

Chapter 31

Energy Balance Analysis for an Island PV Station Used for EV Charging on the Basis of Net Metering



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Introduction

The Aegean Archipelagos is a Greek territory where several remote islands are located. In this European area of the SE Mediterranean there exist more than 30 autonomous thermal power stations (APS) of various sizes [1], starting from 150 kW up to several MW. Until now all these APS are operating using remarkable quantities of diesel or heavy oil (Fig. 31.1), while the corresponding marginal production cost is extremely high, exceeding 1000 €/MWh in certain small islands (Fig. 31.2). As a general picture, the average electricity production cost for the entire Aegean Sea area varies between 250 and 300 €/MWh, being five times higher than the corresponding cost of the Greek mainland [2].

On the other hand, most of the remote islands possess excellent solar potential and very high wind potential in specific island locations. For example, according to the extended long-term measurements by PPC [3], the Hellenic Meteorological Agency [4], CRES [5], and private companies, one may easily conclude that the corresponding annual solar potential ranges between 1500 and 1850 kWh/m² at horizontal plane, while the average wind speed in the Aegean Archipelago varies between 8 and 9.5 m/s (see also Fig. 31.3).

On the basis of the above presented data, it is quite obvious that all these islands could modify their electricity generation model using RES-based (mainly solar and wind) power stations instead of oil-based APSs.

Unfortunately, despite the evident financial and environmental advantages of the proposed RES-based solutions, described by several researchers during the last 30 years [6–10], the actual contribution of RES in the remote islands electrification fuel

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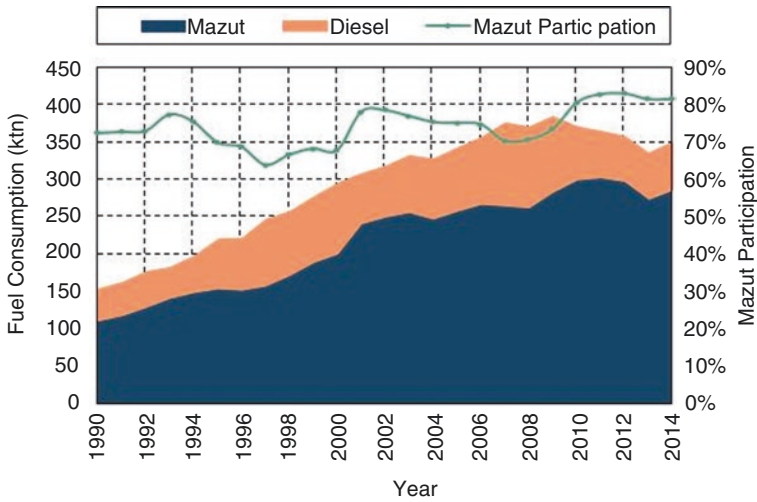


Fig. 31.1 Long-term evolution of fuel consumption for APSs of Aegean Sea

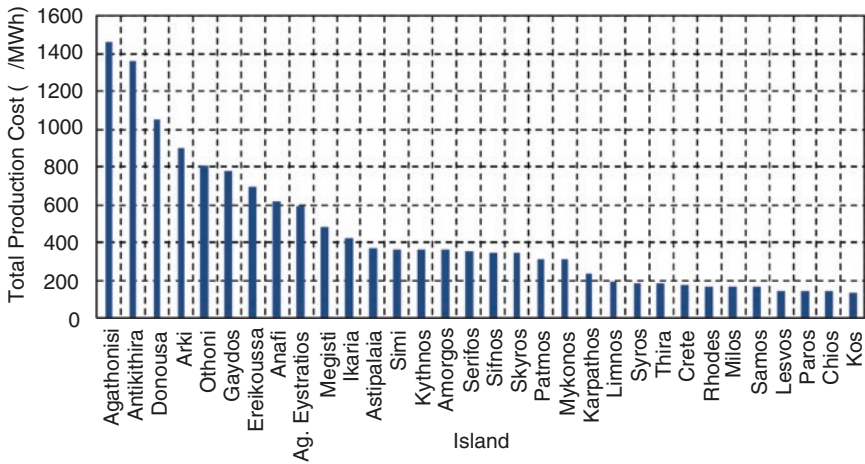


Fig. 31.2 Electricity production cost of Aegean Sea APSs, 2017

mix is poor, thus less than 20% of the electricity consumption is covered by the existing RES-based units for the last 8 years (maximum value of 19% during 2016) (Fig. 31.4).

Moreover the majority of RES-based electricity generation is via wind parks; however, during the last years the PV-based contribution is remarkable (see for example Fig. 31.5). Actually, the ratio between wind and solar electricity generation varies considerably from 6:1 during winter to almost 3:1 during summer.

However, despite the above-described situation the encouragement for new wind and solar power stations is limited for various reasons [11–13]. More specifically,

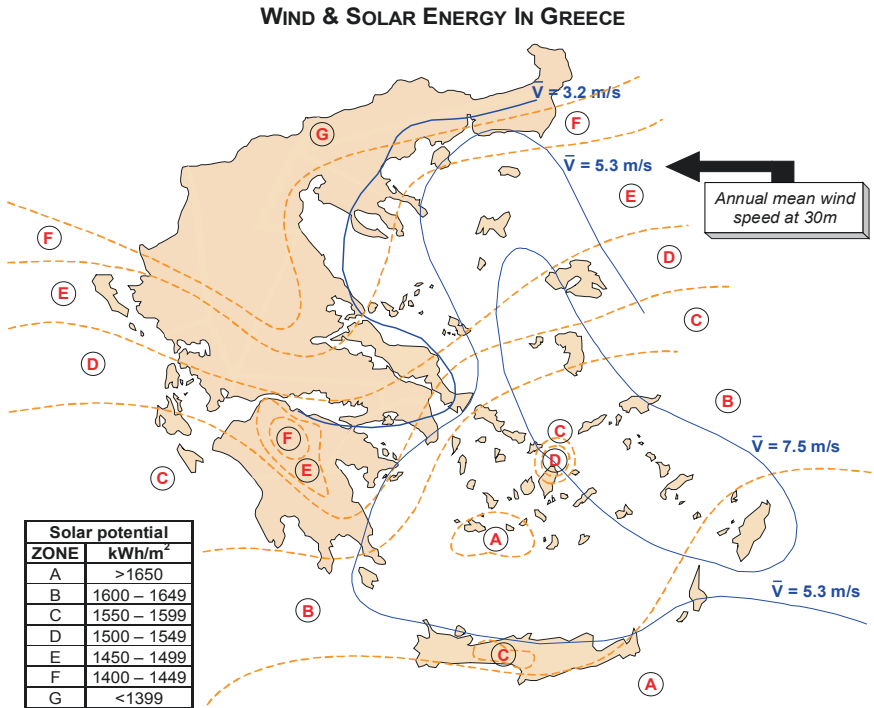


Fig. 31.3 Solar and wind potential in Greece

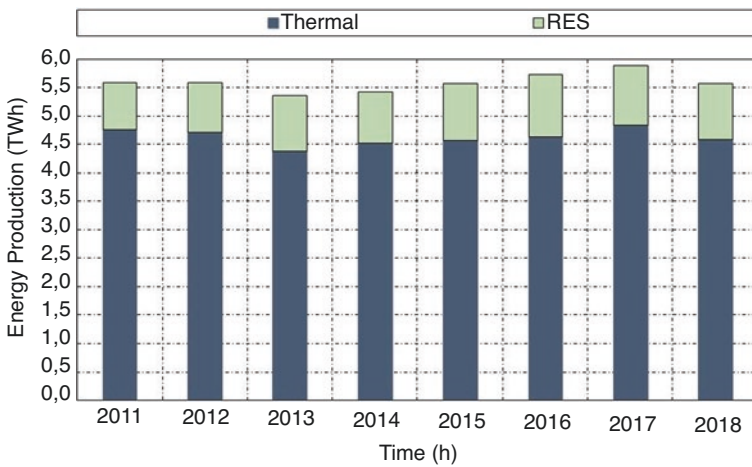


Fig. 31.4 Annual evolution of RES and thermal energy production at the non-interconnected Aegean Sea Islands

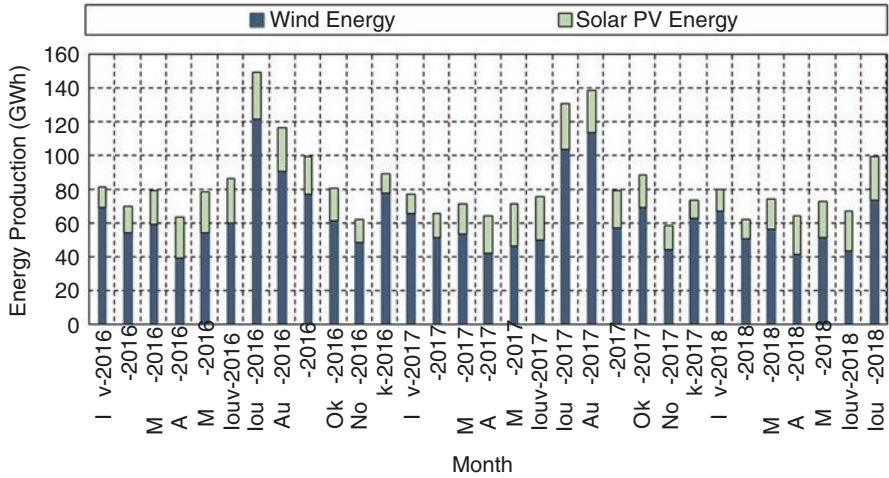


Fig. 31.5 Solar and wind energy production at Aegean Sea non-interconnected islands

medium-sized PV generators are not supported by the Greek State due to grid stability issues, thus the compensation of PV electricity is only 65€/MWh, an extremely low price in comparison with the electricity production cost in the Aegean Archipelagos (Fig. 31.2) and despite the relative high turnkey cost of similar installation in small and remote islands.

In order to increase the clean-green energy portion in the remote islands fuel mix, the idea of using the net-metering technique, recently offered by the Greek State, is examined. More specifically, taking into consideration the availability of the solar potential one may cover his needs using directly small PV generators.

In cases that the electricity requirements of the local consumption are not in accordance with the solar irradiance availability, the net-metering technique can be adopted. Thus the solar electricity production—not directly consumed—is forwarded to the local electrical network, in order to be “stored.” Accordingly, during low (or zero) solar energy production and high electricity consumption periods, energy is imported from the local network.

To this end, the energy balance between the PV station production and the respective electricity consumption is estimated on an annual basis. In this way, the end-user is not surcharged by the local electrical operator since it finally consumes its own solar energy production, on an annual basis.

Proposed Installation

The Dodecanese complex belongs to the SE Mediterranean Sea and possesses excellent solar potential (Fig. 31.3). One of the smallest inhabited remote islands of the complex is Tilos island, located NW of Rhodes (Fig. 31.6).

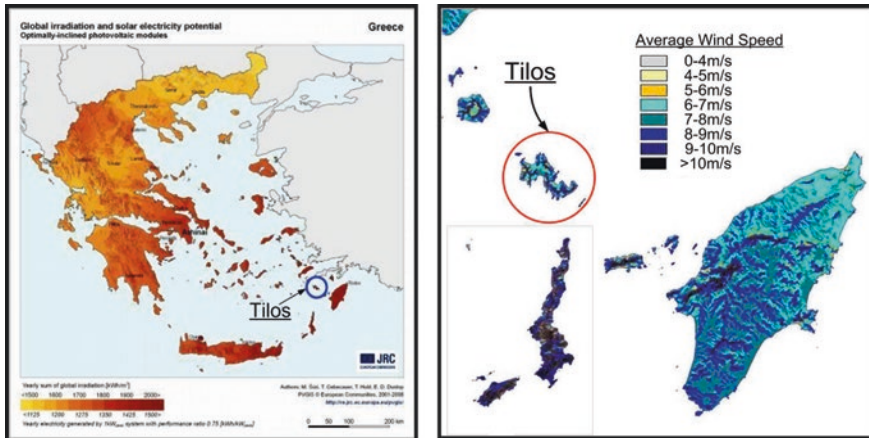


Fig. 31.6 Tilos island location in Dodecanese Complex, along with its solar/wind potential



Fig. 31.7 PV Station at Tilos island

The Soft Energy Applications & Environmental Protection Laboratory (SEA&ENVIPRO) of UNIWA has recently installed a small PV power station in order to offer zero-cost clean energy to the local community.

This decision builds on the collaboration of SEA&ENVIPRO with the Tilos Municipality in several projects in order to encourage the clean-green development of remote islands.

Actually, the PV station has been installed in one of the municipality’s buildings, near the seashore, facing however serious shading effects from the nearby obstacles (Fig. 31.7). The scope of this new PV station is twofold, i.e., first to cover the electricity consumption of the municipality building and secondly to meet the lighting (electricity)



Fig. 31.8 Solar-based EV charging station in Tilos island

demand of the coastal street at the island harbor. On the other hand, the PV station is also supporting an electrical vehicle (EV) charging station, installed also in the same building in order to charge two EVs of the local municipality (Fig. 31.8).

More precisely, the Tilos Municipality PV generator is located in Livadia village, on the roof of an old building, consists of 17 PV panels of 290 W (Jinkosolar Eagle MX 60B) at 15° tilt angle and faces ESE (azimuth angle = -70°) due to several shading problems by the nearby buildings. The peak power of the PV generator is almost 5 kW (i.e., 4.93 kW_p), while special attention was paid for the mounting structures of the PV panels to be corrosion protected due to the sea environment of the installation. Finally, the power output of the PV generator is forwarded to the low-voltage network of the village via a 5 kW inverter (ABB UNO DM 5.0 TL Plus).

On the other hand, the EVs charger is a Schneider EV Link Wallbox EVH2S of 7.4 kW and 40 A, offered (cost-free) by Schneider and providing two charging points of 8–16 A. The entire installation has been designed and installed by the authors, while the UNIWA covered the total installation cost. Due to several issues related with the licensing procedure and the accessibility problems to this remote island, the entire project implementation lasted for almost 10 months. However, under the existing circumstances this time period is quite rational.

Energy Balance Analysis

On the basis of the available solar irradiance (Fig. 31.9), the annual solar potential at horizontal plane is almost 1750 kWh/m², thus the expected annual electricity generation E_y is approximately 8000 kWh taking into account the shading effects of the nearby buildings and the non-optimum orientation of the PV panels. In this context the corresponding capacity factor CF of the installation is given as:

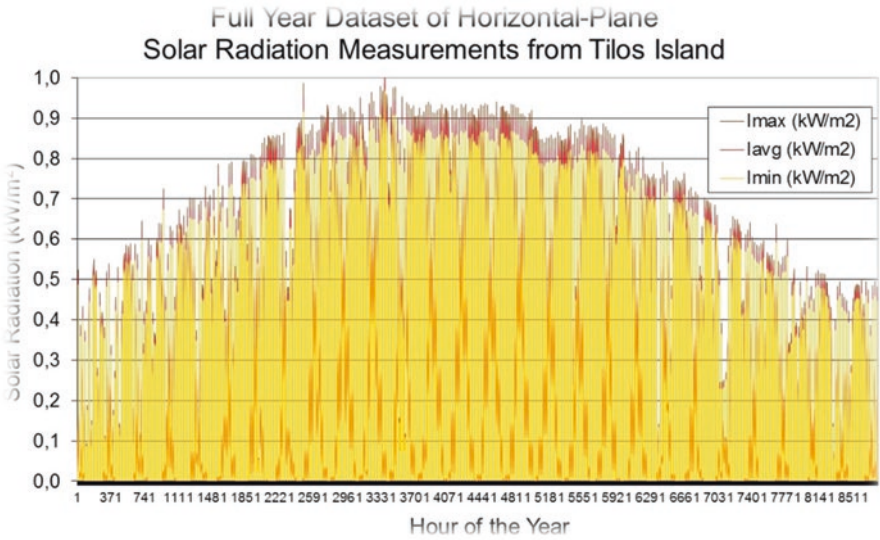


Fig. 31.9 Solar irradiance data for Tilos island [14]

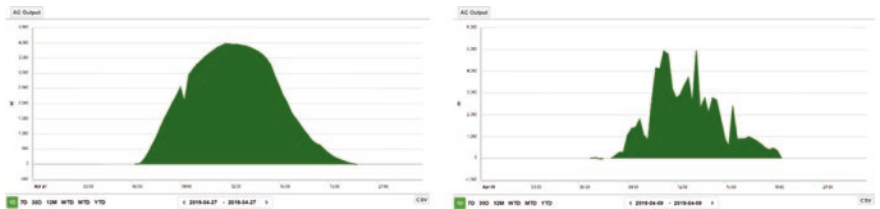


Fig. 31.10 Typical daily PV generator output for Tilos island

$$CF = \frac{E_y / 8760}{P_{peak}} = 19.5\% \tag{31.1}$$

where P_{peak} is the peak power of the PV generator.

In Fig. 31.10, one may find the instantaneous output of PV generator for two representative days (one shiny and one cloudy, respectively). As we can see in Fig. 31.10a, the PV generator approached its peak power during noon, while the electricity output follows the typical solar irradiance profile for a representative April day.

The corresponding daily electricity yield is almost 30 kWh, a quite remarkable value for the spring period under investigation. On the other hand, although the power output of a cloudy day is quite variable (Fig. 31.10b), the noon-time output of the PV generator still approaches its peak power of almost 5 kW. However, during

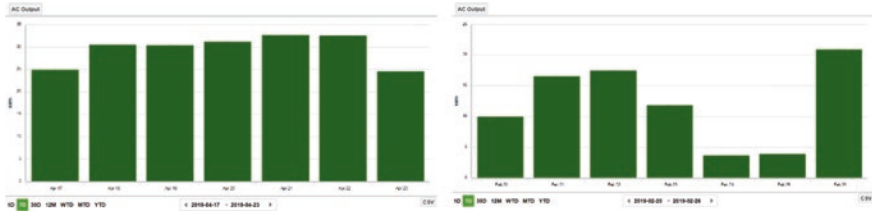


Fig. 31.11 Typical weekly PV generator output for Tilos island

early morning and late afternoon the power output is less than 1 kW. What should be noted is that even during this not very “encouraging” day, the resulting daily energy yield is almost 20 kWh, i.e., two-thirds of the one corresponding to the shiny day of Fig. 31.10a.

In Fig. 31.11, one may find the daily energy production of the PV generator for two selected weeks. In Fig. 31.11a, the daily energy generation of the PV installation is demonstrated for a good spring week, hence the total weekly energy production is almost 210 kWh, while the daily electricity production varies between 24 and 32 kWh. This is not the case for the last week of February (Fig. 31.11b), where the daily electricity production is quite variable, since for two successive days it is less than 5 kWh, while during the following day, more than 20 kWh were produced. This is the worst energy production week since the beginning of operation for the PV generator; however, even during this low irradiance period the total weekly production approaches 85 kWh of clean-green energy.

Finally, in Fig. 31.12a one may find the daily PV generator electricity production for the entire March of 2019. According to the available data, excluding 4 days of March, the energy production of the installation is higher than 15 kWh, while the minimum production appears for two successive days near the end of March. However, even in this case the previous and the following days’ electricity production of the PV station is quite high, covering thus any possible power deficit. Closing, one should take into consideration that the total monthly electricity production during March is almost 625 kWh, thus the average daily clean-green electricity production is slightly above 20 kWh/day and the corresponding capacity factor according to Eq. (31.1) is 17%.

The PV generator performance is much better during April (Fig. 31.12b), where for the entire month the electricity production is higher than 15 kWh, excluding the April 6th where problems of the local electrical network almost zeroed the PV station production. It is also interesting to note that even during April (not a very high irradiance month), there are five consecutive days where the PV generator produces more than 30 kWh/day. To this end, the total monthly electricity production during April is slightly above 715 kWh, thus the average daily clean-green electricity production is almost 25 kWh/day and the corresponding capacity factor according to Eq. (31.1) is higher than 20%.

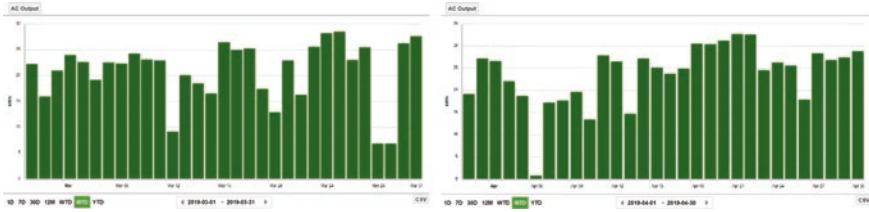


Fig. 31.12 Typical monthly PV generator output for Tilos island

Financial and Environmental Gains

Taking into consideration the performance of the PV installation for the up to now operation period (March and April represent average solar potential months), one may estimate—with adequate accuracy—the expected annual energy yield E_{tot} , which according to Eq. (31.1) is approximately 8000 kWh/year [15, 16]. According to the initial design of the installation, it is assumed that the PV generator will support the charging of two EVs [17, 18]. Due to the size of the island (the biggest road distance is 15 km) the maximum annual distance to be covered is 10,000 km, thus the EV charging station is going to support two EVs or provide electrical energy for a distance D , where $D = 20,000$ km/year.

According to long-term measurements of the SEA & ENVIPRO Laboratory [19], the real energy consumption ε of contemporary medium size EVs is 15–20 kWh per 100 km. Adopting the maximum value, the annual electricity consumption E_{mob} in order to support the operation of the two EVs of the municipality is given by Eq. (31.2):

$$E_{mob} = \varepsilon \cdot D = 4000 \text{ kWh} \tag{31.2}$$

The corresponding petrol/gasoline saving F_{mob} , assuming an average specific fuel consumption of 10 L per 100 km, is $F_{mob} = 2000$ L/year.

On the basis of the above-described analysis, the residual electrical energy via the net-metering scheme is used to partially cover the electricity consumption of the Tilos Municipality. Actually, approximately 4000 kWh of electricity (=8000–4000) are absorbed by the electrical loads of the local municipality.

Taking into consideration the current prices of gasoline in remote islands (i.e., $p_g \approx 2\text{€}/\text{L}$) and the final price of electricity (i.e., $p_e \approx 0.2\text{€}/\text{kWh}$, including all taxes and VAT), the avoided annual cost AV_Cost due to the operation of the small PV generator and the installation of the EV charging station is:

$$AV_Cost = p_g \cdot F_{mob} + p_e \cdot (E_{tot} - E_{mob}) \tag{31.3}$$

For the specific case analyzed, Eq. (31.3) gives an annual avoided cost of almost 5000€, which is approximately 15% of the commercial, first installation cost of the

entire installation [20], leading to a simple payback period of almost 7 years. Keep in mind that the entire installation has been financially covered by the UNIWA, without any cost for the municipality, practically donated by our Lab/University to the local community.

Accordingly, one may equally well estimate the avoided air pollutants due to the replacement of petrol and electricity (produced by thermal power stations consuming diesel oil) with solar energy. In this context the avoided annual emissions $AV-AP$ of air pollutant i (where i may be used for CO_2 , NO_x , SO_2 , PM , etc.) may be estimated by the following relation:

$$AV-AP_i = g_i \cdot D - s_i \cdot E_{mob} + (e_i - s_i) \cdot (E_{tot} - E_{mob}) \quad (31.4)$$

where g_i is the gasoline (petrol) engine emissions per km traveled, D is the total annual distance traveled by the vehicles, s_i is the corresponding emissions related to the PV generator operation and e_i is the specific emission factor of air pollutant i per kWh of oil-based electricity consumed by the municipality loads [21–23].

As an example one may apply Eq. (31.4) for CO_2 emissions, where $g_i = 150$ g/km, $D = 20,000$ km/year, $s_i = 50$ kg/MWh, and $e_i = 750$ kg/MWh. To this end the total annual CO_2 saving is 5600 kg/year, a remarkable quantity for such a small island. Similar calculations may be repeated for every desired air pollutant, using the most accurate values possible for the coefficients involved [24].

On the basis of the above presented analysis one may clearly state that the proposed PV installation under the net-metering scheme and in collaboration with a solar-based EV charging station offers (on a life cycle basis) remarkable financial gains to the Tilos island Municipality (approximately 85,000€ in present values) and significant (almost 120t) (1tonne=1000kg) CO_2 and other air pollutants reduction for the local community.

Conclusions

The proposed study presents the installation procedure of a small PV generator along with an EV charging station in a remote island under the net-metering scheme. Subsequently, the energy balance of the proposed pilot PV–EV charging installation has been analyzed using real-world measurements, validating also its sizing. In this context, and according to the data gathered, it is obvious that the installed PV station has very good efficiency and contributes considerably in covering the electrical needs of the local municipal loads and EVs. To this end, the financial performance (on pure cost-benefit analysis) of the proposed installation is quite attractive, even neglecting that the first installation cost of the entire project is covered by the University. Moreover, there is remarkable avoidance of carbon dioxide emissions as well as notable reduction of sulfur dioxide, nitrogen oxides, and solid particles production otherwise produced by the oil-based internal combustion engines of the local thermal power station operated on the nearby island of Kos. Recapitulating, it

is important to mention that the developed clean-green solution may equally well apply in several other similar cases all around the Mediterranean Sea, providing energy at rational production cost, supporting electro-mobility and minimizing the environmental impacts of the energy supply chain.

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