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# Les cahiers de la Chaire

## Increasing Renewable Energy Integration in European Islands with Storage Stakes: A Case Study of Evia, Greece

Nikolaos PAPASTEFANAKIS,
Sandrine SELOSSE
et Nadia MAIZI

*Mines Paris-PSL*
*CMA*

Working paper

# Increasing Renewable Energy Integration in European Islands with Storage Stakes: A Case Study of Evia, Greece

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## I. INTRODUCTION

Prospective modelling is a valuable mathematical tool for supporting long-term strategic planning in the face of uncertainties associated with future events. This analysis is conducted by defining potential future trajectories - scenarios, with the goal of exploring possible energy futures. The TIMES model is a partial equilibrium linear programming optimization tool that ensures the supply-demand equilibrium. This model identifies future expansion investments that are required in the power system to meet forecasted demand while adhering to techno-economic and environmental constraints, all at the lowest possible cost.

The energy systems prospective modelling results of the two demonstration sites (Procida and Hinnoya) showed that the proposed solutions of the GIFT project that offer flexibility and grid congestion relief, they promote also the further use of RES. More information about the modelling and the results can be found in Deliverable 2.4 (Chlela et al., 2021).

Evia, as a follower island, is being examined for the scalability and replicability of GIFT solutions. The island of Evia is the second largest island in Greece and the sixth largest island in the Mediterranean, as it is also interconnected with the mainland, Cyclades and Sporades. The southern part of the island is particularly interesting regarding its significantly high wind potential. Divers wind plant projects are planned in this part in order to export electricity towards other parts of Greece. More information about the territory can be found in Deliverable 9.1 (Rikos et al., 2020).

In this section, the long-term assessment of the island is presented which allows to draw conclusions about the deployment of RES and GIFT solutions regarding decarbonization aspects but also the benefits for grid of the island, as also the one of Greece and hence the one of Europe.

## II. ENERGY PROFILING OF EVIA

### General information

Evia is the second-largest island of Greece after Crete both in area and population. More precisely, it has a population of 191,206 and a total area of 3,684 km2 and, according to the census of 2011. The island possesses a strategic position for Greece, in terms of location, of renewable potential but also its electricity grid structure. Geographically speaking the island is in very close proximity to the mainland separated by the narrow Euripus Strait which is only 40 m wide at its narrowest point.

Evia is an interconnected island with the mainland as also with two islands in the Aegean Sea, namely Andros to the south and Skiathos to the north (Figure 2). In terms of connections with the mainland, Evia has various types of links, from HV transmission to MV distribution grid, as well as submarine cables (Figure 2). The transmission grid extends to the central part of the island, where a natural gas power plant is located. Over the years, multiple submarine cables have been installed to facilitate the export of electricity production by the wind farms. Besides, there are future projections for the reinforcement of the HV grid as also the submarine cables (ADMIE, 2022b). Furthermore, in order to achieve the national RES penetration targets set, the appropriate reinforcement of the Transmission System infrastructure is planned to contribute to the absorption and distribution of the energy produced by the existing and the new RES Stations (ADMIE, 2022a). In this context, important priority is given to the interconnection of the Greek islands in the Aegean Sea with the mainland. In the case of Evia, there are plans to further interconnect it with Skyros island (Figure 2).

*Figure 1 : Location of Evia in Greece*


*Figure 2 : Evia's Electrical grid and interconnections*

All these future projects primarily stem from the remarkable wind potential in the south part of the island. According to (Kamariotis Stavros et al., 2007), Evia is considered as the second highest wind priority area, boasting a total potential of 3,238 MW. This for the moment unexploited potential justifies the number of upcoming RES projects as seen in the (Figure 3), accounting for an additional 1,200 MW in the coming years. These projections are also supported by the fact that Evia island exhibits significantly greater production capacity than demand, in addition to its close proximity to Athens, the largest consumer.

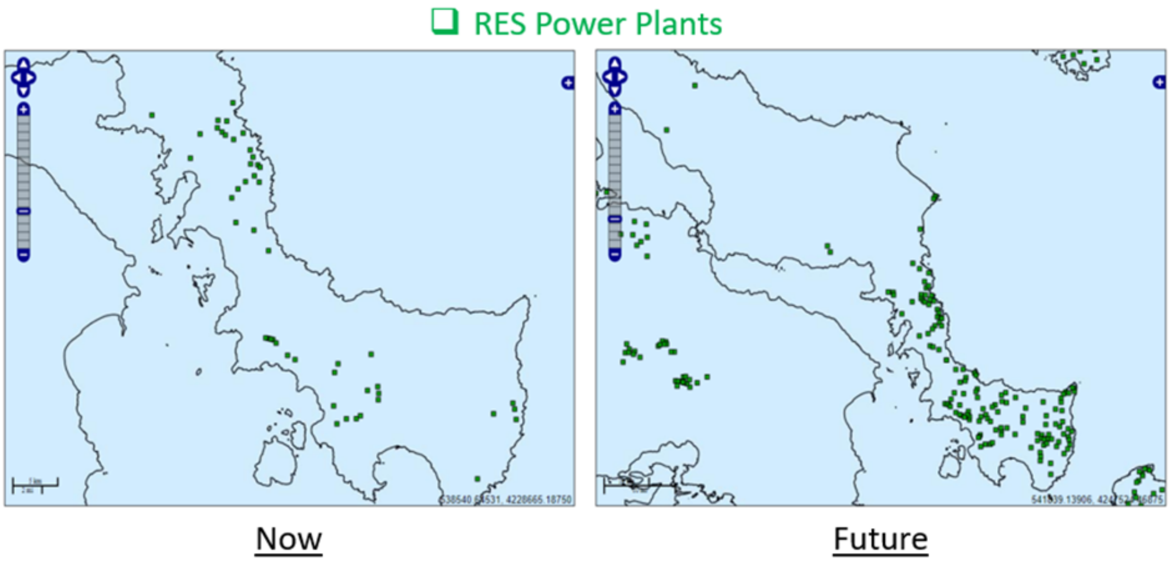



*Figure 3 : Existing and futur RES power plants, Source[1]*

(1) https://www.resoffice.gr/

## III. MODELLING FRAMEWORK: TIMES-EVIA

In this section, the general approach and methodology used to develop TIMES-EVIA is presented. All the technical aspects of the implementation are presented in the Annex.

### Model horizon and tempo-spatial representation

The time horizon of the model is up to 2050, considering 2022 as the base year. This period has been divided into sub-periods of 1 year each up to 2025, then the periods become 5 yearlong until 2050, as shown.

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 2022 | 2023 | 2024 | 2025 | 2030 | 2035 | 2040 | 2045 | 2050 |

*Figure 4. Time horizon breakdown representation*

Each period is then split into three different seasons (winter, summer and a complementary intermediate season), that are in turn split into five blocks to represent different periods of the day (NGT: night, MOR: morning, MID: midday, AFT: afternoon and EVE: evening).

Winter which ranges from the 1st of November up to the 15th of April, is set according to a technical directive of the technical chamber of Greece that contains a definition of the buildings' heating period at different locations according to their climatic zone (Evia is in the climatic zone B). The Summer season ranges from the 15th of May to the 15th of September. This choice is based on the observation of the average irradiation values in Evia for different months of the year, that is the highest from April to September. The Intermediate season corresponds to the rest of the year (15th of April-14th of May, 16th of September-31th of October).

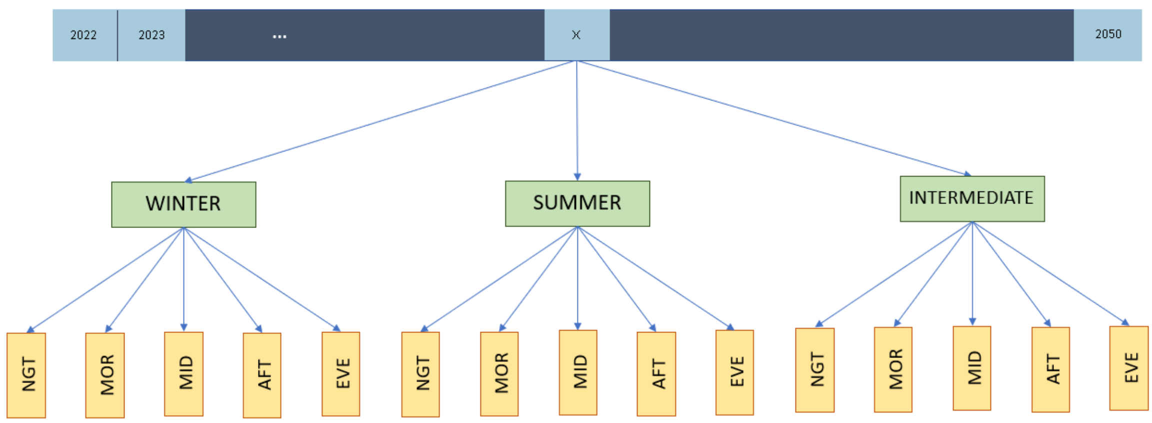



*Figure 5 : Time structure of the model*

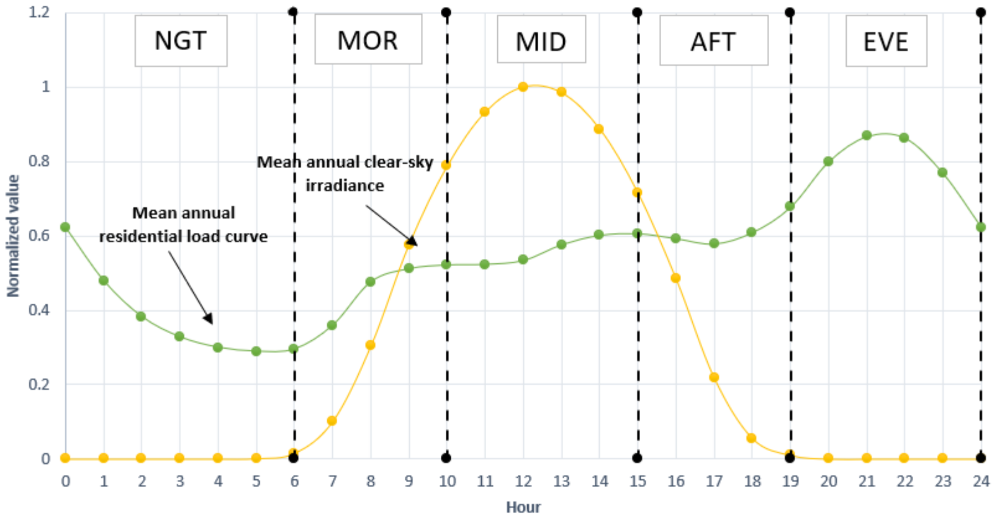



*Figure 6 : Comparison between the annual average clear-sky solar irradiance and the residential load curve on a daily basis (normalization with respect to the peak irradiance value), source : (Grazioli et al., 2022)*

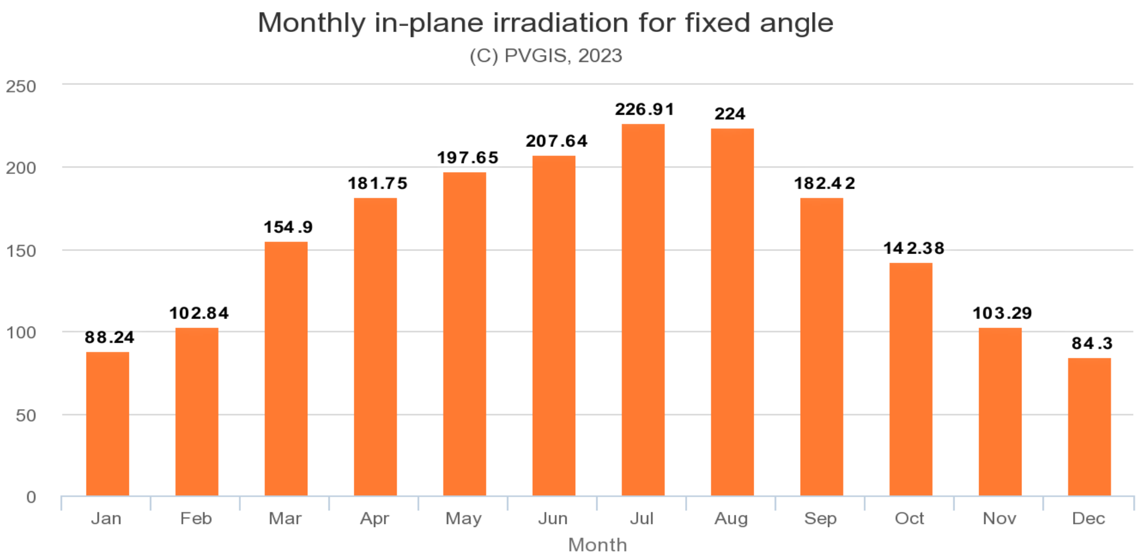



*Figure 7 : Mean monthly solar irradiation value on an optimally oriented PV in Evia, source: PVGIS*

The definition of the time-slices on a daily basis is based on comparison between the annual average load curve of the residential sector in Procida (assumed that Evia has the same shape as Procida, because no data were available) and the annual average global clear-sky irradiance curve for Evia, both of them defined on a daily basis.

For the calculation of the average annual solar irradiance on a daily basis, the global clear-sky irradiance is considered. This choice is made in order to avoid bias deriving from weather conditions variations at specific years. The data is provided by PVGIS tool on an hourly basis for each month of the year. The annual mean value at each hour i, , is then obtained as the average between the global clear-sky irradiance value of each month j:

$$Gcs_i = \frac{\sum_{j=1}^{12} Gcs_{i,j}}{12}$$

## Base year energy system

The energy system at the reference year (2022) is characterized by the definition of the demand and supply side.
The description of the reference energy system is based on the data provided by the Hellenic Statistical Authority and the Municipality of Evia for the island's electricity consumptions (defined as an annual value for each of the sectors). Concerning the production side, data were collected from different sources, such as CRES, DEI, ADMIE, DEDDIE, RAE, etc.[3]

Demand side

The annual total electricity demand of the prefecture of Evia in 2012 was 1.379.924 MWh. As the most recent data were dating in 2012, in order to find the electricity consumption in 2022, there were used trends based on (Ministry of Environment and Energy, 2020). In the following figure is illustrated the typical load curve on a daily basis as well as the seasonality of the 4 seasons. Load curves were firstly extracted for Greece by IPTO[4], and then with the application of a ratio there were obtained the ones of Evia.

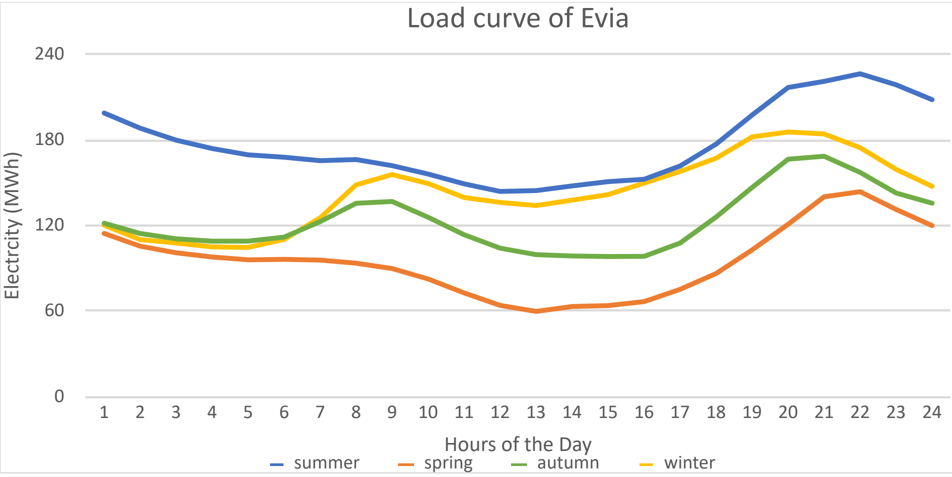



*Figure 8 : Typical load curve on a daily basis and the seasonality of the 4 seasons in Evia, source (IPTO).*

Moreover, as there are no available data concerning the daily load of each sector, the data in the model are in an annual basis. The electricity demand is separately defined for the following end-use sectors:

- Agriculture
- Industry
- Tertiary
- Public
- Residential

(3) DEI : Public Power Corporation, ADMIE : Independent Power Transmission Operator, DEDDIE : Hellenic Electricity Distribution Network Operator, RAE : Regulatory Authority for Energy

(4) https://www.admie.gr/en/data-type/system-load

For modelling purposes, it is necessary to allocate a share of the total annual load to each of the time-slices defined in the model. The electricity load fraction of the entire system per time-slice at daily level and distinguished by season is shown in Figure 10. As it can be seen, the peak of demand occurs in all the seasons during the evening.

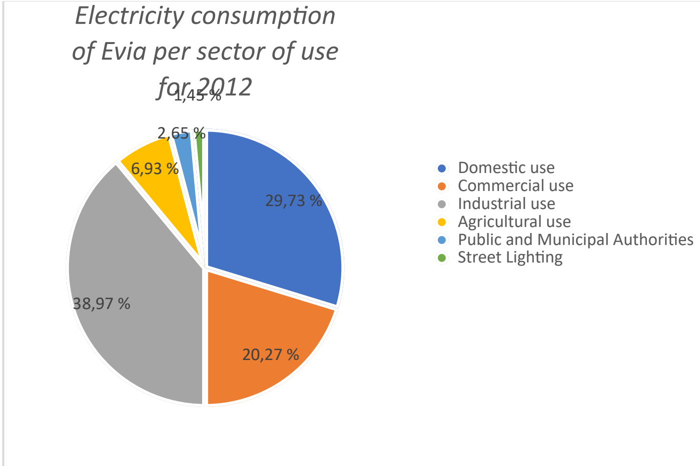



*Figure 9 : Analysis of electricity consumption of Evia per sector of use for 2012*

As concerns the transport sector, based on the Action Plan for Sustainable Development Energy and Climate of the Municipality of Chalkida (Municipality of Chalkida, 2018), the consumption of the island in the transport sector was 601.629,45 MWh of fuels in 2013. Based on the hypothesis that in 2022 the consumption is the same, and the fact that 0.28% of the total fleet in Greece is electric (European Commission, 2023), an annual electricity demand for the transport sector of 1,68 GWh is assumed.

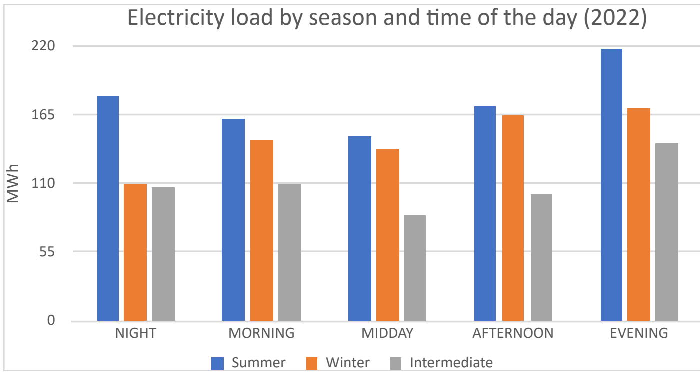



*Figure 10: Estimated electricity load fraction per time-slice at daily level in 2022*

## Supply side

Evia is equipped with a sizeable and diverse portfolio of generation. This portfolio includes primarily three technologies, Photovoltaic systems, Wind farms and a Gas-fired power plant. As PV installations are concerned, they are divided into residential systems (5.66 MW) and PV farms (10.21 MW). Afterwards, the Wind farms are counting for 224.2 MW. Finally, the gas power plant has a total capacity of 416.95 MW and is not used only for the needs of the island, but also for export in order to cover the demand of other parts of Greece.

Comparing the demand with the supply side, we can notice that supply is significantly more important. Evia has one of the most increased renewable potential as concerns wind speed and frequency in Greece (Kamariotis Stavros et al., 2007). Moreover, thanks to its close proximity to the mainland and Athens, the island is “used” as an electricity exporter. Hence, the important capacity of wind farms but also the gas power plant.

For the electricity production by photovoltaics it is necessary to define the annual electricity production variation. This is made through the definition of a capacity factor for each time-slice. The methodology used to estimate this value, based on solar irradiance variation during the year, is detailed in annex.

Base year model structure

As a summary, a simplified scheme of the reference energy system:

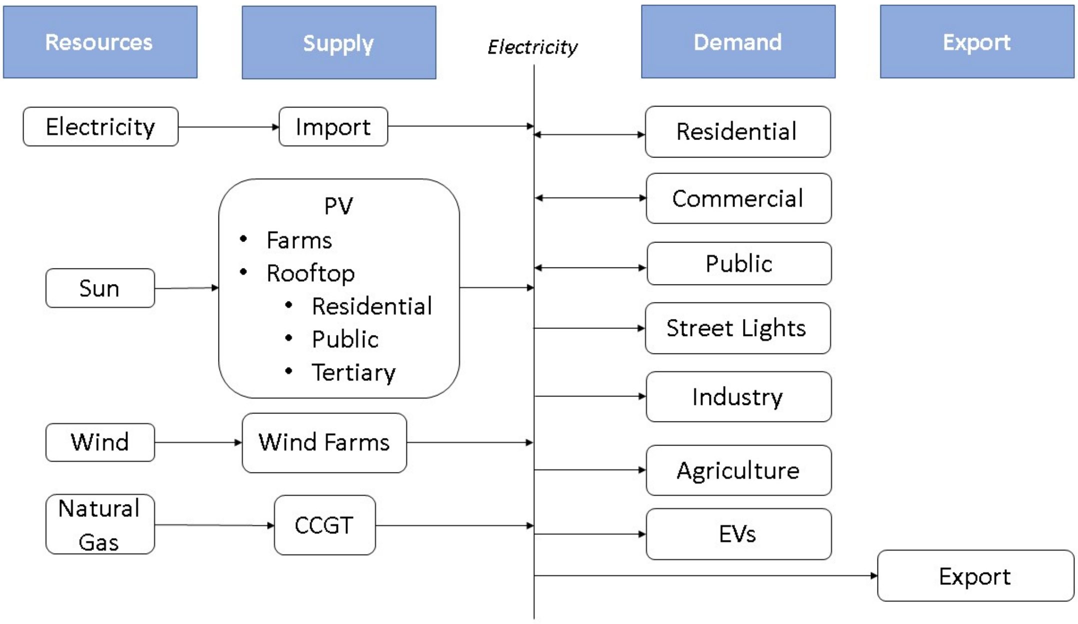



*Figure 11. Simplified scheme of the reference energy system*

It is relevant to mention that the model is able to export the excess production of the power plants. In order to do that, the same price of electricity import is given to the process of export of the different technologies.

## Evolution in time

The estimation of the demand evolution over time and the choice of the new technologies to include in the model are detailed in the following section.

Demand evolution

The evolution of the electricity load in time is based on the long-term strategy to 2050, done by the Greek Ministry of environment and energy (Ministry of Environment and Energy, 2020). It concerns the long-term development of the energy sector in Greece studying different possible future trajectories. For the purpose of this project, the trajectory that expands the National Energy and Climate Plan of 2030 until 2050 was selected.

In this scenario, it's considered that the energy policies of 2030, are expanded and reinforced until 2050.

New technologies

The choice of the new technologies to include in the model is based on several considerations.
Concerning the electricity supply, several technologies are considered. New wind and PV farms and PV rooftop installations in residential, public and tertiary buildings. The available area for new installations is constrained by the available area of land and rooftops. To increase the flexibility of the electricity grid other technologies are included in the model.

In particular, both solutions developed within the GIFT project, HBr and Smart Energy Hub, but also additional storage technologies are considered. However, as many different storage devices are available in the market, the most suitable ones shall be selected for cost and technical reasons. Hence, Li-ion batteries are selected for short-term storage and rSOC systems as a long-term storage.Finally, in accordance with the national context that promotes the decarbonisation of the transportation sector, electric vehicles operating with li-ion batteries are included in the model.

### 1 New wind turbines

New wind turbines are considered as a technology to install in the island given its huge wind potential. It is chosen to make a distinction between the wind turbines that will be connected to HV grid and those to MV grid, in order to better analyse the amount of electricity in the distribution grid. The electricity produced by wind turbines connected to HV grid can either cover the demand or be exported. The modelling approach, the constraint on the maximum installable capacity for each of the applications as well as the input parameters used for this technology are detailed in annex.

### 2 New photovoltaics installations

New photovoltaics are considered as a possible technology to install either on buildings' roofs either as PV farms. It is chosen to make a distinction between the PVs installed in residential, public and tertiary (private) buildings, in order to better analyse the contribution of the installation to the electricity supply of the sector it is referred to. The photovoltaics electricity production will first supply the entire sector demand and afterwards there is the option to be exported. The modelling approach, the constraint on the maximum installable capacity for each of the applications as well as the input parameters used for this technology are detailed in annex.

### 3 Batteries

#### *Li-ion battery*

Li-ion batteries are considered for residential, tertiary and public applications to store electricity at daily level. The investment costs are lower for public and tertiary applications, due to economies of scale. A constraint is set on the maximum installable capacity for each sectorial application. Moreover, an additional constraint is set on the maximum investments on batteries per year. The modelling of li-ion batteries is detailed in annex.

#### *Smart energy hub*

The Smart Energy Hub is composed by a li-ion battery and a rSOC system. The modelling approach as well as the input parameters used to define this technology are detailed in annex.

#### *HBr*

The Elestor flow battery is a HBr (hydrogen bromide) system designed to store the energy produced by renewable energy systems. The modelling approach as well as the input parameters used to define this technology are detailed in annex.

#### Long-term storage

The long-term storage is defined according to the properties of the rSOC component of the Smart Energy Hub. In the model it is used for residential, tertiary and public applications. The modelling approach and the input parameters used for this technology are detailed in annex.

### 4 Electric vehicles

Electric vehicles (EVs) are included in the model as a demand technology, whose load depends on the fleet dimension, technical parameters and behavioural attitudes. Two different new electric vehicles are considered, namely electric cars and electric motorcycles. In the model, it is considered that there is already an electricity demand for EVs in the island at the base year, and it is assumed that the total amount does not change in time and that therefore the load remains the same.For the modelling of EVs, technical parameters that characterise the performance should be fixed.

The choice, based on average values and considering technology improvements in time, is detailed in annex. Then, to estimate the new electricity load, scenarios are defined according to the fleet evolution in time and the users' behaviour.

Both for electric cars and motorcycles, it is assumed that all the vehicles belong to private residential users and that the charge only takes place at home. For both electric cars and motorcycles, the definition of the fleet evolution in time is based on the National Energy and Climate Plan of 2030 (Ministry of Environment and Energy, 2019), that sets a target of 30% electric vehicles in new registrations by 2030. Nevertheless, it is assumed that electric vehicles will be firstly implemented in large cities and afterwards in smaller ones. Starting from this assumption, two scenarios are being considered. In the LOW scenario 30% is achieved in 2040 and 50% in 2050 and in the HIGH scenario, 30% is achieved in 2030 and 70% in 2050. The number of EVs is then calculated by assuming that the total number of cars do not change with respect to 2022 [5].

Additional assumptions are then made for the users' behaviour. In particular, it is assumed that only one round trip and one charge per day and per vehicle are made, that the state of charge at depart is 100%, that the totality of the fleet is deployed each day and that the share of vehicles recharging at peak hours (evening (Robinson et al., 2013)) is 80%. The electricity load related to electric cars is then quantified with the calculation described in annex.

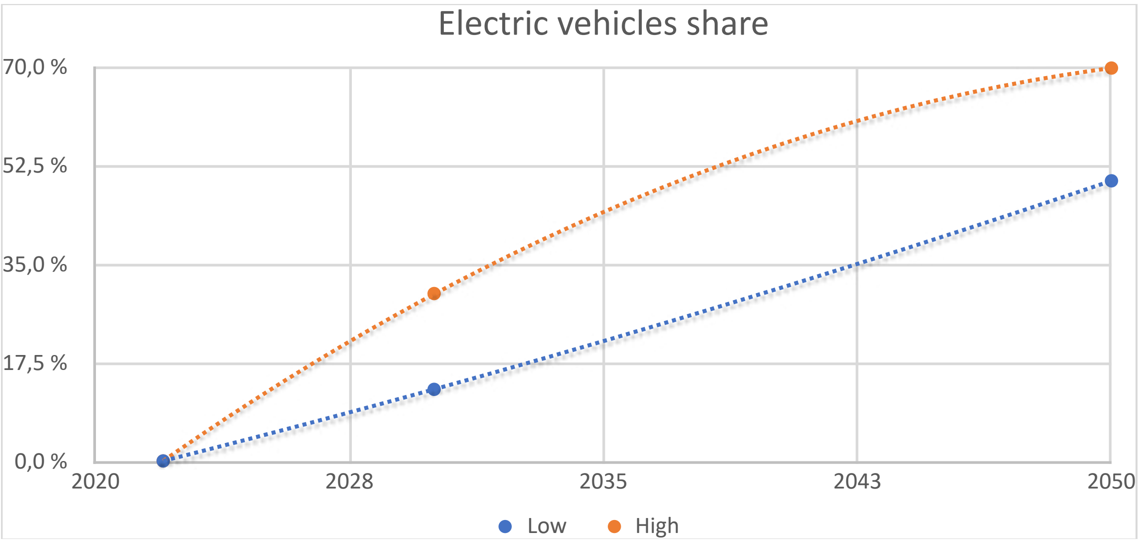



*Figure 12 Evolution of the electric vehicles share (source ministry of Environment and Energy, 2020)*

[5] *The total number of cars and motorcycles in Evia (2022) is given by the Hellenic Statistical Authority*

## Scenarios

The main scenarios were developed in order to consider different possible evolution of the energy system while integrating GIFT project's objectives.
Firstly, a Business As Usual (BAU) scenario is considered in order to show the trajectory of current policies. These policies concern the wind and solar projects that are announced to be done until 2030 as also the fleet evolution of electric vehicles and the energy efficiency measures. Afterwards, no specific plans are yet announced. Hence, in all scenarios it is assumed that the RES development is the same for the period 2023-2030.
For the rest period, as two supply technologies are included in the model, it is chosen to consider two different scenarios for the future development of photovoltaics and wind turbines in the island: a case of modest deployment on the long-term (scenario LOW) and a case of large deployment towards the exploitation of the whole potential (scenario HIGH).
Finally, an additional scenario HIGH_STG is considered that includes all the storage technologies, with the objective to better evaluate the storage effects on the energy system evolution of GIFT solutions and batteries. The comparison is made with respect to the HIGH scenario, as storage technologies are more meaningful with high shares of variable renewable sources.
Practically, the definition of the scenarios is made by imposing a constraint on the maximum amount of annual investments at each year of the horizon. Supply side is already more significant in comparison with the demand, hence capacity additions are forced as constraints. Moreover, an additional constraint is defined for each sectorial photovoltaic and wind turbine application to avoid investments on only one sector and in one year of the horizon. Therefore, the constraint on the maximum capacity of new annual installations results decisive for the determination of the solution. The definition of the constraints is better detailed in annex.

| SCENARIO NAME | DESCRIPTION |
|---|---|
| **BAU** | Current policies. |
| **LOW** | Low renewables development scenario.<br>Low demand EV. |
| **HIGH** | High renewables development scenario.<br>High demand EV. |
| **HIGH_STG** | High renewables development scenario.<br>Deployment of Storage technologies.<br>High demand EV. |

*Tableau 1 : Summary of the scenarios considered for the analysis*

## IV. RESULTS

Based on the described approaches, in this section are presented the results of the prospective modelling.

### Total discounted system cost

The total discounted system cost (in billions €) of the four scenarios is shown in Figure 8.
The total systems cost is in line with the investments that are being done in the energy sector. LOW scenario is the cheapest trajectory, being followed by the BAU. This due to, from one part, the electricity exports in the LOW scenario offering a profit despite investment costs and, from the other part, the electricity imports in BAU scenario resulting in more expenses. The high scenarios are the most expensive due to the investments that take place in order to deploy massively renewable energy sources systems. HIGH_STG scenario is 0.85% more expensive than HIGH scenario, but as it's shown in the results, the benefits in terms of decarbonization, sectorial self-consumption and electricity exports are important. Finally, it should be noted that electricity exports take place in all scenarios, something that can explain the high costs of investments, but from the other part, it offers decarbonized electricity to other parts of Greece.

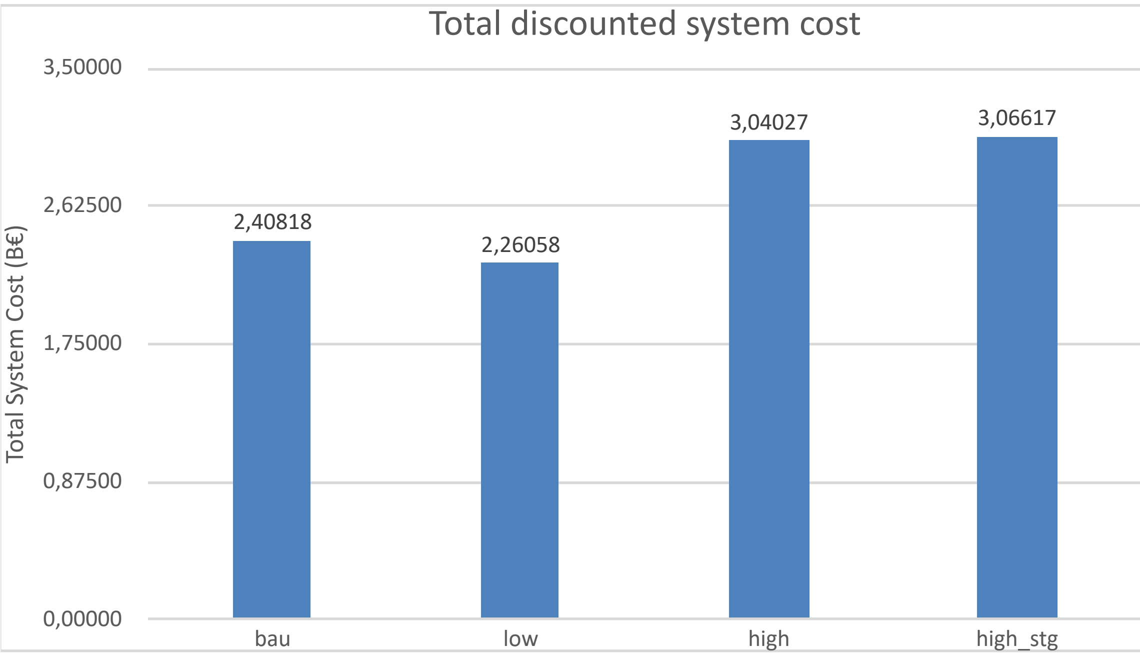



*Figure 13. Total discounted system cost in the four investigated scenarios*

| Scenario | BAU | LOW | HIGH | HIGH_STG |
|---|---|---|---|---|
| **Total (B€)** | 2.40818 | 2.26058 | 3.04027 | 3.06617 |

*Tableau 2 : Summary of total discounted system costs in the four scenarios*

## Investments in new technologies

### Wind turbines

Most of the investments in wind turbines will be directed in those that will be connected to the HV grid. This is because in reality these wind turbines will be used in order to export electricity towards other parts of the mainland. Nevertheless, they're modelized in a way that they can either export the electricity produced either transform it into the MV grid. In BAU, all the projects for wind installations announced until now, will be implemented until 2030, so after few investments are done. In HIGH scenarios, the maximum possible capacities are installed by 2050. Finally, even in LOW scenario significant capacities are added in the last period of 2045 – 2050.

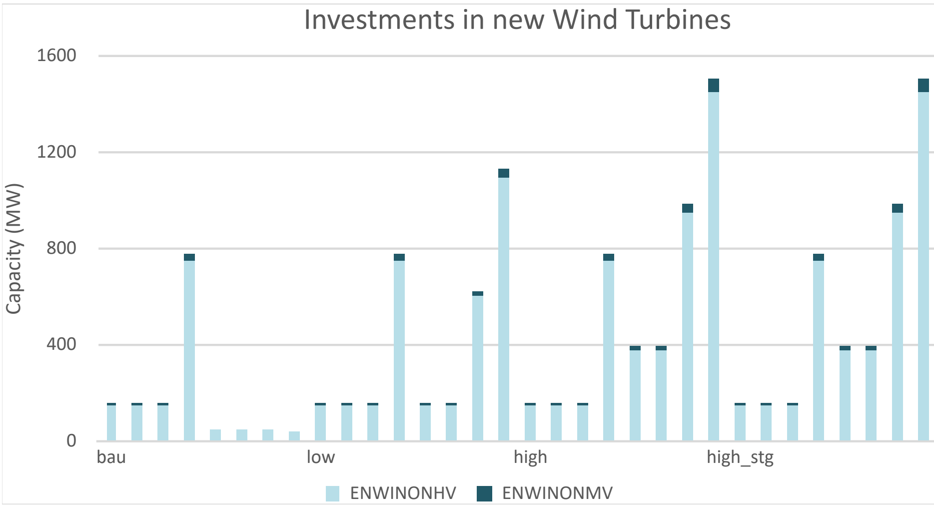
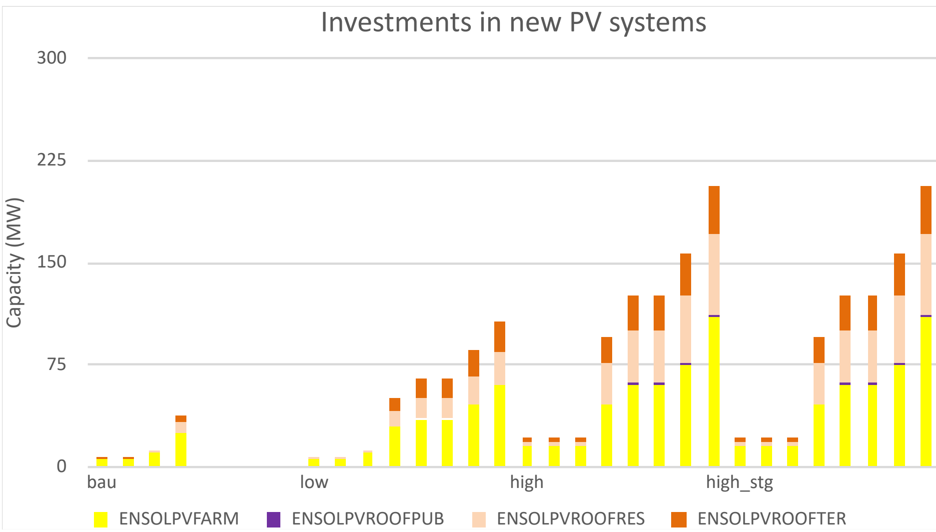



*Figure 14 : Optimal investments on Wind Turbines in the four investigated scenarios*

### PV Systems

As concerns the photovoltaic installations, more than 50% of the capacity additions are due to PV farm systems, with the maximum capacity addition in HIGH scenarios being at 110 MW between the period 2045 - 2050. As concerns the sectorial installations of PV systems, residential ones are the most installed due to the number of residences, with the maximum capacity additions per year achieved in the period 2045 - 2050, accounting for 60 MW. In HIGH scenarios, important investments are done also in tertiary sector, adding 35 MW in the period 2045 - 2050. Although installations in public buildings achieve their maximum in HIGH scenarios, it is important to note that their contribution is limited. Once again, in BAU, all the projects for PV systems announced until now, will be implemented until 2030, so after almost no investments are done as only 1 MW of PV Farm is installed each 5 years.

*Figure 15 : Optimal investments on PV systems in the four investigated scenarios*



Finally, regarding the evolution of the total installed capacities, it can be noticed that more than 80% of them are those of wind turbines in all scenarios, something that is done in order to exploit the high wind potential of the island. It should be also noted, that even in the LOW scenario, almost 2.5 GW of RES capacities are achieved in 2050. Therefore, even in a trajectory of low exploitation of RES, the island will be an important electricity exporter.

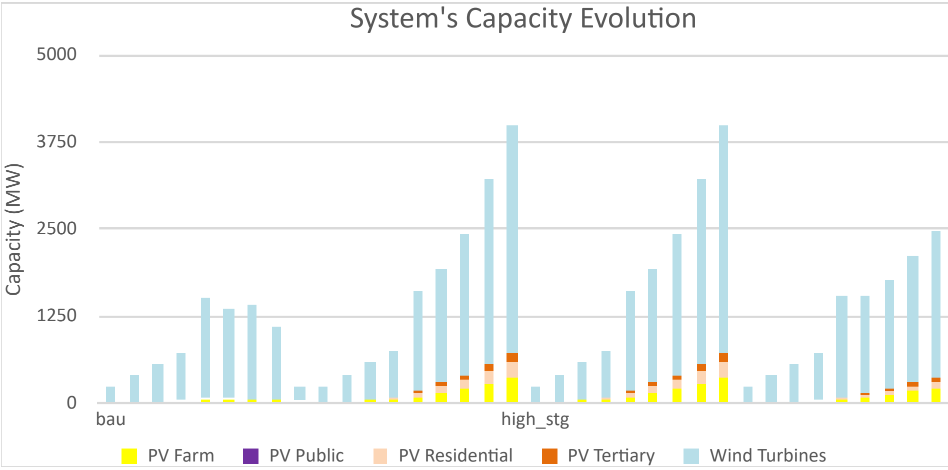



*Figure 16 : Optimal capacities evolution in the four investigated scenarios*

## Storage Systems

As concerns the capacities of storage systems, it is observed that they are installed when high amount of PV systems is implemented. This is the case for the residential and tertiary sector. It seems that it's not economically preferable to install batteries before 2040, because there is not sufficient electricity produced from PV systems, thus it is too expensive to store it. Moreover, it is probably related to the fact that photovoltaics production is low related to the total residential load. Hence, a reflection was to augment the PV installations per sector. Nevertheless, the evolution rhythms that were assumed in all scenarios were based on previous observations. Therefore, it was chosen not to exploit all the potentials with unseen rhythms, but to apply logical and realistic evolution trajectories. Long- term storage technologies are not considered despite their lower price per unit of energy. This is probably due to the large conversion losses related to these processes. In general, despite the fact that high PV penetration is considered, storage system deployment is not intensive. Exceptions were made for the ELESTOR HBr battery and for the Smart Energy Hub, which were forced to be installed with a constraint, in order to analyze their contribution in grid flexibility. Both technologies are installed in 2025. Hence, HBr battery, with the lifetime of 20 years, lasts up to 2045 and afterwards no more investments are done in this technology.

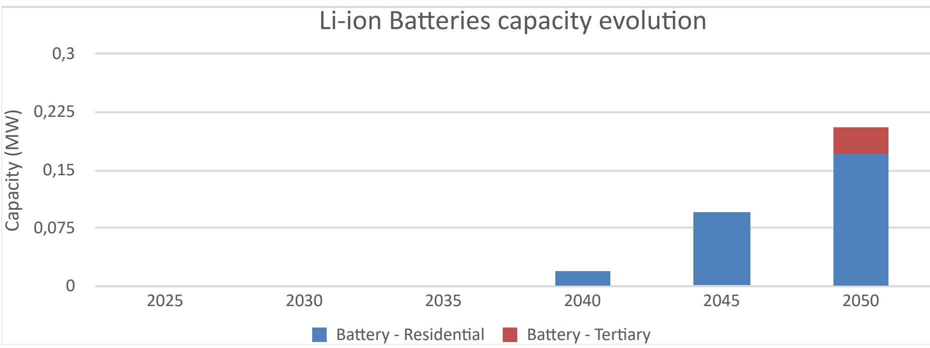



*Figure 17 : Batteries capacity evolution over the time horizon in HIGH_STG_EFF scenario*

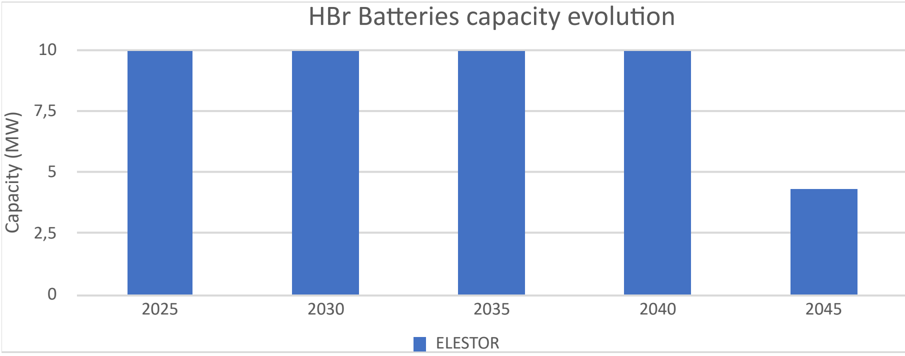



*Figure 18 : HBr battery capacity evolution over the time horizon in HIGH_STG_EFF scenario*

## Renewables share in end-use consumptions

The main objective of the GIFT project is the decarbonization of the energy mix of European islands. An important perspective is to evaluate the decarbonization levels that are reached with the different PV scenarios considered. The results in this figure show the share of self-consumption achieved by sector. In order to find the percentage of self-consumption, the total sectorial demand was divided by the sectorial PV production. The results show that in the end of the modelling horizon, high shares of self-sufficiency are achieved in HIGH scenarios. In LOW scenario 18% approximately is achieved showing that even with low investments, satisfying shares of self-consumption can be obtained. However, in BAU scenario, insufficient share are achieved (2%).

Comparing HIGH and HIGH_STG scenarios, most of the significant differences are observed in public sector, which is caused by the installation of the Smart Energy Hub. We can see that, by its installation in 2025 in combination with the PV installations, is offering a satisfying level of self-sufficiency around 35%. It should be noted that that this percentage represents the entire sector. Moreover, despite the fact that the storage capacities added in residences and tertiary buildings are negligible, it appears to have an impact on the respective sectorial share of self-consumption. In residential sector are achieved the highest percentages, touching 47.2% in 2050 and having a difference of 11.1% more self-sufficiency compared to HIGH scenario. In parallel, the difference obtained between two scenarios in tertiary sector is 1.2% in 2050, which is the time when the batteries were installed in the model.

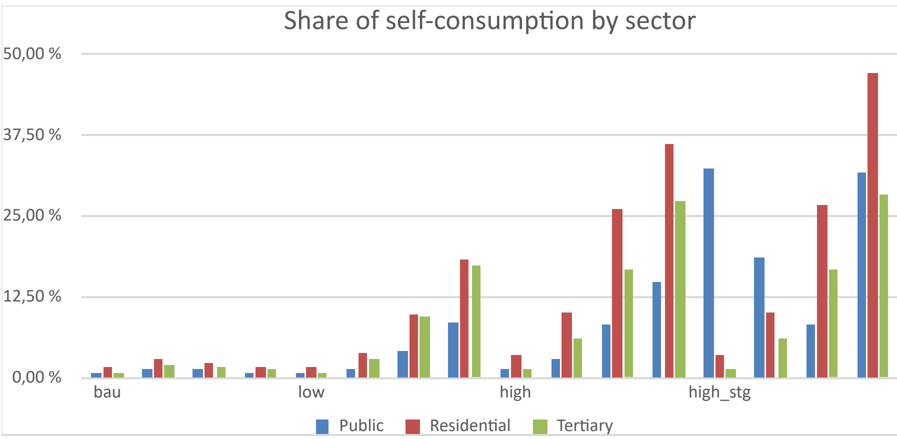



*Figure 19 : HBr battery capacity evolution over the time horizon in HIGH_STG_EFF scenario*

## Renewables share in end-use consumptions

Evia as a large island is expected to have an important demand of EVs in the future. Electric vehicles are attended to augment not only electricity demand, but also the peak load. Smart charging (V1G) is a way to better manage the electricity demand by changing the recharge profile of EVs connected to the grid. Basically, it consists in a modification in the recharge profile of a part of the EVs that by changing the input current that feeds the vehicle. In this way, it is possible to decrease a part of the demand of EVs that occurs at peak hours by shifting this load in off-peak hours. Therefore, by changing the recharge profile of EVs (charging at night hours instead of evenings), additional flexibility can be offered and hence lower the grid congestions. The V1G is a flexible solution that could be used by DSOs. In the model, this is made by estimating a new load profile that assumes 70% of the users that are charging the vehicle at peak hours (evening) are participating in the V1G program. Moreover, it is assumed that the V1G can be made starting from 2025.

The results in Figure 21 show the demand of EVs per timeslice in the model. Thus, the figure can be read as following: the first letter indicates the season: (W: Winter, S: Summer and I: Intermediate) and afterwards the three letters indicate the period of the day as explained in section 1.

The results between HIGH and HIGH_STG were the same, that's why HIGH scenario is not appeared in them. This is due to the fact that batteries are used in order to cover the demand of the sector and not the one of EVs. In 2050 there is the highest electricity demand of the transport sector of the modelling horizon. The results show that the V1G scenario can reduce by 3.4 times the demand at peak hours, confirming that flexibility solutions like this can relieve the pression in the distribution grid. It should be noted also that this scenario is not different from the HIGH scenarios in terms of RES.

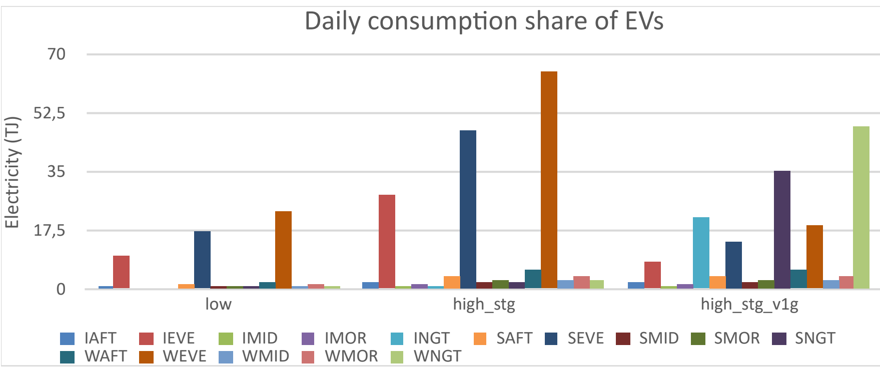



*Figure 20 : Comparison between the daily consumption share by electric vehicles in different scenarios*

## Electricity exports & Imports

In BAU scenario, we can see that electricity exports stop after 2040, because it's the year by which the gas power plant is considered to be closed. Moreover, as seen in Figure 23, the amount of capacities does not allow electricity exports since they are not even able to cover the demand. Hence, in all scenarios, a part of the electricity export is due to the conventional power plant, but also it is evident that electricity export is highly dependent of the RES electricity production, hence the significant augmentation seen between 2025 – 2030. It should be noted that in the end of the modelling horizon of HIGH scenarios, electricity exports are 2.6 times higher than the electricity demand of the entire island, as in the LOW scenario is approximately 1.2 times higher.
After the closure of the gas power plant, it should be noted that electricity imports took place. Important to clarify is that in all time horizon, electricity import is never occurred due to the high supply side compared to the demand. Nevertheless, in BAU scenario, not sufficient capacities exist in the period 2045-2050, thus electricity import covers almost all of the demand.

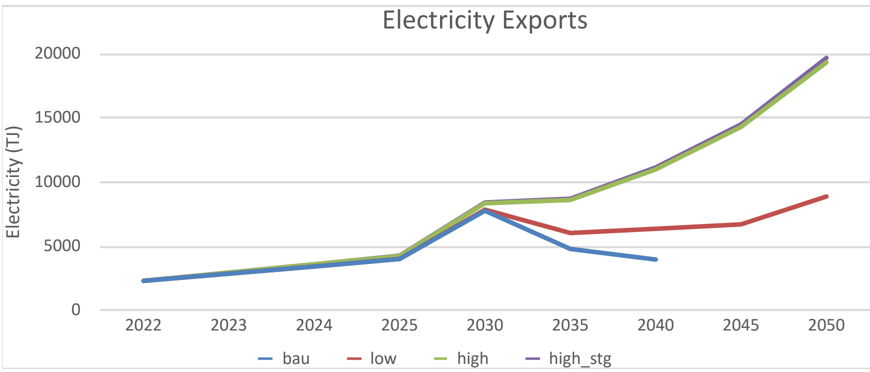



*Figure 21 : Electricity exports for the 4 scenarios*

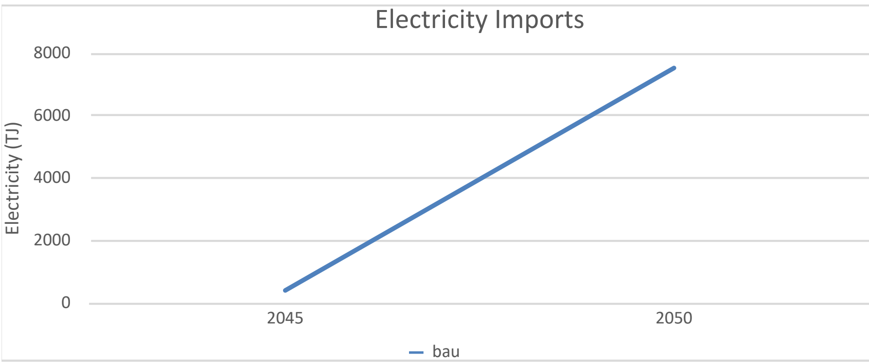



*Figure 22 : Electricity imports for BAU scenario*

# V. DISCUSSION

Evia is considered a strategic island of Greece due to its significant potential for renewable energy sources, as well as its close proximity to the mainland and its interconnection with other islands. It is worth noting that the deployment of RES on the island would not only lead to the decarbonization of Evia, but also will contribute to the overall decarbonization of Greece. This is due to the export to other parts of Greece of the energy excess that is produced in the island through the deployment of RES. Therefore, despite the fact that HIGH scenarios may seem expensive, it is worth mentioning that it will be a milestone for the national electricity needs as also for the operation of the grid.

As concerns the TIMES-EVIA model configuration, it allowed to draw several conclusions for the replicability site. The results obtained considering different realistic renewables' integration scenarios show that promoting the use of RES in the island could lead to important improvements in terms of energy independence, electricity exports but also grid congestion relief. Improvements could be detected even in cases of low renewables deployment. As shown also in the two demonstration sites, Procida and Hinnoya, high shares of RES in end-use electricity consumptions, as also storage and flexibility solution can reduce peak load and relieve the grid congestions.

This analysis also attempted to evaluate the potential benefits coming from the use of the flexibility solutions integrated in the model. Concerning storage solutions, the results showed that the use of these devices is strictly related to the amount of renewable energy integrated in the energy system, as the investments in these devices increase with the share of photovoltaics. As in the case of low renewables' integration in the system, storage is not invested in the model solution; it also suggests that there exists a lower limit over which storage becomes competitive. However, these technologies offer improvements with regard to grid congestion relief and self-consumptions can be observed even when limited investments are made. The improvements could be much more relevant when higher shares of renewables are integrated in the power system. Finally, transport sector is expected to play an important role in the electricity grid in the future. The analysis based on the V1G methods proposed by GIFT showed that this solution offers flexibility by modulating the power of charging in order to avoid the additional electricity demands during peak time.

It is however important to notice that these results are subjected to different limitations. The most important one concerns the assumptions made to cope with the lack of information about the energy system of the island. In fact, the energy use by sector is not reflected in the available data and consequently assumptions were made based on statistical values or other approximative data that in reality differ from the local context of the island. This did not allow to properly represent the seasonal variation in electricity consumptions. Integrating more representative data may lead to different investment choices for the flexibility solutions. Additionally, it is relevant to mention that the model is based on an economic optimization approach. The investment decisions are then influenced by economic considerations, whereas technical aspects such as flexibility requirements, demand response, etc. to ensure the reliability at peak hours are not included. Despite these limitations, it is still an accurate representation of the island's energy system.

In conclusion, the analysis showed that ensuring the decarbonisation of the island is possible, but for this scope other solutions are needed (e.g. storage technologies, V1G or other flexibility solutions when high shares of renewables are included in the power system). Therefore, it is worth noting that the development of the island will be a significant milestone for meeting both national and European electricity demands, but improving also the operation of the respective grids.

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## 1-1. MODEL DEVELOPMENT

### 1.1.1. General settings

Only one region is used to represent the entire energy system of the island.
The currency is set to Euro (€) and the discount rate is 6%.

## 1-2. BASE YEAR ENERGY SYSTEM

The reference energy system at the base year is defined based on the available data. For missing values hypothesis have been made, as explained in the following.

### 1.2.1.Supply side

#### 1.2.1.1. Combined Cycle Gas Turbine Power Plant

The power plant of the Combined Cycle Gas Turbine (CCGT) has a total capacity of 416.95 MW. The import price of natural gas was obtained by (RAE, 2023b). The last data are for December 2022 indicate the prices of natural gas being at 97.22 €/MWh. The Fixed O&M costs were obtained from (Ministry of Environment and Energy, 2020) and the Variable O&M were obtained from (DEI, 2023). The average productivity of the plant is 2500 GWh/year, efficiency of 56% and its availability factor is 65% (DEI, 2023). In the model is assumed that the electricity production from the plant will progressively decrease until its closure in 2040 (also assumed).

#### 1.2.1.2. Wind installations

The wind turbines of the island are in total 224.2 MW, 162 MW connected at the HV grid and the rest of them at the MV grid. Installation years of the plants were obtained by CRES and Fixed O&M were obtained by (Ministry of Environment and Energy, 2020). The availability factor is 0.3 according to (Kamariotis Stavros et al., 2007).

#### 1.2.1.3. Electricity import

For the imports no variations in the electricity price during the day are considered. This choice is made to avoid bias in the results due to economic advantages in specific hours of the day. The price is fixed to 121 €/MWh, resulting from the average of electricity prices in the day ahead market of the month of March of 2023 (RAE, 2023a).

#### 1.2.1.4. Photovoltaics installations

The PV systems installations of the islands are divided into residential systems (5.66 MW) and PV farms (10.21 MW). They were installed between 2012 – 2013 and it it is assumed that they have a lifespan of 20 years and that the technology activity linearly decreases with the passing of time.
For the purposes of the model, the capacity factor of each PV should be defined at each time-slice. This is made starting from the definition of this quantity:

$$CF = E / E\mathrm{max}$$

With $E$ the net electricity generated by the system, $E$max the energy that could have been generated at continuous full-power operation considering the same period of time. The quantification of the energy output of the system at each time-slice assumes an optimally-oriented crystalline silicon PV installation with unitary rated power $CPV$= 1 kWp) and a system loss of 14%.
First of all, the monthly average energy output (in kWh) is obtained using the PVGIS tool. This data is then aggregated for all the seasons considered in the model by summing up the energy output of each month constituting the season, $Ej$ (it is assumed that the energy output at each day of a month is constant). The estimation of the energy output in each time-slice is then made considering the direct irradiance, $Gb$, again obtained using PVGIS for a fixed plane. This value is firstly obtained for each considered season and for each hour of the day by aggregating the values provided by PVGIS for each month of the year. Assuming that the energy output is proportional to the direct irradiance, the fraction of energy production in a specific time-slice t and season j, %$Et,j$, is estimated as:

$$\%E_{t,j} = \frac{\sum_{i=1}^{n} Gb_i}{\sum_{i=1}^{24} Gb_i}$$

With $Gb$ the direct irradiance at the hour $i$, $n$ the number of hours constituting the considered time-slice. The energy output in each time-slice and for each season is then obtained by multiplying the total energy output estimated with PVGIS in each season $j,E$ , for the fraction of energy production, :

$$\%E_{t,j}: \qquad E_{t,j} = \%E_{t,j} \cdot E_j$$

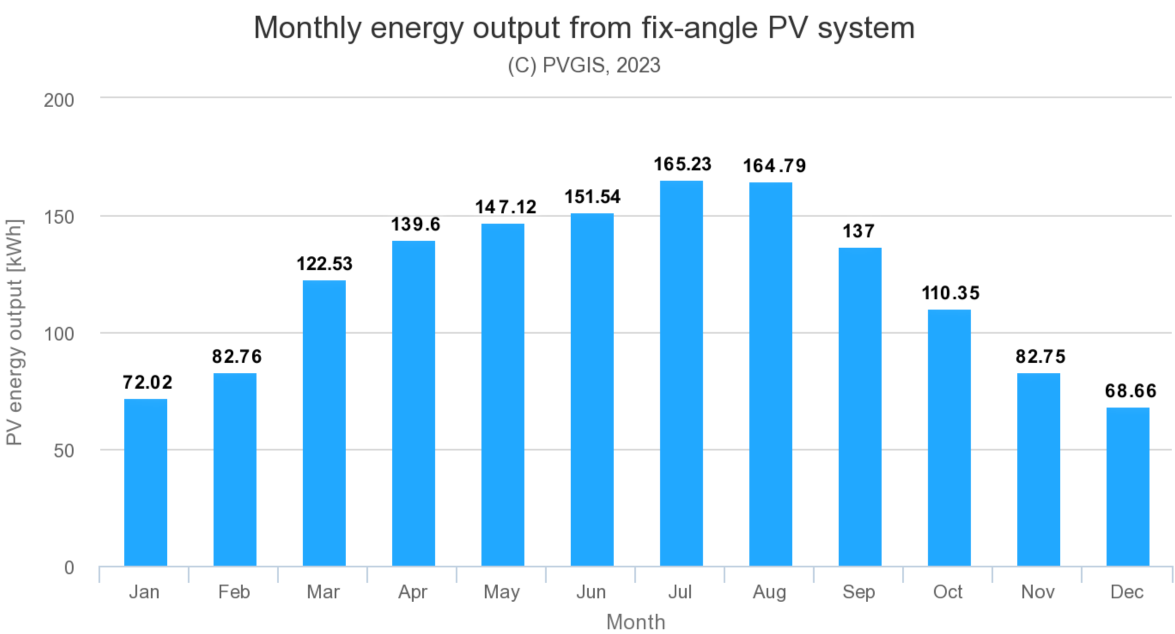


***Figure23 : Monthly energy output from a fix-angle PV system, source PVGIS***

## 1-3. ENERGY SYSTEM EVOLUTION

### 1.3.1.Demand projection

Electricity demand projections were made based on the long-term strategy to 2050, done by the Greek Ministry of environment and energy (Ministry of Environment and Energy, 2020). More precisely, based on different trajectories, the projections estimated concern the total final energy consumption of Greece for each sector. For this project, the trajectory that expands the National Energy and Climate Plan of 2030 until 2050 was selected. In this scenario, it's considered that the energy policies of 2030, are expanded and reinforced until 2050. With other words, energy efficiency and electrification measures are taken into consideration in the projections of the different sector's demand.
The following process was followed in order to find the island's demand. From the final energy consumption, only the electricity consumption was extracted. To determine the insular electricity consumption of each sector, a ratio was used that represents the comparison of Evia's energy consumption to that of Greece. The ratio was calculated by dividing the final energy consumption of Evia by that of Greece, based on the latest available data from the Hellenic Statistical Authority (for the years 2008-2012), resulting in an average of approximately 3%. The first graph shows the demand evolution of the most energy intensive sectors of the island, as respectively the second one shows the less intensive sectors.

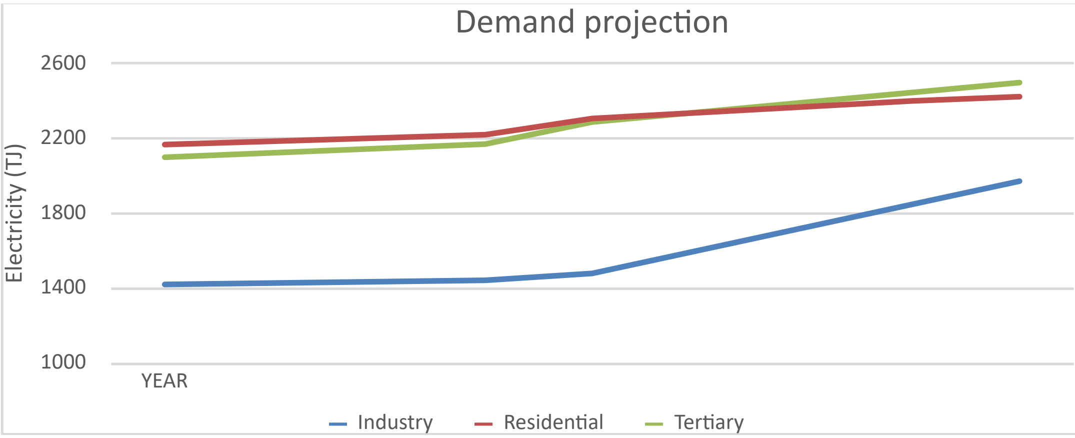


*Figure24 :Demand projection of Industrial, Residential and Tertiary sector up to 2050, source (Ministry of Environment and Energy, 2020)*

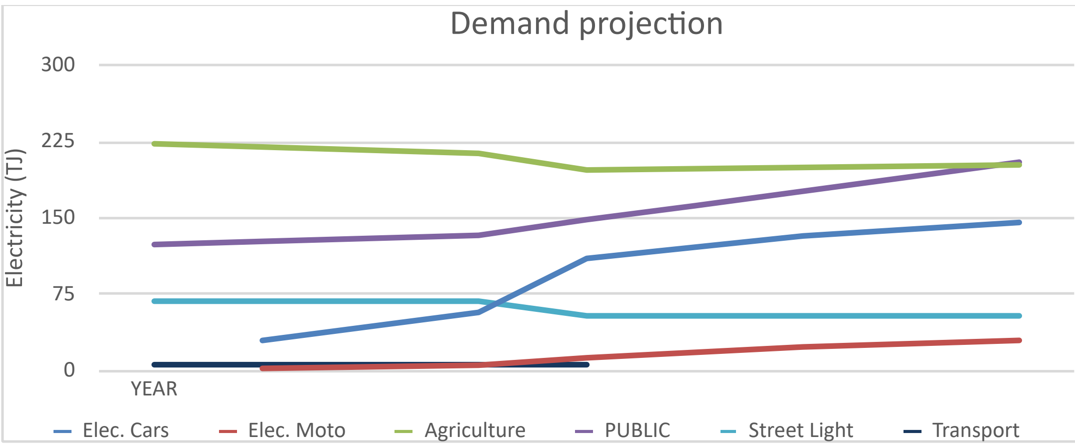


*Figure 25 :Demand projection of new EVs, street lights, agriculture, public and transport sector up to 2050, source (Ministry of Environment and Energy, 2020)*

As concerns the public buildings, the demand forecast was made as following. Based on the national electricity forecast done by (ADMIE, 2022a), it was taken the same ratio and it was applied on the electricity consumption of public building in Evia in 2012 until 2050. Finally, as concerns the street lightning, based on the Action Plan for Sustainable Development Energy and Climate of the Municipality of Chalkida (Municipality of Chalkida, 2018), the consumption of street lighting is 19 GWh. It is foreseen the gradual replacement with low consumption LED lamps until 2030, that will save around 4 GWh per year. It was chosen as hypothesis that this change will occur around 2030.

As concerns the EVs demand projection Based on the projections of the long-term strategy to 2050 for the future transport demand (Ministry of Environment and Energy, 2020), two main scenarios are considered in this analysis. The Low Scenario corresponds to a trajectory with current policies until 2030 and afterwards to a tendency of Business as Usual. Nevertheless, it is considered that the implementation of electric vehicles is expected to begin in large cities and gradually extend to smaller towns. The High Scenario corresponds to a more expanded utilisation of electricity in the transport sector, achieving in 2030 the national target of 30% share of electric passenger vehicles (EVs) in new registrations and arriving at 70% in 2050. The scenarios concern both electric cars and motorcycles.

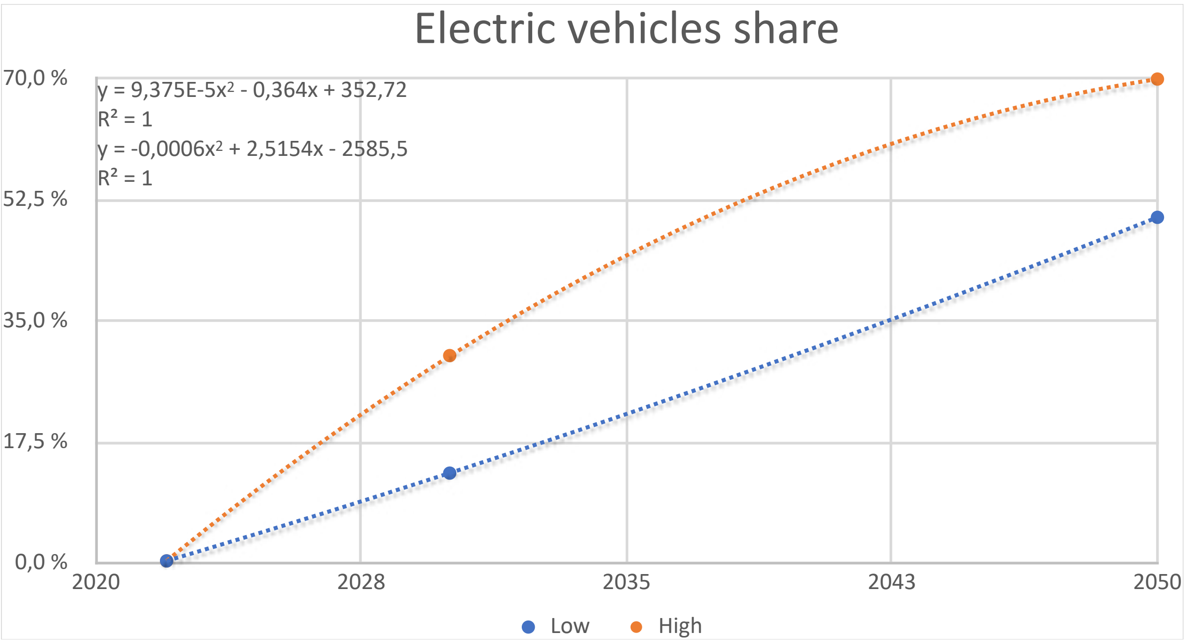


*Figure 26 Evolution of electric vehicles share for LOW and HIGH scenarios, source (Ministry of Environment and Energy, 2020)*

### 1.3.2.New technologies

Several new technologies are included in the model, namely:

- New PV installations
- New Wind Turbines
- Li-ion batteries
- HBr
- Smart Energy Hub
- rSOC storage
- Electric vehicles

The modelling approach for each of them is detailed in the following.

#### 1.3.2.1. New photovoltaics installations

The photovoltaics are separately modelled for the residential, tertiary and public sector, in order to better evaluate the contribution of this technology to the supply of each of them. It is assumed that all new PVs are installed with an optimal slope and plane orientation. With this hypothesis, the capacity factor at each time-slice is estimated using the same methodology applied for the existing PV installations.
The following characteristics were obtained from (Ministry of Environment and Energy, 2020)

| Parameter | Value |
|---|---|
| **Life** | 25 Years |
| **Investment costs** | Residential/Tertiary/Public<br>2022: 721€/kW<br>2030: 690 €/kW<br>2050: 495 €/kW |
| **Fixed O&M costs** | Residential/Tertiary/Public<br>2022: 22 €/kW<br>2030: 15 €/kW<br>2050: 11 €/kW |
| **Capacity factor** | According to solar irradiance (PVGIS) |

*Tableau 3: Techno-economic parameters for PV systems*

### 1.3.2.1. New wind turbines installations

The following characteristics were obtained from (Ministry of Environment and Energy, 2020)

| Parameter | Value |
|---|---|
| Life | 20 Years |
| Investment costs | 2022: 1200 €/kW<br>2030: 1066 €/kW<br>2050: 848 €/kW |
| Fixed O&M costs | 2022: 22 €/kW<br>2030: 21 €/kW<br>2050: 20 €/kW |
| Capacity factor | 0.3 |

*Tableau 4: Techno-economic parameters for wind turbines*

### 1.3.2.1. Li-ion batteries

Li-ion batteries are coupled to photovoltaics to better manage the energy potential of the solar installation. This device is modelled in TIMES as a standard timeslice storage process operating at daynite level. Three different Li-ion battery technologies are defined, one for each of the sectors that have photovoltaics installed on buildings.
It is assumed that new investments for this technology will only be available starting from 2023. The lifespan of all the batteries is set to 15 years in 2023, based on the average value indicated in (EASE, 2023). The investments costs are separately defined for residential applications and public and tertiary ones. Moreover, as the investment costs are expected to decrease in the near future, different values are defined for different years. Both for the definition of the costs and their evolution up to 2040 reference is made to (Tarvydas et al., 2018). As the analysis considers different scenarios of Li-ion batteries penetration in the market, reference is made to the values for a moderate deployment of these systems. It is assumed that for residential applications the batteries have a C-rate equal to 0.35; for the tertiary and public one instead the C-rate is assumed to be 0.25. For 2050 instead, a hypothesis is made on the investment costs (about 220 €/kW for residential applications, 180 €/kW for tertiary and public ones). No fixed operation and maintenance costs are considered for batteries. Finally, it is assumed that the cost of the battery is equal to the cost of the entire battery system.

| Parameter | Value |
|---|---|
| Max capacity per installation | Residential: 10 kWh<br>Tertiary/public: 25 kWh |
| Life | 15 years |
| Investment costs | *Residential:*<br>2020: 450 €/kW<br>2025: 400 €/kW<br>2030: 350 €/kW<br>2035: 300 €/kW<br>2040: 250 €/kW<br>2050: 220 €/kW<br>*Tertiary/public:*<br>2020: 400 €/kW<br>2025: 350 €/kW<br>2030: 300 €/kW<br>2035: 250 €/kW<br>2040: 200 €/kW<br>2050: 180 €/kW |
| Efficiency | 2023: 92%<br>2030: 94% |

*Tableau 5: Summary of the input parameters for new Li-ion battery installations*

*7 The C-rate represents the discharge rate of a battery. The capacity of a battery rated at 1C means that a fully charged battery will be completely discharged in 1 hour. 2C rate means that the battery can be fully discharged in half an hour. ½C rate means that the battery can be fully discharged in 2 hours. (JRC, 2020a)*

### 1.3.2.1. HBr battery

In context of GIFT, the flow battery from Elestor can store electricity from the grid during off-peak hours and discharge it when needed. The Elestor flow battery is a HBr (hydrogen bromide) system designed to store the energy produced by renewable energy systems. It is assumed that the technology will be installed in 2025. All input parameters used in the model of Hinnoya were used in this model (Chlela et al., 2021).

<table>
<tr><th></th><th>ELESTOR flow battery</th></tr>
<tr><td>Materials</td><td>HBr (hydrogen bromide, as electrolyte)</td></tr>
<tr><td>Power capacity</td><td>50</td></tr>
<tr><td>Energy capacity (kWh)</td><td>250<br>(Negligible loss of energy capacity during lifetime)</td></tr>
<tr><td>Efficiency (%)</td><td>charging or discharging efficiency of around 80%<br>(to be confirmed with practical tests 2020Q4);<br>64% for the roundtrip efficiency<br>NB efficiency depends on the operational mode of the system, that is variable. Please see below example how such efficiency picture will look like. It will be a table with efficiencies depending on SoC and power.
<table>
<tr><th>Nominal Stack Power [%]</th><th></th><th colspan="10">Electrolyte SoC [%]</th></tr>
<tr><td></td><td></td><td>0 - 10</td><td>11 - 20</td><td>21 - 30</td><td>31 - 40</td><td>41 - 50</td><td>51 - 60</td><td>61 - 70</td><td>71 - 80</td><td>81 - 90</td><td>91 - 100</td></tr>
<tr><td rowspan="2">10</td><td>Charge</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Discharge</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td rowspan="2">20</td><td>Charge</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Discharge</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td rowspan="2">30</td><td>Charge</td><td></td><td></td><td></td><td></td><td></td><td></td><td>95</td><td>97</td><td>98</td><td>99</td></tr>
<tr><td>Discharge</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td rowspan="2">40</td><td>Charge</td><td></td><td></td><td></td><td></td><td>88</td><td>90</td><td></td><td></td><td></td><td></td></tr>
<tr><td>Discharge</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td rowspan="2">50</td><td>Charge</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Discharge</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td rowspan="2">60</td><td>Charge</td><td></td><td></td><td>77</td><td>79</td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Discharge</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td rowspan="2">70</td><td>Charge</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Discharge</td><td></td><td></td><td>74</td><td>75</td><td>76</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td rowspan="2">80</td><td>Charge</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Discharge</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td rowspan="2">90</td><td>Charge</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Discharge</td><td>61</td><td>63</td><td>66</td><td>67</td><td>68</td><td>70</td><td>75</td><td>78</td><td>89</td><td>98</td></tr>
<tr><td rowspan="2">100</td><td>Charge</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td>NA</td><td>NA</td></tr>
<tr><td>Discharge</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td>97</td><td>99</td></tr>
</table>
This list will be finetuned over time and will be included inside the battery model</td></tr>
<tr><td>Ramp constraints (p.u. per min)</td><td>In principle direct ramp-up/ramp-down to full charge power shall be possible. Further experiments needed to confirm this.<br>Further measurements to be done on pilot models, more info expected by end 2020</td></tr>
<tr><td>Time of charge/ discharge (s)</td><td>Fast switching operation possible to change over (milliseconds).</td></tr>
<tr><td>Lifetime (years)</td><td>T.b.d. (Target 20 years)</td></tr>
<tr><td>Max cycles</td><td>15,000 charge/discharge cycles (expected)</td></tr>
<tr><td>Losses</td><td>Some losses will occur (e.g. hydrogen leakage, parasitic power)<br>To be quantified during project</td></tr>
<tr><td>Energy cost (€/ kWh)</td><td>Target 50 €/MWh (LCOS)</td></tr>
<tr><td>Total project cost</td><td>2025: 300 € /kWh + 3000 €/kW<br>2035 : 80€ /kWh + 800 €/kW</td></tr>
</table>

*Tableau 6: technical parameters of ELESTOR flow battery*

### 1.3.2.2. Smart energy Hub

The Smart Energy Hub is a hybrid system composed by two different technologies, namely a rSOC (reversible Solid Oxide Cells) and a Li-ion battery. It is assumed that the technology will be installed in 2025. All input parameters used in the model of Procida were used in this model (Chlela et al., 2021).

| | **Smart Energy Hub (SYLFEN)** | | |
|---|---|---|---|
| | **rSOC** | | **Battery** |
| | **electrolysis mode** | **fuel cell mode** | |
| **Materials** | max storage: 50 kg of compress hydrogen 200 bar | | Li-Ion |
| **Capacity (kW)** | 11-40 kWe<br>+<br>4 kWth (produced, max) | 1.6 to 5 kWhe<br>+<br>4 kWth (produced, max) | maximum peak charge/ discharge power of +/-50kW<br>permanent charge/ |
| **Energy (kWh)** | 1970<br><br>(possibility to have 0% of state of charge) | | 50 kWh<br>(but useful capacity of 40 kWh)<br>(keep 10% of state of charge in order to avoid deep discharge) |
| **Efficiency (-)** | 75% electrical<br>80% thermal + electric | 50% | 90% |
| **Ramp constraints (p.u. per min)** | Switching time between power set point lower than 10' but must remain stable for 1 hour<br><br>(thermal stability is required) | | Fast switching between power set point including charge and discharge switching mode.<br>The switching time is of |
| **Lifetime (years)** | 20 years (expected) | | 5 years at the time of installation<br>10 years expected in 2025 with technology |
| **Max cycles** | No limitations except that it is not possible to change the mode more than 6 times per day | | 1 cycle per day preferably, 2 cycles possible if not complete discharge to DoD |
| **Losses** | Negligible | | Negligible |
| **Energy cost (€/kWh)** | 76 €/kWh | | |
| **Capacity cost (€/kW)** | 1700 €/kW in charging mode<br>2780 €/kW in discharging mode | | |

*Tableau 7: Summary of technical characteristics of the Smart Energy Hub*

### 1.3.2.1. Long-term (rSOC) storage

The rSOC storage is also considered as a separate technology that can operate at a seasonal level, giving the possibility to “shift” the electricity supply from one season to another. In TIMES, it is modelled as a *standard timeslice storage* process operating at seasonal level.

The technical characteristics of this technology are defined on the basis of the ones used for the rSOC of the Smart Energy Hub. However, in this case the system is modelled as a unique process, with an efficiency $\eta_{LTSTG}$ that is given by the product between the one of the electrolyser, $\eta_{elysr}$, and the one of the fuel cell, $\eta_{FC}$:

$$\eta_{LTSTG} = \eta_{elysr} \bullet \eta_{FC}$$

| Parameter | Value |
|---|---|
| Life | 20 years |
| Efficiency | 37.5% |
| Investment costs | 52.55 €/kWh |

*Table 3 : Summary of the input parameters for new seasonal storage installations*

***Tableau 8: Summary of technical characteristics of the Smart Energy Hub***

### 1.3.2.1. Electric vehicles

Electric vehicles are included in the model as additional consumption demands for the transportation sector. The investment costs, the fixed and variable costs for this technology are set to zero. According to Hellenic Statistical Authority, there are 56.000 vehicles and 25.000 motorcycles in the island.

For the estimation of the additional electricity demand of each type of new vehicle, different hypothesis are made. For electric cars, the consumption per unit of distance is assumed to be 0.2 kWh/km (according to (Pasaoglu et al., 2013) is the max electricity consumption). The average distance travelled per day is set to 20 km for the LOW and 30 km for the HIGH scenario, based on the fact that is a large island. Concerning the battery capacity, it is defined an increasing value with time, given the expected technology improvements in the near future. The values are set according to IEA, 2020. Assuming that the e-cars fleet is only used by residential users, the charging station capacity is typically a slow charging one. The capacity is then set to 3.5 kW (Azzone et al., 2016).

The main technical assumptions for electric cars:

| Electric cars modelling - main hypothesis | |
|---|---|
| Consumption [kWh/km] | 0.2 |
| Distance per day [km] | LOW: 20<br>HIGH: 30 |
| Charging station capacity [kW] | 3.5 |
| Battery capacity [kWh] | 2020: 35<br>2025: 50<br>2030: 75<br>2040: 80 |

***Tableau 9: Hypothesis made for the modelling of electric cars***

Similar hypothesis is made for the electric motorcycles (cf. Table 18). However, in this case the electricity consumption per unit of distance is lower, still based on (Pasaoglu et al., 2013). In this case no battery capacity improvements are considered.

| Electric motorcycles modelling - main hypothesis | |
|---|---|
| Consumption [kWh/km] | 0.13 |
| Distance per day [km] | 10 |
| Charging station capacity [kW] | 3.5 |
| Battery capacity [kWh] | 15 |

*Tableau 9:*
*Hypothesis made for the electric motorcycles' technical parameters*

Starting from these assumptions the additional electricity load can be defined by defining the deployment scenario (number of vehicles, travel routine, battery state of charge at depart, users charge behaviour). The calculation, based on the hypothesis of one charge per day, is explained in the following.

First of all, the electricity consumption per EV *i* and per day *d*, $E_{EV,i,d}$, is determined:

$$E_{EV,i,d} = c_i \bullet d_i$$

With $c_i$ the specific electricity consumption (kWh/km) and $d_i$ the distance travelled per day.

Then, the electricity consumption of the total fleet per day, $E_{EV,d}$, is estimated by considering the number of deployed EV:

$$E_{EV,d} = E_{EV,i,d} \bullet SH_d \bullet n_{EV}$$

With $SH_d$ the share of EVs used per day, $n_{EV}$ the number of EVs present on the island.

The EVs electricity load is defined both for peak and off-peak consumption periods. For the peak period the daily load $E_{EV,peak,d}$ is defined as:

The same applies for the daily off-peak period consumption, $E_{EV,offpeak,d}$:

$$E_{EV,offpeak,d} = E_{EV,d} \bullet SH_{offpeak}$$

With $SH_{offpeak}$ the share of electric vehicles recharged in the off-peak period ($SH_{offpeak} = 1 - SH_{peak}$).

Finally, the annual consumption can be estimated both for the peak and off-peak period as:

$$E_{EV,peak} = E_{EV,peak,d} \bullet 365$$

$$E_{EV,offpeak} = E_{EV,offpeak,d} \bullet 365$$

For the definition of the EVs electricity load at each time-slice it is assumed that only one recharge per day occurs. With this hypothesis, different scenarios could be defined according to the users charge behaviour. This is equivalent to define the share of EVs charged at each time-slice.

The time-slice consumption fraction at each time-slice *t*, $\%E_{EV,t}$, is defined as:

$$\%E_{EV,t} = \frac{(SH_{t,peak} \bullet E_{EV,peak,d} + SH_{t,offpeak} \bullet E_{EV,offpeak,d}) \bullet N_j}{E_{EV,peak} + E_{EV,offpeak}}$$

With $SH_{t,peak}$ and $SH_{t,offpeak}$ the share of electric vehicles charged at the time-slice *t* of the peak and off-peak period respectively, $N_j$ the number of days in the considered season *j*.

## 1-4. SCENARIOS DEFINITION

At a first attempt, two main scenarios are considered in the analysis, namely a case with low deployment of RES (LOW) scenario and a scenario with higher penetration (HIGH). Then, one additional scenario is considered in which storage technologies are included (HIGH_STG).
The calculations made to define these scenarios in the model are presented in the following.

### 1.4.1.Annual photovoltaics investments

To avoid excessive investments on photovoltaics at a given year, annual growth rate constraints are included in the model. In particular, a constraint on the maximum amount of PVs installations $N_{max,t}$ is set at each year *t* of the horizon according to the following equation:

$$N_{max,t} = c_t$$

Where is the integer value defining the maximum amount of new photovoltaics installations at year t.
Concerning the residential sector, the value set for 2022-2025 is set in accordance with the observations on the capacities trend. From 2012 to 2013 there were added 1.3307 MW and from 2013 to 2014 there were added 1.9967 MW.

For the PV installations in tertiary and public sectors, the trends were assumed based on the maximum capacity available, as shown in the section 1.5.2.

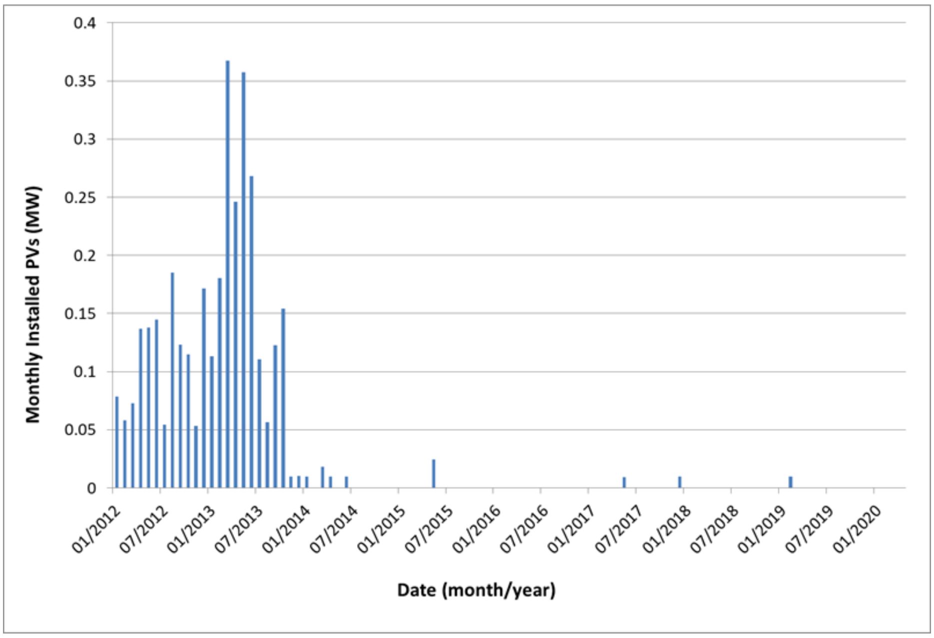


*Figure 27 Monthly installed PVs by the years*

The different bound values $c_t$ used to define the two PVs deployment scenarios (LOW and HIGH) :

| Sector | Year | LOW (MW/year) | HIGH (MW/year) |
|---|---|---|---|
| **Residential PV** | 2023-2025 | 2 | 4 |
| | 2025-2030 | 3 | 5 |
| | 2030-2040 | 4 | 7 |
| | 2040-2050 | 5 | 8 |
| **Public PV** | 2023-2025 | 0.05 | 0.1 |
| | 2025-2030 | 0.05 | 0.1 |
| | 2030-2040 | 0.1 | 0.2 |
| | 2040-2050 | 0.2 | 0.3 |
| **Tertiary PV** | 2023-2025 | 1 | 2 |
| | 2025-2030 | 2 | 4 |
| | 2030-2040 | 3 | 5 |
| | 2040-2050 | 4 | 6 |

*Tableau 11 Summary of hypothesis for the development of PVs per sector*

The Low scenario results in 84.5 MW and in the HIGH scenario in 166 MW of new pv installations of the residential sector. The Low scenario results in 83 MW and in the HIGH scenario in 136 MW of new pv installations of the tertiary sector. The Low scenario results in 3.4 MW and in the HIGH scenario in 5.8 MW of new pv installations of the public sector.

As concerns the installation of PV farms, according to the Action Plan for Sustainable Development Energy and Climate of the Municipality of Chalkida (Municipality of Chalkida, 2018), there will have been implemented a PV farm of 45MW until 2030. This capacity concerns only the wider region of the Municipality of Chalkida, so it's assumed that 12% more capacity will be installed in the whole island, resulting in 50MW (LOW scenario) and 100% more capacity resulting in 90 MW (HIGH scenario). For the period 2030-2050, no further plans are yet announced, so it's assumed that the same amount of capacities will be added in period 2030-2040 and a little bit more augmented in period 2040-2050.

| Year | LOW [MW] | HIGH [MW] |
|---|---|---|
| **2023-2025** | 20 | 45 |
| **2025-2030** | 30 | 45 |
| **2030-2040** | 70 | 120 |
| **2040-2050** | 90 | 150 |

*Tableau 12 Summary of hypothesis for the development of PV farms*

The Low scenario results in 160 MW and in the HIGH scenario in 360 MW of new installations of PV farms.

### 1.4.2. Max photovoltaics capacity constraints

A constraint on the max capacity of PVs in the island is defined in the model. As the photovoltaics installations are separately defined for the residential, tertiary and public sector, the estimation of the max amount of installable capacity must be independently defined for the three PV types as well.
The methodology applied to estimate the maximum amount of photovoltaics' capacity for each sector is explained in the following.

#### 1.4.2.1. Residential PV installations

For the residential sector, it is assumed that the PV technology can only be installed on roofs to ease the calculation (but in reality, it is not the case).

According to Hellenic Statistical Authority, 72% of residences in Greece have a roof surface between 50-120 m². As an assumption, it's considered an average roof surface of 70 m². This leads approximately to a 10 kWp roof capacity.

$$C_{max,building} = 10\ kW/building$$

Considering the total number of residential buildings provided by Hellenic Statistical Authority, $n_{RES}$, the max installable capacity on residential roofs, $C_{max,RES}$, can be estimated:

$$C_{max,RES} = C_{max,building} \bullet n_{RES} = 10 \bullet 100\ 000 = 1\ 000\ 000\ kW = 1\ GW$$

However, as it is not realistic that all the roofs are covered by PVs, it is assumed that at most only 1/2 of the roof are used for PVs:

$$C'_{max,RES} = C_{max,RES} \bullet \frac{1}{2} = 1000000\ kW \bullet \frac{1}{2} = 500\ \boldsymbol{MW}$$

#### 1.4.2.1. Public PV installations

For the public sector, it is assumed that the PV technology can only be installed on roofs to ease the calculation (but in reality, it is not the case). According to Hellenic Statistical Authority, Evia possesses 582 public buildings (2011). Assuming an average available surface of 100 m² from *PVWatts Calculator,* a max installable capacity on public roofs of 15 kWp is consdidered.

$$C_{max,building} = 15\ kW/building$$

Considering the total number of public buildings, $n_{PUB}$, the max installable capacity on public buildings roofs, $C_{max,PUB}$, can be estimated:

$$C_{max,PUB} = C_{max,building} \bullet n_{PUB} = 15 \bullet 582 = 8\ 730\ kW = 8{,}3\ MW$$

However, as it is not realistic that all the roofs are covered by PVs, it is assumed that at most only 2/3 of the roof are used for PVs, the maximum amount of installable capacity is estimated as:

$$C'_{max,PUB} = 8{,}3\ MW \bullet \frac{2}{3} = 5{,}82\ \boldsymbol{MW}$$

1.4.2.1. Tertiary PV installations

For the estimation of the tertiary maximum PV capacity care should be taken for the definition of the buildings' roofs on which to install the PV systems. According to Hellenic Statistical Authority, a classification is made between the stores-offices and the hotels of the island.
The max capacity is estimated based on assumptions on the available surface using PVWatts Calculator, considering an average of 100 m2 for stores and offices and 350 m2 for hotels.
The summary of the assumptions for the total installable PV capacity is shown in Tableau 13.

| Type of business | Nb of buildings | Assumed average surface [m2] | Equivalent installable capacity per building | Total installable capacity [MW] |
|---|---|---|---|---|
| **Store - Office** | 5 000 | 100 | 15 | 75 |
| **Hotels** | 1 500 | 350 | 50 | 75 |
| **Total** | | | | **150** |

*Tableau 13 Summary of the values used for the estimation of the total installable PV capacity in the tertiary sector*

### 1.4.3. Annual wind turbines investments

To avoid excessive investments on wind turbines at a given year, annual growth rate constraints are included in the model. In particular, a constraint on the maximum amount of wind turbines installations $N_{max,t}$ is set at each year t of the horizon according to the following equation: $N_{max,t} = c_t$

Where is the integer value defining the maximum amount of new wind turbines installations at year t.
The value set for 2023-2030 is set in accordance with the projects under development accounting for 1242 MW, among which 1202 MW will be connected in HV grid, and the other 40 MW in MV grid. In the model, it is assumed that these capacities will have been installed until 2030. Moreover, according to departmental office of the technical chamber of Greece, the max capacity of wind turbines in the island is 3238 MW (Kamariotis Stavros et al., 2007). For the period 2030-2050, no further plans are yet announced, so it's assumed that in the HIGH scenario will be exploited all the possible potential of wind energy, and in the LOW scenario there will be a slower implementation, but still progressive. In summary, we have made the following assumptions for the capacities trend.

| Year | LOW HV [MW/year] | LOW MV [MW/year] | HIGH HV [MW/year] | HIGH MV [MW/year] |
|---|---|---|---|---|
| **2023-2025** | 125 | 4 | 125 | 4 |
| **2025-2030** | 137.5 | 8 | 137.5 | 8 |
| **2030-2040** | 30 | 2 | 70 | 4 |
| **2040-2050** | 50 | 2 | 120 | 5 |

*Tableau 14 Summary of the values used for the development of wind turbines*

The Low scenario results in 2.040 MW and in the HIGH scenario in 3.232 MW of new wind turbines installations.

### 1.4.4. Max batteries capacity constraint

Another constraint is set for the maximum capacity of the batteries, that is separately defined for each of the sectors of application. For the residential, tertiary and public sector the maximum capacity is defined as it follows:

$$C_{max,\,BAT,s} = C_{\bar{BAT},s} \bullet N_{B,s}$$

Where $C_{\bar{BAT},s}$ is an average capacity size of a battery used in the specific sector *s*, $N_{B,s}$ the total number of buildings of the considered sector *s* in the island.

*Tableau 15 Summary of the values used to define the max batteries capacity constraint*

| Application (s) | $C_{\bar{BAT},s}$ [kWh] | $N_{B,s}$ [-] | C-rate | $C_{max,\,BAT,s}$ [MW] |
|---|---|---|---|---|
| **Residential** | 10 | 100 000 | 0.35 | 350 |
| **Tertiary** | 25 | 7 500 | 0.25 | 46.88 |
| **Public** | 25 | 582 | 0.25 | 3.64 |

### 1.4.5. Max batteries capacity constraint

An additional constraint is imposed on the maximum amount of new batteries investments at each year of the horizon. The values used for this constraint, specified for each sector of application and kept constant for all the years, are summarized in Tableau 16.

As long as the long-term storage is concerned, a ratio of 10% is assumed compared to total sector storage. For example, the storage of residential sector is 350 MW in 2050, so the long-term storage for this sector is considered 35 MW.

| Application | Max capacity increase [MW /year] |
|---|---|
| **Residential** | 17.5 |
| **Tertiary** | 4.68 |
| **Public** | 0.364 |

*Tableau 16 Summary of the values used as maximum amount of new investments on batteries*

### 1.4.6. Smart Energy Hub investments

A constraint is also imposed on the Smart Energy Hub investments. According to (Rikos et al., 2022), it is not suitable for large islands but there is the possibility to install several of them. The minimum size of a SEH unit is 150-200MWh/year. Due to the modular construction of SEH, the maximum consumption that serves is 1000-1200MWh/year, which makes the solution suitable for medium-sized islands, especially if more than one unit is deployed. Based on this, in the HIGH_STG scenario, we fix it in its maximum size.

### 1.4.7. HBr investments

According to (Rikos et al., 2022), It could be applied either to its minimum size (1MW/10MWh) or to a larger model (i.e. >10MW and for operation >10 hours). Based on this, in the HIGH_STG scenario, we fix it in its maximum size, with a maximum capacity of 5 batteries.

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chaire modélisation prospective au service du développement durable

# Les cahiers de la Chaire

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Nikolaos PAPASTEFANAKIS,
Sandrine SELOSSE
et Nadia MAIZI

*Mines Paris-PSL*
*CMA*

Working paper