Impact of climatic conditions of different world zones on the energy performance of the photovoltaic-wind-battery hybrid system

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Abstract. The growth of economies and the world population has led to an increase in the electricity demand, toward a disproportionate use of fossil fuels. The PV-wind hybrid system is considered an optimal solution in terms of technical efficiency and costs to reduce the use of fossil sources. The strong variability of renewable energies generated by solar and wind systems in different locations around the world sometimes leads to the need to use battery storage systems. In addition, the self-consumed energy produced by the hybrid system is strongly dependent on the load trend. Owing to the strong influence of the climatic conditions on a hybrid system energy performance, its optimal sizing is a very complex issue that must be addressed in each weather condition. This paper presents an energy feasibility study of a PV-wind-battery hybrid system considering different yearly climatic conditions in the world, according to the Koppen classification. The system is used to supply electrical energy to a district composed of five office buildings. The electrical load consists of artificial lighting systems, electrical office devices and electric vehicle charging stations. The effects produced by different yearly climatic conditions on three hybrid systems, characterized by the same overall nominal powers and different photovoltaic and wind nominal powers, were investigated. TRNSYS 17 was used for the dynamic simulation of the hybrid system. The overall aim is to identify the most proper climatic conditions by means of the optimization of several energy indicators: maximization of the self-consumed renewable energy and of the renewable energy produced utilized to supply the load, namely minimization of the energy imported from and exported to the grid. For this issue, a global indicator, that measures the energy exchange of the hybrid system and load with the grid, is proposed to select the optimal trade-off localities and hybrid systems.

1. Introduction
The greater economic development has caused excessive consumption of fossil energy sources all over the world. Anthropogenic climate change represents a real threat to human life conditions, recognized both by the scientific community and political institutions. The European Union has outlined a regulatory and financial framework for the reduction and management of the risks deriving from climate change, requiring member states to adopt adequate measures for the sustained abatement of greenhouse gas emissions. These policies will lead to profound transformations in productive systems and lifestyles, requiring a more sustainable and careful development both at economic and human costs.
An optimal solution is represented by the use of local clean and sustainable energy sources, considered highly available in nature. Solar and wind energies are available in more or less magnitude worldwide. On one hand, the wind turbine produces clean electrical energy with low environmental impact. It does not produce toxic gases and the same wind turbines can face a very long life cycle before being destined for disposal. On the other hand, the photovoltaic (PV) system uses solar energy and transforms it into electricity, producing clean and renewable energy.

The weather conditions are relatively unpredictable; consequently, the combination of different renewable technologies permits to compensate the lack of one of these sources, reducing the generated power fluctuation, for example when there are cloudy or not windy days. In addition, the presence of battery permits to store the excess of energy and to give it back when it is necessary. The wind and solar energy are not predictable a priori owing to the stochastic and intermittent behaviour. For this reason, the dynamics of a hybrid system are determined by the locality considered. Hybrid systems can be involved both in grid-connected (GC) and stand-alone (SA) applications. In the first case, the energy missing to satisfy the load is imported from the grid and the energy in excess is exported to the grid; in the second case, the hybrid system must supply the entire load in absence of an alternative integrating fossil system and the energy in excess must be dissipated. By considering some of the more recent and relevant researches developed worldwide, the literature overview highlighted that the hybrid system was investigated in a comprehensive manner [1-18]. Figure 1 shows a sketch of the apportionment of these researches in the different climates, according to the Koppen classification [19]. For each climate, the magnitude of GC and SA applications is highlighted.

Figure 1. Literature overview: Köppen Climate classification combined with stand-alone or grid-connected analysis.

As shown in Figure 1, there is a link between the climate and the grid connection type. In particular, in climates A and B, SA systems are prevalently studied; in climates C, SA and GC systems are equally tested; in D climates, the GC systems are more frequent than the SA one. In general, the connection to the grid is absent in remote locations, such as islands, mountains or underdeveloped villages. In addition, the figure highlights that hybrid systems were more extensively studied in warm-temperate climates C. In these climates, the high solar energy and economic availability have led to rapid diffusion of these systems. Instead, despite tropical and arid climates A and B are characterized by a rich solar renewable energy, usually, they are undeveloped zones. Finally, for the Borealis climates D, the reduced number of researches is owing to the low solar availability and cold
weather conditions. In each of these climates, owing the available of wind source worldwide, the combination of a wind and battery storage system with a PV system can be useful to create a reliable renewable system that is able to compensate the low solar energy during diurnal hours in D climates, and to provide, directly or by means of the battery, renewable energy during the nocturnal hours in all climates.

The hybrid system can be used to create a link between building district and everything that surrounds it, such as infrastructures and transports. For example, hybrid systems are used to realize infrastructure to charge electric vehicles (EVs) or to assist heat pumps for the building air conditioning [20-21]. This paper shows the energy behaviour of some hybrid systems, in the presence of a battery storage system, with the same overall nominal power and different PV and wind nominal power subject to different climatic conditions. All analyses are performed by the use of TRNSYS 17 [22]. The goal is to identify optimal climatic conditions for hybrid systems by means the use of different energy indicators, such as the self-consumed renewable energy, the utilization of the renewable energy produced, and a combination of these ones, namely the grid energy interaction factor.

2. Methodology

2.1. The PV-wind hybrid system configurations

As shown in Figure 2, a GC PV-wind hybrid renewable system is used to produce electrical energy to meet the electrical consumption of a district composed of five office buildings. The district requires electrical energy for the artificial lighting (EL) systems, electrical devices (EDs) of office rooms and for the charging stations of EVs placed in the parking lot of each building. Each building consists of two floors of 100 m$^2$, divided into eight thermal zones, which correspond to the number of rooms characterized by different orientations and occupants’ behaviour. All vertical building walls are 50% glazed.

The system has in support the following devices: DC/DC converter contains the device of maximum power point tracking of the PV generator; AC/DC rectifier transforms the alternating current produced by the wind generator into direct current; a regulator limits the charge and discharge status of the battery; the inverter transforms the direct current coming from the wind, PV and battery systems in alternating current.

![Diagram of the photovoltaic-wind-battery hybrid system for district use.](image)

In Figure 2, $P_{pv}$ and $P_{w}$ are, respectively, the outgoing power from the PV generator and the wind generator, $P_{pv,\text{eff}}$ and $P_{w,\text{eff}}$ the power outgoing from the PV and wind static converters, $P_g$ is the total power generated, $P_{in}$ and $P_{fb}$ are respectively the ingoing and outgoing powers from the storage system, $P_{tl}$ is the power coming from the hybrid system entering the load, $P_{ig}$ and $P_{fg}$ are, respectively, the powers exported to and imported from the grid.
2.2. Technical data of the system components
The PV module considered with polycrystalline silicon cells has a nominal power of 250 W, area of 1.6236 m$^2$, efficiency under reference conditions of 15.3% and nominal operative cell temperature of 46°C. The wind micro-generator placed 4.5 meters above the roof, i.e. 14.5 meters above the ground, has a nominal power of 2500 W, cut-in, cut-off and nominal wind speed of respectively 3 m/s, 18 m/s and 10 m/s. An electrical lithium-ion battery of 2 kWh and an efficiency of 0.98, and a static converter DC/DC, AC/DC rectifier, DC/AC inverter and regulator with respectively 0.94, 0.90, 0.97 and 0.98 of efficiency were employed to realize the hybrid system.

2.3. Description of localities across the Koppen climate zones
A preliminary study was conducted to select different representative weather conditions worldwide. In particular, data extracted from typical meteorological year files .tm2 available in TRNSYS libraries were used to compare forty-eight localities, two for each sub-group of the Koppen classification. As reported in Table 1, thirteen localities were chosen by selecting weather conditions very windy and sunny, very windy and low sunny, low windy and sunny, low windy and very sunny, in addition to consider different Koppen groups and sub-groups, latitudes, longitudes and altitudes.

### Table 1. Localities considered across the Koppen climate zones.

| Koppen classification | Location         | Country    | Time zone (GMT) | Latitude (°) | Longitude (°) | Altitude (m a.s.l.) |
|-----------------------|------------------|------------|-----------------|--------------|---------------|---------------------|
| Af                    | Toamasina        | Madagascar | 3               | -18.1        | 49.4          | 6                   |
| Af                    | Singapore        | Singapore  | 8               | 1.0          | 104.0         | 16                  |
| Aw                    | Kano             | Nigeria    | 1               | 12.0         | 8.5           | 481                 |
| As                    | Lihue, Hawaii    | United States | -10        | 22.0         | 159.3         | 45                  |
| BWh                   | Baghdad          | Iraq       | 3               | 33.3         | 44.4          | 33                  |
| BSk                   | Baku             | Azerbaijan | 4               | 40.4         | 49.8          | 5                   |
| Cwa                   | New Delhi        | India      | 5.5             | 28.6         | 77.2          | 212                 |
| Ctc                   | Reykjavik        | Iceland    | 0               | 64.1         | 21.9          | 66                  |
| Cwb                   | Nairobi          | Kenya      | 3               | -1.1         | 36.9          | 1624                |
| Dfa                   | Toronto, Ontario | Canada     | -4              | 43.7         | 79.4          | 116                 |
| Dwa                   | Seoul            | South Korea | 9              | 37.6         | 127.0         | 86                  |
| Dsa                   | Hakkâri          | Turkey     | 3               | 37.6         | 43.8          | 1720                |
| Dsb                   | Flagstaff, Arizona | United States | -7             | 35.13        | 111.7         | 2135                |

Overall, four localities fall in the A group of the tropical (megathermal) climates, two in the B group of the dry (arid and semiarid) climates, three in the C group of the temperate (mesothermal) climates, and four in the D group of the continental (microthermal) climates according to the Koppen classification. The latitudes of the locations selected vary between -18.1° and 64.1°, the longitude between 8.5° and 159°, the altitudes between 5 m and 2135 m above the sea level. The statistical characteristics of the selected localities are reported in Table 2. The table shows the minimum, first quartile, median, third quartile, maximum, mean, ad range values of the external air temperature, horizontal solar radiation and wind speed in the thirteen localities during the entire typical meteorological year.

By considering the mean values, Kano represents the sunniest locality with medium-high wind speeds, Reykjavík the windiest and least sunny locality; New Delhi the least windy locality with medium-high solar radiations. Instead, Seoul and Singapore present simultaneously low solar and wind speed levels. The other localities are characterized by weather intermediate conditions.
Table 2. Statistical characteristics of the thirteen localities.

| Location   | External air temperature (°C) | Horizontal solar radiation (W/m²) | Wind speed (m/s) |
|------------|-------------------------------|-----------------------------------|------------------|
|            | Min   | Q1   | Med | Q3   | Max | Mea | Ran | Min   | Q1   | Med | Q3   | Max | Mea | Ran |
| Toamasina  | 12.8  | 20.9 | 23.4| 25.9 | 32.5| 23.3| 19.7| 0     | 0    | 0   | 376 | 1105| 206 | 1105| 0.0  | 1.0  | 1.7  | 2.7  | 8.7  | 2.0 | 8.7 |
| Singapore  | 21.0  | 24.8 | 26.6| 28.4 | 33.7| 26.6| 12.7| 0     | 0    | 0   | 329 | 1018| 185 | 1018| 0.0  | 0.7  | 1.5  | 2.8  | 14.2 | 2.0 | 14.2 |
| Kano       | 7.4   | 22.2 | 26.5| 30.6 | 43.4| 26.3| 36.0| 0     | 0    | 8   | 548 | 1040| 256 | 1040| 0.1  | 1.9  | 3.3  | 5.0  | 13.8 | 3.6 | 13.7 |
| Lihue      | 13.0  | 22.3 | 24.2| 25.6 | 29.8| 23.9| 16.8| 0     | 0    | 24  | 388 | 1093| 208 | 1093| 0.3  | 4.0  | 5.6  | 6.7  | 14.1 | 5.5 | 13.8 |
| Baghdad    | -2.9  | 11.6 | 20.1| 28.3 | 43.7| 20.1| 46.6| 0     | 0    | 0   | 477 | 1013| 238 | 1013| 0.0  | 1.2  | 2.1  | 3.2  | 10.5 | 2.4 | 10.5 |
| Baku       | -8.0  | 6.9  | 14.3| 22.0 | 37.7| 14.6| 45.7| 0     | 0    | 0   | 236 | 983 | 152 | 983 | 0.2  | 3.1  | 5.0  | 7.1  | 18.6 | 5.4 | 18.4 |
| New Delhi  | 4.4   | 19.2 | 26.3| 31.0 | 44.6| 25.1| 40.3| 0     | 0    | 0   | 461 | 1028| 225 | 1028| 0.0  | 0.6  | 1.2  | 2.0  | 7.9  | 1.4 | 7.9  |
| Reykjavik  | -11.7 | 0.4  | 4.8 | 8.6  | 17.4| 4.4 | 29.1| 0     | 0    | 0   | 125 | 792 | 89  | 792 | 0.2  | 3.4  | 5.5  | 7.8  | 19.2 | 5.8 | 19.1 |
| Nairobi    | 6.7   | 16.3 | 19.2 |22.2 | 31.0 | 19.2| 24.3| 0     | 0    | 0   | 385 | 1190| 211 | 1190| 0.2  | 2.8  | 4.6  | 6.9  | 18.4 | 5.1 | 18.3 |
| Toronto    | -21.8 | -0.8 | 7.7 | 16.2 | 31.1 | 7.4 | 52.8| 0     | 0    | 0   | 253 | 1014| 154 | 1014| 0.1  | 2.3  | 3.8  | 5.7  | 15.0 | 4.2 | 14.9 |
| Seoul      | -14.6 | 2.9  | 12.9 |21.0 | 33.9 | 11.8| 48.4| 0     | 0    | 0   | 220 | 1000| 139 | 1000| 0.0  | 0.9  | 1.9  | 3.4  | 15.2 | 2.4 | 15.2 |
| Hakkâri    | -16.7 | 0.7  | 10.0 |19.5 | 34.1 | 10.1| 50.7| 0     | 0    | 0   | 343 | 1063| 196 | 1063| 0.0  | 0.5  | 1.1  | 2.1  | 12.2 | 1.6 | 12.2 |
| Flagstaff  | -25.8 | -0.5 | 7.2 | 14.7 | 34.2 | 7.3 | 60.0| 0     | 0    | 23 | 397 | 1071| 214 | 1071| 0.1  | 1.8  | 2.9  | 4.7  | 20.6 | 3.2 | 20.6 |

2.4. Description of electrical load

Three types of electrical loads are present in the building district: EDs of the office rooms, artificial EL system, and charging stations of the EVs.

The ED load is owing to the presence in each thermal zone of two personal computers and one printer with overall power of 75 W. The use is from Monday to Wednesday from 8:00 to 18:00. The working time is different only for two rooms, where it is from 8:00 to 14:00 on Monday, Wednesday and Friday. The EL load is owing to a LED lighting system that ensures adequate lighting in the office rooms of 400/500 lux and consumes 125 W in each room with the same time schedule of the ED load. In this time schedule, a brightness on/off differential controller switches off or switches on the artificial EL system as a function of the incident horizontal solar radiation value and of the input control function value at the previous time step. The solar radiation is compared with the upper and lower dead-band differences to evaluate when it is adequate to ensure a minimum level of natural lighting. For the case study, the upper and lower dead bands are respectively 200 W/m² and 120 W/m².

An EV charging infrastructure consisting of four charging stations is placed in the parking lot of each building of the district. Each charging station has a charging power available of 2.3 kW, with overall power of 46 kW in the district. Eight Nissan Leaf EVs of 24 kWh are charged during the working hours. By including the energy recovered through the braking regeneration system, the average consumption of the EV is 0.1714 kWh/km. Each EV requires two charging hours to recover the daily consumption of 5.14 kWh/day, considering that each EV travels on average 26.8 km/day. Consequently, on weekdays during the working hours, the daily charging schedule of each EV charging infrastructure requires two charging hours at 9.2 kW for the first group of four EVs, and another two charging hours at 9.2 kW for the second group of four EVs. The charge period is between 9:00 and 13:00.

For the chosen localities, Figure 3 shows the yearly electric loads linked to ED, EL and EV loads. The main contribution to the yearly electrical consumption is characterized by the energy required to charge the EVs of about 48 MWh, which is independent of the locality. At the same way, the ED energy consumption is about 8 MWh in all localities. As expected, the highest yearly electrical consumption occurs in the locations with the lowest solar radiation levels, which determine the highest electrical consumptions of the artificial EL system. For the EL system in the order, Reykjavik, Baku, Seoul, Toronto, and Hakkâri present the highest values from 8 MWh until to 4 MWh.
Figure 3. Yearly electric load owing to the ED, EL and EV

2.5. Parametric analysis

For the thirteen localities, a parametric analysis was developed by considering a PV-wind-battery hybrid renewable system of 130 kW. This value was determined by using a pre-design method [23] that employs a correlation in which intervenes the mean yearly electric load and the desired levels of self-consumed and utilized energy to evaluate the required overall nominal power of the hybrid system. To analyse different hybrid system behaviours, in addition to considering very and low sunny and very and low windy localities, three different hybrid systems were considered by varying the nominal power of the PV generator and wind generator. For this issue, the number of PV modules and wind turbines was changed. In all hybrid systems, the battery storage system was maintained unchanged to 30 kWh, obtained by using 15 battery units. The nominal powers of the three hybrid systems are:

- hybrid system 1 (S1) with 30 kW of PV power and 70 kW of wind power;
- hybrid system 2 (S2) with 50 kW of PV power and 50 kW of wind power;
- hybrid system 3 (S3) with 70 kW of PV power and 30 kW of wind power.

These 39 scenarios were dynamically simulated in TRNSYS environment to calculate the hourly values of the output powers from each component. These powers were used for the calculation of the relative hourly and yearly energy.

2.6. Energy analysis

Three different contributes can be identified in the balance of the yearly energy required by the load, Eq. (1), and in that of the yearly energy generated, Eq. (2):

\[ E_{dtl} + E_{th} \eta_{inv} + E_{fg} = E_L \]  
\[ \frac{E_{dtl}}{\eta_{reg} \eta_{inv}} + \frac{E_{th}}{\eta_{reg}} + \frac{E_{fg}}{\eta_{reg} \eta_{inv}} = E_g \]

Where, \( E_{dtl} \) is the yearly energy produced by the PV and wind generators and sent directly to the load, \( E_{th} \) and \( E_{th} \) are the yearly energy sent and drawn from the battery, \( E_{fg} \) and \( E_{fg} \) are the yearly energy imported from and exported to the grid, and \( E_L \) is the yearly energy required by the load.

Two energy indicators [21, 23] are used to study the system energy performance, Eq. (3) and (4): the PV-wind fraction \( f_{pv,w} \) that measures the fraction of energy required by the load satisfied by the hybrid...
system; the utilization factor of the generated energy $f_{u,g}$ that quantifies the fraction of produced energy by the hybrid system employed to satisfy the load.

$$f_{pv,w} = \frac{E_{dtl} + E_{tb}\eta_{inv}}{E_L}$$  \hfill (3)

$$f_{u,g} = \frac{E_{dtl}}{\eta_{reg}\eta_{inv}} + \frac{E_{tb}}{\eta_{reg}}$$  \hfill (4)

The first indicator takes into account the energy imported from the grid $f_{pv,w} = (1 - E_{fg}/E_L)$, while the second one the energy exported to the grid $f_{u,g} = (1 - E_{tg}/E_g)$.

Since high values of $f_{pv,w}$ and $f_{u,g}$ are simultaneously required to a highly reliable hybrid system, and since the two indicators have opposed behaviour by varying the power installed, a new indicator that involves both indicators was defined. The grid energy interaction factor GEIF, a combination of the two indicators, permits to identify the most appropriate localities for the hybrid systems considered. The GEIF quantifies the interaction of the hybrid system and load with the grid, namely the energy imported from and exported to the grid. When GEIF = 0 then the energy produced is entirely used and it is that strictly necessary to satisfy the load; an increasing value of the GEIF means a high level of energy drawn from and exported to the grid, denoting a low synchronism between the energy produced and the energy required by the load. A higher battery storage capacity assures a lower GEIF. Instead, the effect of an increase of the PV and wind power on the GEIF is not preliminarily predictable, since this effect depends on the solar radiation and wind speed trends compared with the load trend.

$$GEIF = \frac{E_{fg} + \frac{E_{tg}}{\eta_{reg}\eta_{inv}}}{E_L} = (1 - f_{pv,w}) + (1 - f_{u,g})\frac{E_g}{E_L}$$  \hfill (5)

The objective of this analysis is to minimize the GEIF to identify the most reliable hybrid system and the most appropriate locality.

### 3. Results and discussion

For each simulation scenario, with reference to Figure 2, the yearly energies outgoing from each system component were evaluated. Figure 4 at the top reports the overall energy produced by the three hybrid systems S1, S2 and S3, sum of the energy produced by the PV system outgoing from the DC/DC converter $E_{pv,eff}$ and the energy produced by the wind system outgoing from the AC/DC rectifier $E_{w,eff}$ for the thirteen localities. As expected, the PV and wind energy contributions vary with the locality as a function of the solar and wind sources available. By considering the system S2 with the same PV and wind nominal power installed, it is possible to distinguish the predominant renewable system. For example, in Reykjavik and Baku, the wind contribute is very predominant, while in New Delhi, Hakkari, Toamasina, Baghdad and Singapore the solar contribute is very predominant. In general, with reference to S2, the maximum energy generated is highlighted in Lihue with 208 MWh, followed by Reykjavik with 190 MWh, and Baku, Nairobi and Toronto with about 185-170 MWh. A highest PV power installed, namely by moving from S1 to S3, leads to higher energy generated in solar predominant localities and to lower energy generated in windy predominant localities.

Such energy generated is distributed into the hybrid system, load and grid in accordance with energy balance Eqs. (1) and (2). Figure 4 at the bottom shows the three energy contributions employed to satisfy the load, namely $E_{dtl}$, $E_{tb}$ and $E_{fg}$ and, in addition, the energy exported to the grid $E_{tg}$ reported in negative vertical axes.
Figure 4. For the different locations and hybrid systems S1, S2 and S3: at the top, energy produced; at the bottom, energy sent directly to the load, energy drawn from the grid and energy imported from the grid and energy exported to the grid.

It is evident that two different behaviours can be distinguished for windy and solar predominant localities by increasing the PV power and reducing the wind power. In particular, an increase of PV power determines a reduction of the energy exported to the grid in windy predominant localities, while determines the growth of the energy exported to the grid in solar predominant localities. Being the PV energy more contemporaneous with the load trend, the energy imported from the grid: in solar predominant localities reduces, while in windy predominant localities the effect produced is not preliminarily detectable. In Reykjavik, which is the windiest localities, is preferable to install a higher wind power rather than prefer a greater contemporaneity of the energy produced with the load owing to the increase of the PV power installed. In fact, in this locality, the energy imported from the grid increases by raising the PV power. Instead, in the other windy predominant localities, Baku, Nairobi, Toronto and Lihue, a higher synchronism between the energy produced and the load prevails on a higher overall renewable energy production. This is also evident from the Figure 4 at the top, in which, despite an increase of the PV power installed in a windy predominant locality leads to lower overall energy
produced, the further PV energy produced is directly sent to the load, denoting a higher simultaneously.

Opposite behaviour to energy imported from the grid is evinced for the energy produced sent directly to the load, being almost unchanged the energy drawn from the battery in all localities and hybrid systems. This energy remains almost constant since the battery storage capacity is the same and the load trend almost the same in all 39 scenarios. The different weather conditions give rise to only a variation of the energy drawn from the battery between a percentage of 11% and 17% of the overall yearly energy required by the load, denoting that, although if in different time instants, the battery is always exploited in the same measure.

Overall, these behaviours can be summarized by means of the use of the PV-wind fraction and the utilization factor of the energy generated, reported in Figure 5.

Figure 5. PV-wind fraction, utilization factor and grid energy interaction factor in the different locations obtained with the hybrid systems S1, S2 and S3.
For system 2, the highest PV-wind fraction of 0.84 is achieved in Lihue, to which is associated with a very low utilization factor value of 0.25. Instead, the maximum utilization factor of 0.52 and 0.51 respectively in Toamasina and Hakkari is obtained with a relatively high value of the PV-wind fraction of 0.72 and 0.67 respectively. By increasing the PV power installed, in windy predominant localities, an increase in the utilization factor is highlighted. Instead, for the solar predominant localities, a higher PV power installed determines both higher energy generated and energy exported to the grid. When the energy generated grows in a slight manner than the energy exported to the grid, the utilization factor decreases, such as in Toamasina, Lihue, New Delhi and Hakkari. Vice versa, in the other localities. The PV-wind fraction rises in extent manner in solar predominant localities, decreases in very windy localities, such as Reykjavik, and in the other windy predominant localities increases in a slight manner. To detect an overall result of the energy performance of hybrid systems considered in the thirteen localities, the grid energy interaction factor GEIF must be employed to minimize the interaction between the hybrid system and load with the grid. Figure 5, in addition to reporting the PV-wind fraction and the utilization factor, shows the GEIF for the different hybrid systems by varying of the locality. By considering hybrid system S2, with the same PV and wind power, the most appropriate weather conditions are those of Toamasina and Hakkari since are characterized by the minimum value of the GEIF equal to one. Instead, the worst weather conditions for the hybrid system S2 are those of Lihue. From a general point of view, by increasing the PV power from system S1 to S3, the solar predominant localities present a higher GEIF, except Seoul where it undergoes a very slight reduction. Instead, in the windy predominant localities, a higher PV power installed is always convenient since in all localities the GEIF is reduced. This is owing to the reduction of both the energy exported to and imported from the grid. Only in Reykjavik the energy imported from the grid increases; however this, the increase is lower than the reduction of the energy exported to the grid, determining a lower GEIF.

4. Conclusions
The impact of climatic conditions of different Koppen zones on the energy performance of PV-wind hybrid renewable systems with battery storage employed to satisfy the electrical energy demand of a building district was assessed. The building district involves office devices, artificial lighting systems and electric vehicle charging stations. Three hybrid systems with the same overall nominal power and different PV and wind powers installed were considered. For this issue, a yearly energy analysis summarized by means of two energy indicators quantifying the self-consumed energy and the utilized energy was developed. In addition, an overall indicator, named grid energy interaction factor GEIF, obtained as a combination of the two indicators, was defined and evaluated. The results have shown that the GEIF depends on the renewable source predominance, in addition to the load trend. In general, an increase of the PV power installed leads to a GEIF increase in solar predominant localities and a GEIF reduction in windy predominant localities. In the windy predominant localities, the further PV power produced is more contemporaneous with the load trend. In fact, the main contribution to the overall electrical load is owing to the electric vehicle that is placed during the diurnal hours. Overall, the minimum GEIF values were obtained in Toamasina and Hakkari, characteristic localities of the Tropical rainforest climate Af and Mediterranean-influenced hot-summer humid continental climate Dsa. These localities are characterized by medium levels of solar radiations and relatively medium-low levels of wind speeds. Being the load strongly concentrated in the morning hours, these optimal weather conditions guarantee the load satisfaction in these hours employing in part directly solar and wind energy produced and in part the energy produced in the afternoon and nocturnal hours. This avoids an excess of energy produced not storable to be exported to the grid, as occurs in very sunny or windy localities. In the future development of this research, the effect produced by the battery storage capacity increase on the optimal weather conditions for other load conditions will be investigated.

5. References
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