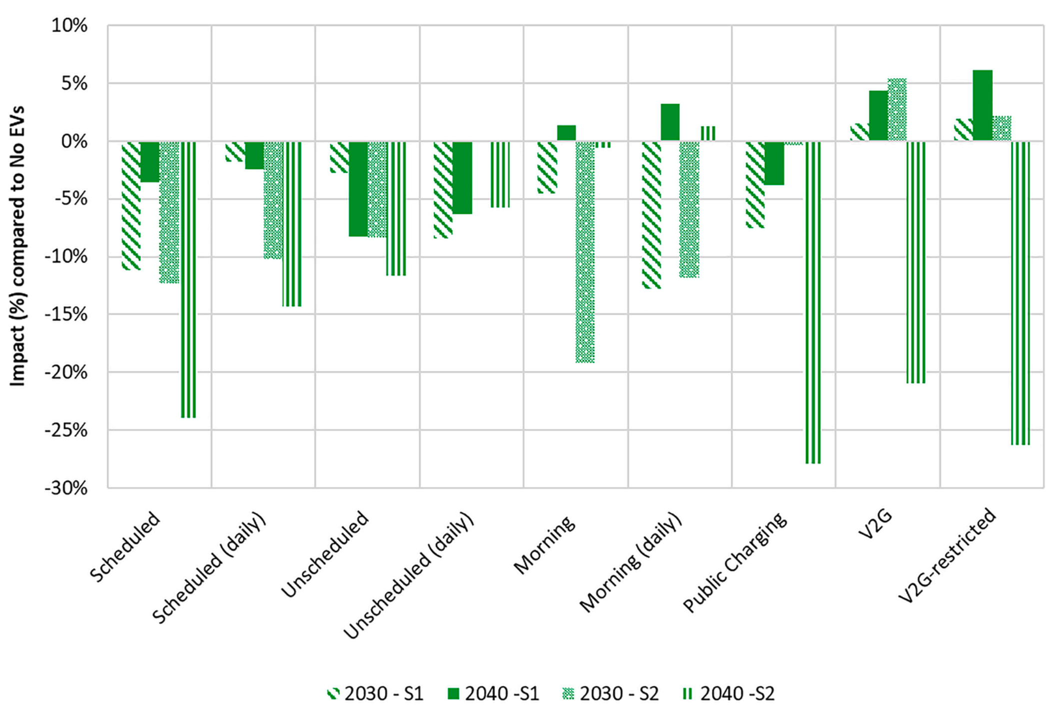

Fig. 15. EV charging scenarios impact on RES integration vs No-EVs baseline case - Interconnection scenario.

increase of emissions is higher, proportional to the additional loads that trigger the dispatch of larger quantities of thermal generation. Biweekly Morning charging scenarios have minimal benefit from an environmental point of view, as between 10:00 and 16:00, there is limited RES excess that could be absorbed. At the same time, most of the charging demand is met by the oil-fired generation already committed, making their start-up and shut-down unaffordable, particularly on large-sized island systems. Similar conclusions are drawn for the Scheduled scenario, which will lead to an inevitable increase in CO_{2eq} emissions up to 12% due to committing thermal units. Overall, almost all charging plans seem to produce additional emissions in the local system. In 2040, the scenery changes as there is a margin for up to 9% emissions reduction across several scenarios such as the morning and V2G, except for Public charging. This is achieved while allowing higher amounts of stored and dispatchable renewable energy to cover charging demand. Regarding the S2 case, only daily Morning charging succeeds in a 5.6%

Table 6
Additional RES capacity as a result of EV deployment.

Scenario		Year	
		2030	2040
Main Scenario	**EVs Growth**	**MW**	
Autonomous-Batteries	**S1**	120	480
	S2	260	720
Interconnection	**S1**	65	360
	S2	150	600

emissions reduction. It is noteworthy that solar capacity increases benefiting the system when combined with utility storage and EVs.

In the Interconnected case (Fig. 19), the impact of electric mobility takes nationwide dimensions as a significant amount of demand is met by imported energy. Specific scenarios such as the Scheduled daily and V2G result in emissions reduction up to 12.5% in 2030, supporting RES growth while eliminating curtailments. Under the S2 Scenario, emissions follow the increasing trends of the charging demand loads, with the instant dispatch of thermal generation to meet the regional demand in some extreme peaks despite price reductions and enhanced imports. Exceptions concern primarily the V2G restricted scenario, which caters to the local energy system requirements while reducing emissions by 5.7% in the AVG week. By 2040, the majority of the available generation capacity on the Greek islands will consist of renewable energy, with no margin for significant discrepancies. Those scenarios with the most consistent results in minimising the carbon footprint are the V2G with a 5% reduction in S1 and 2% in S2 benefiting from coupling energy storage with interconnectors. Concerning S2, the Unscheduled scenario minimises emissions by 7.5%, benefiting from clean energy imports during peak time.

In the MAX week, a relative increase is recorded across most charging options as high as 12% in 2030 considering the Autonomous-Batteries system. The V2G scenarios continue recording emissions

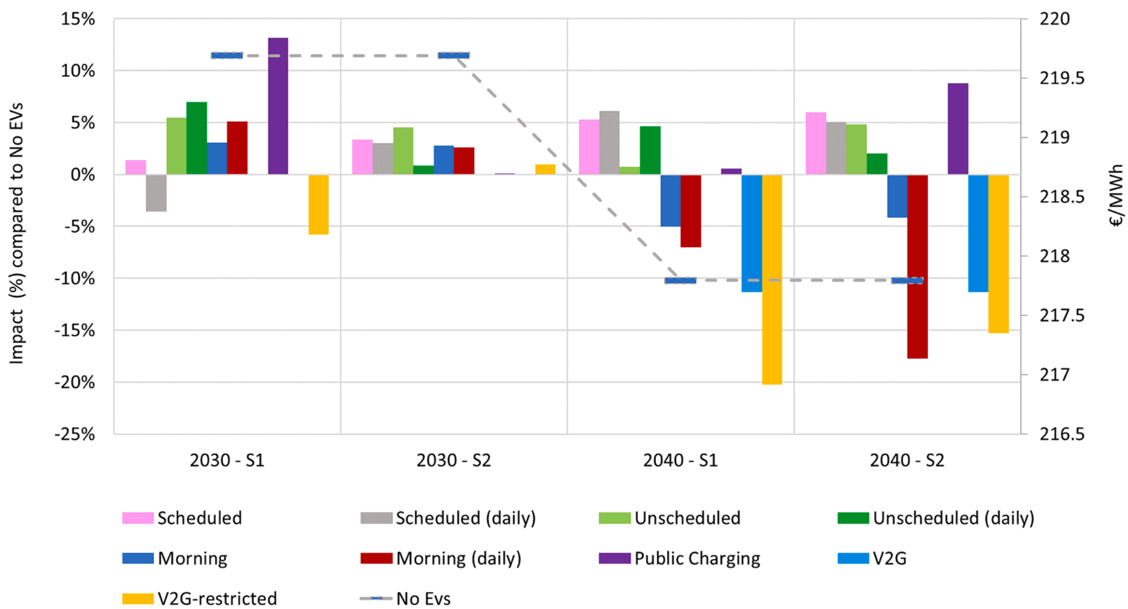

Fig. 16. EV charging scenarios economic impact (X-axis) vs No-EVs baseline (Y-axis) - Autonomous-Batteries scenario.

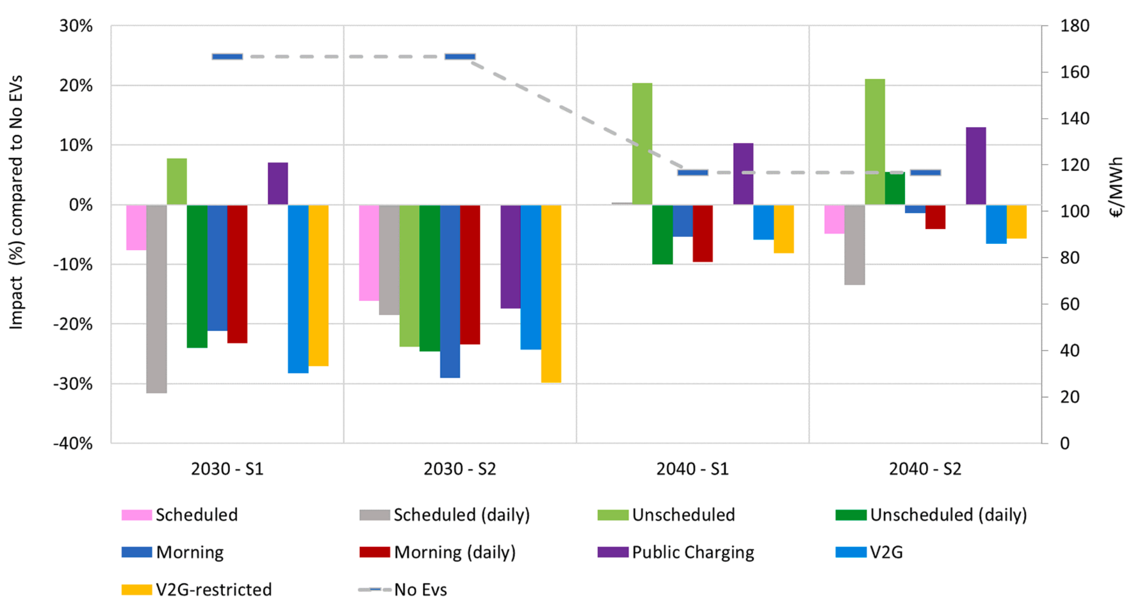

Fig. 17. EV charging scenarios economic impact (X-axis) vs No-EVs baseline (Y-axis) - Interconnection scenario.

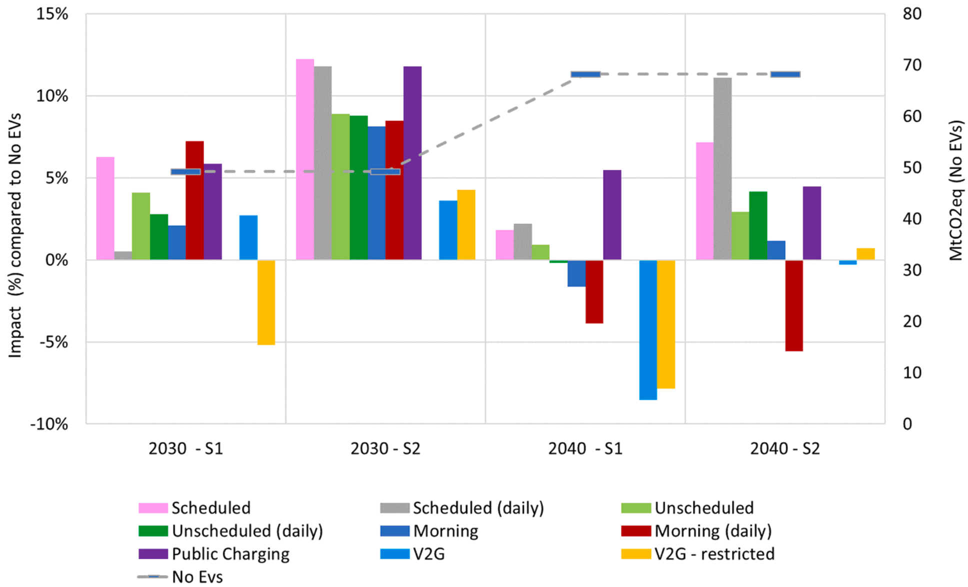

Fig. 18. EV charging scenarios environmental impact on CO_{2eq} emissions (X-axis) vs No-EVs baseline (Y-axis) -Autonomous-Batteries scenario.

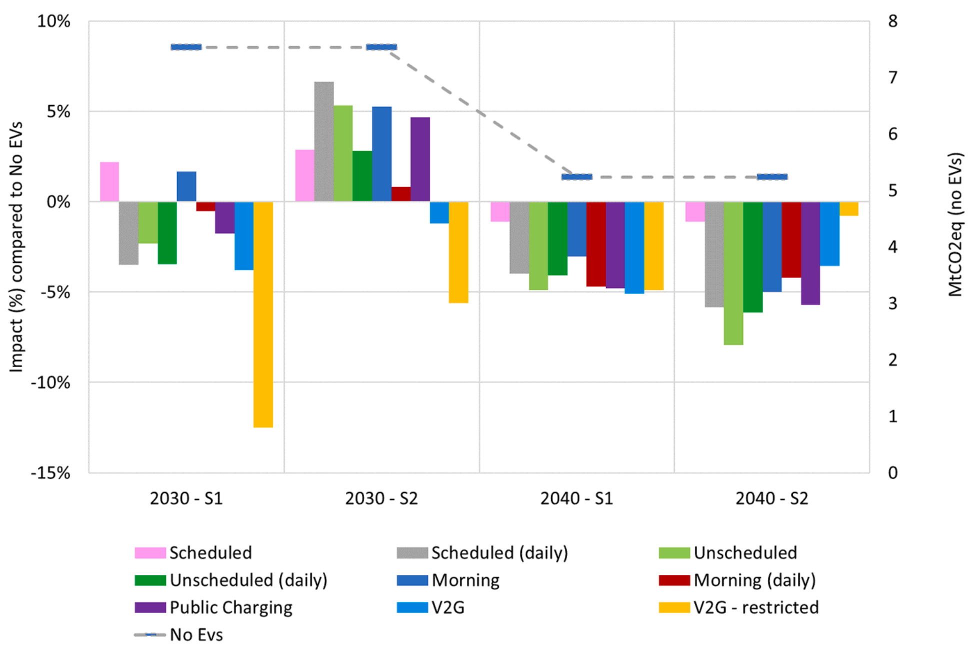

Fig. 19. EV charging scenarios environmental impact on CO_{2eq} emissions (X-axis) vs No-EVs baseline (Y-axis) - Interconnection scenario.

decrease up to 4%. By 2040 the margin for emissions reduction is limited, particularly under the ambitious S2 scenario. In the interconnected context, the emissions increase is limited to 6% across all scenarios; hence the V2G and Morning daily charging patterns attain reduced releases up to 9%, assuming an EV deployment strategy aligned with the NECP. In 2040, emissions decrease up to 9.7% under the Morning daily in S2 while the V2G continue to reduce emissions by up to 7%. Exceptions remain here in the Public and Tourism scenarios with poor performance.

4. Conclusions & Discussions

EVs operation on remote islands' electricity systems paves the way for decarbonisation while presenting multiple benefits but also risks. The requirement for small driving ranges and the limited size of the Greek islands allows for faster-regulated charging infrastructure deployment. On the other hand, the current fossil fuel-based electricity mix in the autonomous, fragile local power grids requires heavy investments in generation and transmission capacity. This analysis assesses a wide range of charging scenarios alongside two EV deployment scenarios (S1 & S2) using PLEXOS, proposing methods applicable to other remote regions worldwide.

National targets [1] propose EVs to be massively deployed over the coming years; consequently, additional loads will be straining islands systems while increasing thermal dispatch, necessitating smart charging and discharging techniques. The simulations show that the V2G scenarios represent the dominant strategy in bringing multiple benefits to the local systems compared to a scenario without EVs. Particularly, bidirectional (V2G) and, on certain occasions, Scheduled charging could support smoothening the daily demand profiles on the Greek islands.

Furthermore, V2G brings down power shortages by 30-100% compared to a non-EV case in the interconnected context while also eliminating curtailments in S1, supposing slow growth in line with the MERGE EU project figures [35,61]. Under S2, assuming the achievement of the target of 24% integration of EVs by 2030 and 82% by 2040 aligned with the NECP [1], only the V2G-restricted scenario keeps the curtailed values below 2%. In contrast, peak-charging alternatives usually cause high levels of unserved demand and curtailed generation. To allow for smart charging strategies to be applied, incentives such as low-pricing zones, combined with aggregators representing EVs in energy markets need to be established. Coordinated control among vehicle users, aggregators and power plants will reduce costs and avoid extensive uninstructed energy deviations, which may cause system losses and imbalanced voltage profiles.

The results prove that electromobility could increase the dispatch of more renewables by up to 7% and mobilise additional RES investments ranging between 600 and 720 MW, according to the interconnection status of the Greek islands. However, higher RES participation will not necessarily lead to lower costs and emissions levels and vice versa. We also need to quantify the impact of energy storage, imports, thermal generation, and the power flows' interaction among the islands. Hence, a relevant $CO2_{eq}$ emissions reduction may be achieved if bidirectional charging is coupled with a moderate (S1) deployment scenario up to 8.5% in the Autonomous-Batteries scenario. When EVs increase fast (S2), such reductions become challenging, leading to additional thermal power dispatch. If the islands become interconnected, there is a higher potential across all scenarios for emissions reduction up to 7% due to the limited operational oil-fired capacity and high-RES share participation. Notably, EVs uptake may only be valorised preceding RES expansion on the Greek islands.

Considering power generation costs, when EVs are deployed in the autonomous context, the system will experience an increase of up to 13% in 2030 and approximately 9% in 2040, concerning the Public charging scenario due to enhanced oil-fired generation. In the Interconnection scenario, costs increase reaches 21% in 2040, whereas charging scenarios such as Scheduled and V2G can potentially lessen such effects with costs decreasing up to 12%. In contrast to 2030 with the Interconnection scenario experiencing costs decline up to 31%, in 2040, a larger margin for costs reduction was observed in the Autonomous-Batteries scenario up to 20% due to the continuation of thermal stations' operation.

Overall, the analysis proved that V2G scenarios perform adequately concerning the economic and environmental impact. From the security of supply perspective, the results demonstrate improvements under the interconnected context accompanied by thermal generation restrictions without however eliminating power shortages recorded already in a non-EV case. Future work should not be limited to representative weeks to reduce computational time but include simulations using a full calendar year. Moreover, applying EVs optimisation in the electricity market context will emerge insights into the optimum bidding strategies for maximising revenue streams and EVs impact on wholesale prices.

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

5. Data Availability

Datasets related to this article can be found at:

https://ev-database.org/car/1203/Volkswagen-ID3-Pro-S hosted by the Electric Vehicle Database [25]

https://www.statistics.gr/el/statistics/-/publication/SIN03/- hosted by the Hellenic Statistical Authority, 2016 [29]

https://www.statistics.gr/el/statistics/-/publication/SFA40/- hosted by the Hellenic Statistical Authority, 2013 [31]

https://data.worldbank.org/indicator/NY.GDP.MKTP.KD.ZG hosted by The World Bank, 2019 [34]

https://ec.europa.eu/eurostat/statistics-explained/index.php/End-of-life_vehicle_statistics#Number_of_end-of-life_vehicles, hosted by Eurostat, 2017 [35]

https://www.statistics.gr/el/statistics/-/publication/SME18 hosted by the Hellenic Statistical Authority, 2018 [36]

https://mintour.gov.gr/wp-content/uploads/2021/02/rent_a_car_bike.xls hosted by the Hellenic Republic - Ministry of Tourism, 2018 [41]

https://www.statistics.gr/el/statistics/-/publication/STO04/- hosted by the Hellenic Statistical Authority, 2019 [42]

6. Model Availability

The model developed in PLEXOS is available to the readers upon request.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Appendix A

Island	Year			
	2030		2040	
	Scenario			
	S1 BSEV (MWh)	S2	S1	S2
Chios	26.3	350.4	478.4	1980.5
Crete	302.6	4035.5	5450.3	22576.4
Ikaria	4.3	57.6	78.7	325.8
Kalymnos	10.3	137.9	188.3	779.6
Karpathos	2.9	38.8	53.0	219.4
Kos	15.3	204.6	279.3	1156.6
Lemnos	8.0	106.6	145.5	602.5
Lesvos	38.7	516.6	705.2	2919.8
Milos	2.4	32.1	43.8	181.3
Mykonos	3.8	50.9	63.4	263.7
Naxos	8.1	107.3	142.8	592.0
Paros	6.4	85.2	110.9	460.3
Patmos	2.2	29.6	40.4	167.1
Rhodes	58.7	783.6	1069.7	4429.1

(*continued on next page*)

(*continued*)

Island	Year			
	2030		2040	
	Scenario			
	S1 BSEV (MWh)	S2	S1	S2
Samos	16.6	221.4	302.2	1251.2
Skiros	2.0	26.1	35.6	147.7
Syros	9.9	132.7	180.5	747.5
Thera	7.4	98.6	128.0	531.1

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