# Hybrid Renewable Energy Systems for power generation: state of the art and trends

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**Abstract**: In the last decades, the energy consumption increases due to several factors such as the economic and population growth and the climate change. Both the rapid depletion of the fossil fuels and the rising concern on the environmental issues make the renewable energy sources (RESs), e.g. solar, wind, etc., a promising alternative with the aim to produce low-carbon heat and electricity. Within this energy transition scenario, several countries, by promoting new government policies, make efforts to encourage their diffusion. Such sources allow achieving multiple environmental and financial goals, e.g. the reduction of the greenhouse effect, lower costs, high efficiency and the opportunity to provide electricity to remote areas. For these reasons, the scientific literature focuses on supporting hybrid renewable energy systems (HRESs). Such systems integrate one or more RESs and a backup source, e.g. diesel, oil, natural gas, etc. or the electric grid, and they often include an energy storage (ES) system. HRESs join the strengths of each power source and they try to reduce the impact of their weaknesses. The aim of this paper is to revise the literature on HRESs for power generation, identifying the main technologies and facilities for both on-grid and off-grid applications, considering different operative and geo-climate scenarios and different users. The scope, i.e. research question, is to categorise the developed models and approaches by considering different KPIs identifying feasibility limits, best practices and suitable directions for future research.

**Keywords**: Hybrid Renewable Energy System; Sustainability; Renewable energies; Review.

## 1. Introduction and research question

Greenhouse effect, soil, air pollution and the depletion of conventional sources of energy, i.e. fossil fuels, are the most important reasons driving toward the use of the Renewable Energy Sources (RESs) (Bortolini et al., 2015). According to the Energy Information Administration (EIA) these resources are naturally replenishing and virtually inexhaustible in duration, allowing to meet the increasing energy demand and to achieve both environmental and economic targets, e.g. bringing down the concentration of $CO_2$ and reducing operative costs. Furthermore, in several countries, remote areas still do not have access to electricity. In such contexts, RESs could play a key role suppling energy and overcoming the national grid connection lacks due to feasibility constraints and low convenience because of the low electricity consumption (Bianchi et al., 2014, Bortolini et al., 2015).

In the current energy context, the World Energy Outlook (IEA, 2019) report states that the global electricity production coming from RESs is growing, reaching up to 550 TWh in 2019, with a continue increase. Additionally, in 2018, the global renewable generation capacity, not accounting hydro, amounted to 1246 GW. Wind and solar accounts for the most of the shares, with capacities of 564 GW and 486 GW, respectively (Fig. 1). Renewable generation capacity increases of about the same amount as in 2017, up to 171 GW. Solar energy continues to dominate, with a capacity increase of 94 GW, followed by wind energy, with an increase of 49 GW.

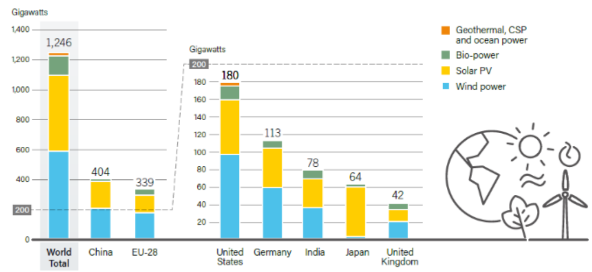


**Figure 1: Renewable power capacities: worldwide, EU-28 and top countries (IEA, 2019).**

Despite the positive features of the RESs, i.e. cleanliness and unlimited nature, drawbacks exist, e.g. dependence on the weather conditions, intermittent and fluctuant nature of the sources, grid instability, etc. These negative features keep challenging to predict the available primary energy leading to the risk of not being able to supply the loads or requiring plant oversizing, rising investments and operative costs. To overcome, partially, these lacks, the integration of energy storage (ES) systems is frequent (Yang et al., 2018). Additionally, researchers and practitioners focus on the design and optimisation of Hybrid Renewable Energy Systems (HRESs). These systems join two or more RESs, with connection to a backup source, i.e. Non-Renewable Energy Source (NRES) or the national grid (Lian et al., 2019). By using

HRESs, the advantages of each RES are enhanced minimising its intrinsic limits.

According to the literature, HRESs are divided into two categories, i.e. on-grid and off-grid (or stand-alone) applications. The difference between them depends on the use of the national grid as the backup source. The former works in parallel to the grid and use it to balance lacks and energy production excesses, the latter is isolated and fully independent.

Sizing a HRES is a complex process involving several factors (Erdinc and Uzunoglul, 2012). Preliminarily, it requires the knowledge of time series of the RES availability, during the day and the seasons, for the selected geographical area. If not measured on field, mathematical models and stochastic techniques allow estimating these data, e.g. auto regressive, auto regressive integrated moving average, correlation analysis, artificial neural networks, etc. (Alsina et al., 2016; Alencar et al., 2017). The second step aims at identifying which is the best mix of RESs that allows achieving technical, economic and environmental sustainability of the HRESs. Finally, the best solution to store energy and to combine NRESs are to be considered.

The optimisation of a HRES allows to use efficiently the available local RESs and to reduce global costs. Moreover, a well-designed HRES is able to produce the maximum possible energy, to save fuel and to supply the electricity demand effectively (Siddaiah and Saini, 2016). To face the sizing problem a wide range of techniques exists. A tentative classification groups them into three areas: (1) deterministic models; (2) Artificial Intelligence (AI) based methods; (3) simulation models and tools.

Finally, the last step of the sizing problem is the performance assessment. Several KPIs focus on the techno-economic point of view and the environmental perspective.

Starting from this overview, the Research Question (RQ) behind this paper is the following: "*What are the current trends and perspectives on HRES research?*". To tackle this RQ, this paper presents a review and classification of the existing HRESs following a multi-perspective approach. According to this purpose, the remainder of the paper is organized as follows. Section 2 describes the review data source and methodology, while Section 3 discusses the key evidences. Finally, Section 4 concludes this paper with a brief research agenda.

## 2. Data source and methodology

The dataset for this study is retrieved from Web of Science which is one of the most widely used search engine among the scientific community. The keywords driving the search are 'hybrid renewable energy plants' and 'renewable energy sources'. To explore the published papers over the last decade, the time horizon from 2010 to 2020 is selected. The study, among all the editorial destinations, is limited to journal papers and reviews. Fig. 2 shows that countries such as the United States, China and Italy have more interest in investigating on RESs and HRESs.

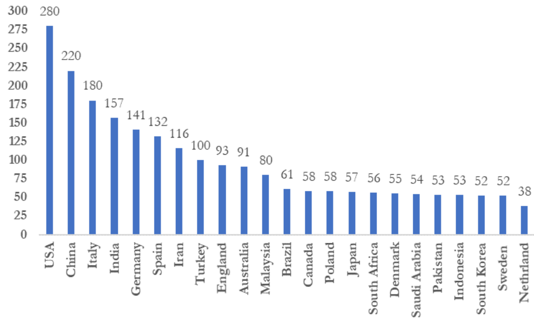


**Figure 2: Articles on HRESs by country.**

Fig. 3 indicates the number of researches on this topic per year showing a strong increasing trend.

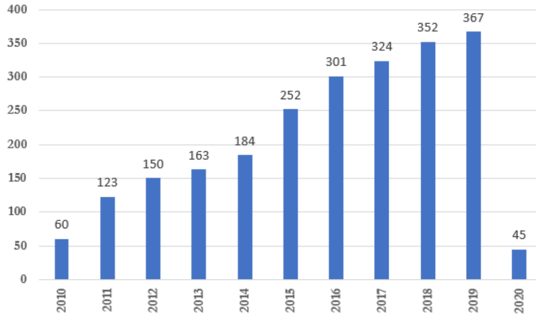


**Figure 3: Articles on HRESs by year.**

The set of works is filtered using other keywords, e.g. 'solar', 'wind', etc., and cutting paper on hydro generation, only. Finally, taking into account the topic relevance, the papers with the highest number of citations are selected. A reduced subset made of 21 papers is compared adopting seven criteria of analysis.

i. Energy sources, i.e. adopted RESs and NRESs;
ii. Presence of ES system;
iii. Off-grid vs. on-grid modes, i.e. if the plant is or not connected to the national grid;
iv. Size of the plant, i.e. the nominal power output of the plant, in MW;
v. Temporal resolution, i.e. the level of granularity of the climatological data used for the plant design and management;
vi. Performance metrics and KPIs, i.e. techno-economic and environmental;
vii. Design technique, i.e. the approach to size the HRES.

Table 1 classifies the contributions considering the two RESs of major interest i.e. solar photovoltaic (PV) and wind. These papers are discussed in Section 3, while Section 3.1 revises papers on other energy sources.

**Table 1: Literature review on HRESs.**

| Author(s) and Year | RES – NRES | | | ES | Off/On grid | | Size | Temporal Resolution | | | KPI | | Sizing Methods | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | PV | Wind | Fossil | | Off | On | | H | M | A | Cost | Environmental | D | AI | S |
| Giannoulis and Haralambopoulos, 2011 | | ✓ | ✓ | | ✓ | | 66 MW | ✓ | | | ✓ | ✓ | | | ✓ |
| Marano et al., 2012 | ✓ | ✓ | | ✓ | ✓ | ✓ | 1.7 MW | ✓ | | | ✓ | ✓ | | ✓ | |
| Rehman et al., 2012 | ✓ | ✓ | ✓ | | ✓ | | 8.9 MW | ✓ | | | ✓ | | | | ✓ |
| Paiva and Carvalho, 2013 | ✓ | ✓ | | | | ✓ | 26.4 MW | | | ✓ | ✓ | | ✓ | | |
| Bortolini et al., 2014 | ✓ | | | ✓ | | ✓ | 600 kW | ✓ | | | ✓ | | ✓ | | |
| El Alimi et al., 2014 | ✓ | ✓ | ✓ | | ✓ | | 3.5 kW | ✓ | | | ✓ | | ✓ | | |
| Wang et al., 2015 | ✓ | ✓ | ✓ | ✓ | ✓ | | 10 kW | | | ✓ | ✓ | | ✓ | | |
| Busaidi et al., 2015 | ✓ | ✓ | | | ✓ | | 5 MW | | ✓ | | ✓ | | ✓ | ✓ | |
| Bhattacharjee and Acharya, 2015 | ✓ | ✓ | | ✓ | ✓ | | 1.2-1.5 kW | | | ✓ | ✓ | | | | ✓ |
| Arefin et al., 2016 | ✓ | ✓ | ✓ | ✓ | ✓ | | 52 kW | | ✓ | | | ✓ | ✓ | | ✓ |
| Cozzolino et al., 2016 | ✓ | ✓ | ✓ | ✓ | ✓ | | 2.8 MW | | ✓ | | ✓ | ✓ | | | ✓ |
| Berrada and Loudiyi, 2016 | ✓ | ✓ | | ✓ | ✓ | ✓ | 1 MW | ✓ | | | ✓ | | | | ✓ |
| Das, 2016 | ✓ | ✓ | ✓ | ✓ | ✓ | | 10-60 kW | ✓ | | | ✓ | | | | ✓ |
| Rangnekar et al., 2016 | ✓ | ✓ | ✓ | ✓ | ✓ | | 210 kW | ✓ | | | ✓ | | | ✓ | |
| Hossain et al., 2016 | ✓ | ✓ | ✓ | ✓ | | | 2.7 MW | ✓ | | | ✓ | | | | ✓ |
| Yadav, 2017 | ✓ | ✓ | ✓ | ✓ | ✓ | | 2.9MW | ✓ | | | ✓ | | | | ✓ |
| Akram et al., 2017 | ✓ | ✓ | | ✓ | | ✓ | 244 MW | ✓ | | | ✓ | ✓ | | ✓ | |
| Hemeida et al., 2019 | ✓ | ✓ | | ✓ | ✓ | | 4.2 MW | ✓ | | | ✓ | | ✓ | | |
| Mohammed et al., 2019 | ✓ | ✓ | | ✓ | ✓ | | 16 MW | ✓ | | | ✓ | | | ✓ | |
| Nyeche and Diemuodeke, 2019 | ✓ | ✓ | | ✓ | | ✓ | 1.8 MW | | ✓ | | ✓ | | | ✓ | ✓ |
| Salameh et al., 2020 | ✓ | ✓ | ✓ | ✓ | ✓ | | 44 MW | ✓ | | | ✓ | ✓ | | | ✓ |

***Temporal Resolution*: *H*=*Hourly; M*=*Monthly; A*=*Annual; Sizing Methods*: *D*=*Deterministic model; AI*=*Artificial Intelligence; S*=*Simulation.***

## 3. Discussion and key evidences

Among the different RESs, solar and wind are the most suitable sources for a HRES. This is due to both their easy installation and to independence by fuel cost fluctuations (Lian et al., 2019). Furthermore, the current literature has a great number of studies on off-grid systems respect to grid connected (Fig. 4).

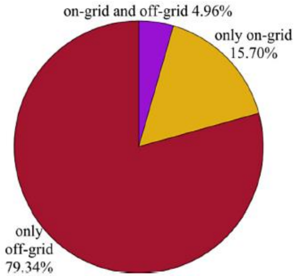


**Figure 4: Articles on on-grid and off-grid HRESs (Lian et al., 2019).**

Concerning the temporal resolution, researchers adopt, mostly, an hourly data basis to increase the design accuracy. Evidences show that the most adopted indicators are techno-economic indices rather than environmental ones. Frequently, the environmental sustainability of HRESs is assumed as a precondition. Nevertheless, the most recent papers quantify the positive impact of HRESs on global warming.

About the last criteria, i.e. the sizing methodology, the predominance of simulation appears. Hybrid Optimization of Multiple Energy Resources (HOMER) software is a standard, while growing interest on AI rises. In detail, the majority of the selected papers, to address the HRES design problem, employs simulation and, among the commercial tool, HOMER software (Meyer and Al-Hadhrami, 2012; Bhattacharjee and Acharya, 2015; Hossain et al., 2016; Ahmad et al., 2018; Wajjaha et al., 2019). This tool comprises three phases: (1) simulation, (2) optimisation and (3) sensitivity analysis, while it aids designers in maximising the Net Present Value (NPV) achieving optimal capacity schemes, using, generally, hourly data.

Bilal et al. (2013), Papaefthymiou and Papathanassiou (2014), Busaidi et al. (2015), Rangnekar et al. (2016), Nadjemi et al. (2017) and Akram et al. (2018) follow AI based methods, i.e. Genetic Algorithms (GA), Particle Swarm Optimization (PSO), Simulated Annealing (SA), etc., that allow to solve nonlinear NP-hard problems. As example, Bilal et al. (2013) examine the economic and environmental performances of an off-grid plant composed of PV-wind-diesel-ES using GA. Nadjemi et al. (2017) applies Cuckoo Search (CS) to size a PV-wind plant in Algeria providing a techno-economic and environmental sensitivity analysis. They also compare different kind of AI methods, concluding the higher accuracy of CS in their context.

Finally, examples of applications of deterministic models to size HRESs for both industrial and residential scenarios are in El Alimi et al. (2014), Bortolini et al. (2015), Fang et al. (2017) and Akram et al. (2018).

Several papers focus both on the analysis of the performances of existing plants and on the design of new ones; others deal with the sizing and management of HRESs, including the evaluation of the NRESs and of the best ES system solutions (Paiva and Carvalho, 2013).

In this perspective, Giannoulis and Haralambopoulos (2011) propose a study with the aim of analysing the economic and technical performances of an off-grid PV-diesel generator plant with a power generation of 66 MW. The data used to perform the comparison toward the electric grid are on hourly basis. The Authors conclude that such a system is a promising technology highlighting the advantages in terms of Levelised Cost of Electricity (LCOE) and $CO_2$ emission reduction. Marano et al. (2012) achieve the optimal management of a PV-wind plant, adopting a dynamic programming algorithm and outlining the reduction of the level of $CO_2$. Paiva and Carvalho (2013) present a technical and economic analysis for a hybrid plant of 26.4 MW in Brazil. The paper compares distinct scenarios evaluating the NPV of the plant using a Monte Carlo approach.

The literature agrees that HRES size optimisation is fundamental to spread the penetration of RESs and to return on the initial investment. El Alimi et al. (2014) develop a deterministic technique to size a PV-wind stand-alone application for a household in Tunisia (3.5 kW rated plant) with the aim of minimising the LCOE and the annual capital cost. Wang et al. (2015) present the modelling of a PV-wind-diesel system using Deep-Cycle Lead-Acid (DCLA) batteries as ES system. The goal of the study is to achieve the optimal configuration to fulfil the electricity demand for a single-family residential home, with a rated power output of 10 kW, minimising the annual global cost.

An additional study, focused on a rural area, comes from Arefin et al. (2016). The work evaluates the performances of a PV-wind-diesel-ES hybrid system using real time data of solar irradiation and wind speed in the state of Selangor, Malaysia. Using simulation, the outcomes show a significant potential in the reduction of the annual Net Present Cost (NPC) and $CO_2$ emissions. Busaidi et al. (2015) review the HRESs in Oman discussing the different techniques to size off-grid PV-wind plants. The comparison among the approaches is applied to two cases adopting AI to minimise the Cost of Electricity (COE).

The mismatch between the availability of RESs and the need of energy during the peak demand leads to develop an affordable battery ES system. Das (2016) and Berrada and Loudiyi (2016) investigate on a system comprising PV, wind and a battery bank. The former Author presents a feasibility analysis of an off-grid system located in Bangladesh proving its sustainability with a simultaneous decrease of COE and NPC, the latter Authors, by adopting non-linear programming optimization, provide the performances of both on-grid and off-grid systems for a market in Spain. The Authors, considering different types of ES systems, show that the storage technologies add a driver of cost to the supplied energy but guarantee the service level.

Zaibi et al. (2018) presents an architecture composed by a PV and an ES system, i.e. battery bank and hydraulic storage in water tanks, for an off-grid system by using hourly average data. The aim of the paper is to investigate on the loss of electric power supply probability and on the amount of embodied energy. Bhattacharjee and Acharya (2015) aim at taking advantage of joining PV and wind source through a plant supplying electricity to an educational building in Tripura, India, characterized by a low wind topography. The study comprises a technical and economic feasibility analysis providing the value of the COE.

Cozzolino et al. (2016) propose and apply a strategy to manage a hybrid PV-wind-fuel cell power plant for artificial islands connecting Tunisia and Italy. The Authors carry out different load simulations using reference load profiles and measured weather data on a monthly basis. The analysis points out a low value of the utilisation factors, both for wind turbines and PV panels. Hossain et al. (2016) work on multiple RESs. The research proposes a model for a large resort in Malaysia with extensions to tourist locations with similar weather conditions. By optimising the systems using HOMER, the result ensures significant reduction in $CO_2$ emissions and economic viability in terms of COE and NPC.

Akram et al. (2018), for a plant similar to the previous one, analyse the performances of a micro-grid connected system in Saudi Arabia. Two algorithms are implemented, the former is used to size the plant, the latter sizes the ES system. The data to perform the analysis are on hourly basis and the drivers of these algorithms minimise the cost and maximise the reliability. Bortolini et al. (2014) assess a multi-scenario analysis for an on-grid PV-ES system located in Bologna, Italy, with a power rate of 600 kW. The paper shows the technical and economic design providing a model to minimise the LCOE. The key data include the hourly irradiation level, the air temperature and the load profile. A HRES is proposed by Rangnekar et al. (2016) with the aim of evaluating the performances in terms of cost. The plant consists in a PV-wind-diesel-ES system and the analysis investigates several parameters, e.g. state of charge of the batteries, the power generated by source, etc. In the optimal configuration, a reduction of the cost and of the unmet load occurs. Comodi et al. (2016) analyse two domestic solar hot water systems taking into account the Life Cycle Assessment (LCA) of the plant. The same parameter is evaluated in Iannone et al. (2015).

Hemeida et al. (2019) compare the performances of the individual configuration of PV-wind in presence of ES system against a HRES. The power output of the wind turbine is of 3.2 MW, while the PV system provides 1 MW. Yadav (2017) conducts a study to compare different HRESs, providing the value of COE by using a commercial simulation tool. Mohammed et al. (2019) propose an optimisation method for a stand-alone PV-wind-ES plant adopting a PSO algorithm to evaluate the NPC and COE. In 2020, Salameh et al. (2020) optimise an off-grid plant, conducting a techno-environmental analysis, evaluating the COE and the gas emissions. Finally, Nyeche and Diemuodeke (2019) aim at sizing a PV-wind-pumped hydro storage system to satisfy the energy demand of a community in Patani, Nigeria. The paper estimates the minimum capacity of the system and provides the value of the LCOE.

The next paragraph shows a set of literature contributions about HRESs integrating other RESs, different from the solar and wind sources.

### 3.1 Additional renewable sources

Using the previous methodology, papers with both lower citations and applications are selected. The choice of the most appropriate mix of RESs strongly depends on the weather conditions and on their local availability. Close to the solar and wind sources, researches focus on other RESs of potential interest for integration within HRESs.

A research stream of interest is on geothermal plants. Despite the large area required for their installation, their possibility to work either in closed-loop, with minimal gas emissions e.g. carbon dioxide or hydrogen sulfide, either in open-loop, in which emissions are higher but not from fossils, makes them a good solution for areas with geothermal fonts. In this field, Wajjahat et al. (2019) combine a geothermal plant with PV and wind sources to meet higher demand and to feed the grid during the low consumption. A sensitivity analysis shows the trend of the NPC and COE varying some boundary conditions and economic parameters. Kazmi and Sheikh (2019) propose the design of an on-grid hybrid geothermal-PV-wind HRES minimising the NPC and the COE. Olabi et al. (2019) present a review on hybrid geothermal plants and highlight that the limits coming from the low-grade nature of the source can be overcome by integrating other RESs. Briola et al. (2020) present an original configuration that integrates biomasses and geothermal energy, analysing the trend of the fluid temperature to determine the energy performances.

Biomasses from primary and secondary sources are a second relevant RES for applications in HRESs. Ahmad et al. (2018) study a PV-wind-biomass system presenting a feasibility analysis for a grid-tied micro-grid. By using average annual data, their sensitivity analysis illustrates the possibility to lower LCOE and NPC.

Finally, with regard to hydro, Fang et al. (2017) discuss the performances of a power generation plant by exploiting hydropower and PV source. The case study concerns a large hydro-PV power plant. The key results emphasize the relevance of interconnecting hydro and PV, encouraging the diffusion of such model, even using other RESs.

## 4. Conclusions

Respect to fossils, Hybrid Renewable Energy Systems (HRESs) represent a competitive solution to supply energy with the goal of a safe and clean environment (Al-Badi et al., 2012). A rising number of countries is investing in this sector and researchers are optimising these power generation systems to achieve efficiency and to facilitate their deployment. The current literature focuses both on off-grid and on grid plants, considering multiple types of loads. About the design and sizing of HRESs, the literature is wide, while the sizing problem affects several fields. Multi-objective approaches are needed and encouraged.

### 4.1 Research agenda

The review proposed in this paper allows drawing several conclusions and directions for future research.

(1) Photovoltaic (PV)-wind-diesel systems are broadly investigated, hence other type of RESs are encouraged to be analysed;

(2) Current literature on capacity optimization lacks research concerning planning and construction steps. These stages need to be added in the optimization process;

(3) This paper highlights that more than 80% are off-grid systems, thus large-scale grid-connected HRES are encouraged to be developed, joining the advantages of existing hydropower systems;

(4) The calculation of the generated power should be obtained by real-time data and adopting low recording time, e.g. hourly and less then hourly resolution;

(5) The selection of the energy storage (ES) system should involve the environmental impact, considering all stages, including production and end-of-life;

(6) Deterministic design methods have limits to solve large complex problems. Artificial Intelligence (AI) based methods and simulation show their potential in this field;

(7) The evaluation of the environmental goals should attract more attention by proposing and applying original indicators and by optimising bi- or tri-objective functions;

(8) studies should involve the whole life cycle of the plant, from cradle to grave, from the technical, economic, and environmental perspectives;

These points constitute a viable research agenda for the next efforts of researchers and practitioners.

### References

Ahmad J., Imran M., Khalid A., Iqbal W., Ashraf S., Adnan M., Ali S., Khokhar K. (2018). Techno economic analysis of a wind-photovoltaic-biomass hybrid renewable energy system for rural electrification: A case study of Kallar Kahar. *Energy*, 148, 208-234.

Akram U., Khalid M., Shafiq S. (2017). Optimal Sizing of a Wind/Solar/Battery Hybrid Grid-connected Microgrid System. *IET Renewable Power Generation*, 12, 72-80.

Al-Badi A., Bourdoucen, H. (2012). Feasibility analysis of renewable hybrid energy supply options for Masirah Island. *International Journal of Sustainable Engineering*, 5, 244-251.

Alencar D., Affonso C., Oliveira R., Moya Rodríguez J., Leite J., Reston Filho J.C. (2017). Different Models for Forecasting Wind Power Generation: Case Study. *Energies*, 10, 1976, 1-27.

Alsina E.F., Bortolini M., Gamberi M., Regattieri A. (2016). Artificial neural network optimisation for monthly average daily global solar radiation prediction. *Energy Conversion and Management*, 120, 320-329.

Arefin S., Julai S., Kibria M.A.K., Ullah K.R., Rahman S., Chong W. T., Rahman K. (2016). Performance Analysis of an off-grid Wind-PV-Diesel-Battery Hybrid Energy System Feasible for Remote Areas. *Journal of Cleaner Production*, 125, 121-132.

Bentouba S. and Bourouis M. (2016). Feasibility study of a wind-photovoltaic hybrid power generation system for a remote area in the extreme south of Algeria, *Applied Thermal Engineering*, 99, 713-719.

Berrada A. and Loudiyi K. (2016). Operation, sizing, and economic evaluation of storage for solar and wind power plants. *Renewable and Sustainable Energy Reviews*, 59, 1117-1129.

Bhattacharjee S. and Acharya S. (2015). PV–wind hybrid power option for a low wind topography. *Energy Conversion and Management*, 89, 942-954.

Bianchi M., Branchini L., Ferrari C., Melino, F. (2014). Optimal sizing of grid-independent hybrid photovoltaic–battery power systems for household sector. *Applied Energy*, 136, 805-816.

Bortolini M., Gamberi M., Graziani A. (2014). Technical and economic design of photovoltaic and battery energy storage system. *Energy Conversion and Management*, 86, 81-92.

Bortolini M., Gamberi M., Graziani A., Pilati F. (2015). Economic and environmental bi-objective design of an off-grid photovoltaic–battery–diesel generator hybrid energy system. *Energy Conversion and Management*, 106, 1024-1038.

Briola S., Gabbrielli R., Bischi B. (2019). Off-design performance analysis of a novel hybrid binary geothermal-biomass power plant in extreme environmental conditions. *Energy Conversion and Management*, 195, 210-225.

Busaidi A., Kazem H. A., Al-Badi A., Khan M. (2016). A Review of optimum sizing of hybrid PV-Wind renewable energy systems in Oman. *Renewable and Sustainable Energy Reviews*, 53, 185-193.

Comodi G., Bevilacqua M., Caresana F., Paciarotti C., Pelagalli L., Venella P. (2016). Life cycle assessment and energy-CO2-economic payback analyses of renewable domestic hot water systems with unglazed and glazed solar thermal panels. *Applied Energy*, 164, 944-955.

Cozzolino R., L. Tribioli, G. Bella. (2016). Power management of a hybrid renewable system for artificial islands: A case study. *Energy*, 106, 774-789.

Das H. (2016). Feasibility Analysis of Standalone PV/Wind/Battery Hybrid Energy System for Rural Bangladesh. *International Journal of Renewable Energy Research*, 6, 402-412.

El Alimi S., Maatallah T., Ben Nasrallah S. (2014). Break-even analysis and optimization of a stand-alone hybrid system with battery storage for residential load consumption - A case study. *Renewable and Sustainable Energy Reviews*, 37, 408-423.

Erdinc O. and Uzunoglu M. (2012). Optimum design of hybrid renewable energy systems: Overview of different approaches. *Renewable and Sustainable Energy Reviews*, 16, 1412-1425.

Fang W., Huang Q., Huang S., Yang J., Meng E., Yunyun L. (2017). Optimal sizing of utility-scale photovoltaic power generation complementarily operating with hydropower: A case study of the world's largest hydro-photovoltaic plant. *Energy Conversion and Management*, 136, 161-172.

Giannoulis E.D. and Haralambopoulos D. (2011). Distributed Generation in an isolated grid: Methodology of case study for Lesvos - Greece. *Applied Energy*, 88, 2530-2540.

Hemeida A., El-Ahmar M., El-Sayed A.M., Hasanien H., Alkhalaf S., Esmail M.F.C., Senjyu, T. (2019). Optimum design of hybrid wind/PV energy system for remote area. *Ain Shams Eng. Journal*, 11, 11-23.

Hossain M., Mekhilef S., Olatomiwa L. (2016). Performance evaluation of a stand-alone PV-wind-diesel-battery hybrid system feasible for a large resort center in South China Sea, Malaysia. *Sustainable Cities and Society*, 28, 358-366.

Iannone R., Miranda S., Riemma S., De Marco I. (2015). Improving environmental performances in wine production by a life cycle assessment analysis. *Journal of Cleaner Production*, 111, 172-180.

IEA (2019), World Energy Outlook 2019, IEA, Paris https://www.iea.org/reports/world-energy-outlook-2019

Kazmi S. and Sheikh M. (2019). Hybrid geothermal–PV–wind system for a village in Pakistan. *SN Applied Sciences*, 1, 754, 1-15.

Lian J., Zhang Y., Ma C., Yang Y., Chaima E. (2019). A review on recent sizing methodologies of hybrid renewable energy systems. *Energy Conversion and Management*, 199, 112027, 1-23.

Marano V., Rizzo G., Tiano F. A. (2012). Application of dynamic programming to the optimal management of a hybrid power plant with wind turbines, photovoltaic panels and compressed air energy storage. *Applied Energy*, 97, 849-859.

Meyer J. and Al-Hadhrami L. (2012). Feasibility study of a wind-pv-diesel hybrid power system for a village. *Renewable Energy*, 38, 258-268.

Mohammed O., Amirat Y., Benbouzid M. (2019). Particle Swarm Optimization of a Hybrid Wind/Tidal/PV/Battery Energy System. Application to a Remote Area in Bretagne, France. *Energy Procedia*, 162, 87-96.

Nadjemi O., Nacer T., Hamidat A., Salhi, H. (2017). Optimal hybrid PV/wind energy system sizing: Application of cuckoo search algorithm for Algerian dairy farms. *Renewable and Sustainable Energy Reviews*, 70, 1352-1365.

Nyeche E.N., and Diemuodeke O. (2019). Modelling and Optimisation of a Hybrid PV-Wind Turbine-Pumped Hydro Storage Energy System for Mini-Grid Application in Coastline Communities. *Journal of Cleaner Production*, 119578, 1-12.

Olabi A.G., Mahmoud M., Soudan B., Wilberforce T., Ramadan M. (2019). Geothermal based hybrid energy systems, toward eco-friendly energy approaches. *Renewable Energy*, 147, 2003-2012.

Paiva J. and Carvalho A. (2013). Controllable hybrid power system based on renewable energy sources for modern electrical grids. *Renewable Energy*, 53, 271-279.

Papaefthymiou S. and Papathanassiou S. (2014). Optimum sizing of wind-pumped-storage hybrid power stations in island systems. *Renewable Energy*, 64, 187-196.

Rangnekar S., Khare A., Mittal A., Suhane P. (2016). Sizing and Performance Analysis of Standalone Wind-PV based Hybrid Energy System using Ant Colony Optimization. *IET Renewable Power Generation*, 10, 964-972.

Salameh T., Ghenai C., Merabet A., Alkasrawi M. (2020). Techno-economical optimization of an integrated stand-alone hybrid solar PV tracking and diesel generator power system in Khorfakkan, United Arab Emirates. *Energy*, 190, 116475, 1-16.

Siddaiah R. and Saini R.P. (2016). A review on planning, configurations, modeling and optimization techniques of hybrid renewable energy systems for off grid applications. *Renewable and Sustainable Energy Reviews*, 58, 376-396.

Wang X., Palazoglu A., El-Farra N. (2015). Operational optimization and demand response of hybrid renewable energy systems. *Applied Energy*, 143, 324-335.

Yadav A. (2017). Techno economic feasibility analysis of different combinations of PV-Wind-Diesel-Battery hybrid system for telecommunication applications in different cities of Punjab, India. *Renewable and Sustainable Energy Reviews*, 76, 577-607.

Yahyaoui I., Atieh A., Serna A., Tadeo F. (2017). Sensitivity analysis for photovoltaic water pumping systems: Energetic and economic studies. *Energy Conversion and Management*, 135, 402-415.

Yang Y., Bremner S., Menictas C., Kay M. (2018). Battery energy storage system size determination in renewable energy systems: A review. *Renewable and Sustainable Energy Reviews*, 91, 109-125.

Zaibi M., Cherif H., Champenois G., Sareni B., Roboam X., Belhadj J. (2018). Sizing methodology based on design of experiments for freshwater and electricity production from multi-source renewable energy systems. *Desalination*, 446, 94-103.