Renewable and Sustainable Energy Reviews 62 (2016) 609–620

Contents lists available at ScienceDirect

Renewable and Sustainable Energy Reviews

journal homepage: www.elsevier.com/locate/rser

Optimal planning of hybrid renewable energy systems using HOMER: A review

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ARTICLE INFO

Article history:
Received 11 June 2014
Received in revised form
29 December 2015
Accepted 3 May 2016

Keywords:
Hybrid renewable energy system
HOMER
Optimal sizing

ABSTRACT

World energy consumption is rising due to population growth and increasing industrialization. Traditional energy resources cannot meet these requirements with notice to their challenges, e.g., greenhouse gas emission and high lifecycle costs. Renewable energy resources are the appropriate alternatives for traditional resources to meet the increasing energy consumption, especially in electricity sector. Integration of renewable energy resources with traditional fossil-based resources besides storages creates Hybrid Renewable Energy Systems (HRESs). To access minimum investment and operation costs and also meet the technical and emission constraints, optimal size of HRES's equipment should be determined. One of the most powerful tools for this purpose is Hybrid Optimization Model for Electric Renewables (HOMER) software that was developed by National Renewable Energy Laboratory (NREL), United States. This software has widely been used by many researchers around the world. In this paper a review of the state-of-the-art of researches, which use HOMER for optimal planning of HRES, is presented.

Contents

Abbreviations: EML, electrical machinery laboratory; TGS, thermal generation station; DRC, Democratic Republic of Congo; UAE, United Arab Emirates; K.S.A., Kingdom of Saudi Arabia; UK, United Kingdom; MACS, maximum annual capacity shortage; USA, United State of America; MREF, minimum renewable energy fraction; WEOR, wind energy operating reserve; PVEOR, PV energy operating reserve.

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http://dx.doi.org/10.1016/j.rser.2016.05.039
1364-0321/

1. Introduction

In recent years, population growth and technology development have resulted in increasing energy consumption, especially in electricity sector. Moreover, there are many rural and remote areas particularly in developing countries which have no access to electricity. In order to solve these problems, electricity generation should be increased. Nowadays, a large percentage of the world electricity is supplied by fossil fuel resources. However, these resources cannot meet the future electricity requirements because of their economic and environmental problems. Renewable energy resources have become efficient alternatives for fossil fuel resources. However, when these resources are used to supply the local loads individually, many problems are created such as high investment costs and low security of supply because of intermittent and uncertain nature of them. To solve these problems a new concept, namely Hybrid Renewable Energy Systems (HRESs) has emerged [1]. HRES is a combination of renewable, traditional energy resources, and energy storages to meet the load locally in both grid connected and standalone modes. HRESs are used in standalone mode in remote and rural areas. In this mode, due to uncertain nature of renewable resources, traditional energy resources and energy storages can be used as the back-up resources for them. In fact, during the periods in which the output of renewable resources is not enough to meet the load, remaining part of the load can be supplied by the back-up resources. On the other hand, when the renewable resources have extra generation, the excess energy can be absorbed by the energy storages. Therefore, HRESs have more reliability than only renewable energy systems in standalone mode. HRESs are used in grid connected mode in some places such as universities, hospitals, factories, and town. In this mode, when the grid electricity prices are low, the HRES meets the load from the grid and charges the energy storages with renewable resources. Then, during the periods in which the grid electricity prices are high, the HRES meets the load with its resources and sells the extra energy to the grid. In this manner, energy storages are discharged to meet the load or to sell energy to the grid. In this mode HRESs have more economical than only renewable energy systems. Therefore, HRES provides some advantages, e.g., increasing penetration of renewable energy resources, decreasing Cost of Energy (CoE), reduction of greenhouse gas emission, and providing access to electricity for people in remote and rural areas. These advantages meet all three criteria of Sustainable Development (SD) including economic, environmental, and social aspects.

One of the important issues in HRES is optimal planning of its component, e.g., number of Wind Turbines (WTs), Photo-Voltaic (PV) arrays, batteries, and capacity of generators and converters so that the objective functions are minimized/maximized and all constraints are satisfied. For this purpose, many software and optimization approaches are proposed in the literature. There are appropriate papers that have reviewed optimal planning and operation techniques of HRES from different viewpoints [1–9]. Different optimization methods and modeling of HRESs' component are described in [2]. Design and control techniques reported in the literature to simulate and optimize the stand-alone HRES are reviewed in [3]. Optimization tools and techniques which are used for optimal design of HRESs are reviewed in [5]. Ref. [7] reviews the different aspects of optimal design of HRESs only including WT, PV, battery, and converter. Different studies on HRES in both grid-connected and standalone modes including planning criteria, optimization techniques, energy management, and various configurations are reviewed in [8,9].

One of the most powerful tools for optimal sizing of HRESs' equipment is Hybrid Optimization Model for Electric Renewables (HOMER) software that was developed by National Renewable Energy Laboratory (NREL), United States [10]. Although HOMER software is used in many studies, a brief description is presented on it in review papers [1–9]. Therefore, an article is needed that comprehensively reviews the papers which used HOMER for optimal planning of HRESs which is the main objective of this paper. This review will be useful for researchers who intend to use HOMER for planning of HRES in their regions. It provides the required information about planning of HRES simulated with HOMER such as what components are considered in HRESs? How they are used in stand-alone or grid connected modes? And what uncertain parameters are considered in the articles?

The reminder of the paper is organized as follows. Description of HOMER software is presented in Section 2. Equipment modeled in HOMER and considered in the literature is compared in Section 3. Sensitivity analysis on different uncertain parameters in the articles is reviewed in Section 4. Section 5 presents the discussion on HOMER's outputs. Finally, conclusion is presented in Section 6.

2. HOMER software description

HOMER software is a powerful tool for designing and planning of HRES in order to determine optimal size of its components through carrying out the techno-economic analysis. Many resources such as WT, PV array, fuel cells, small hydropower, biomass, converter, batteries, and conventional generators are modeled in HOMER. HOMER also considers HRES in grid-connected and stand-alone modes. Fig. 1 shows the typical configuration of HRES designed in HOMER. Required input data for simulation with HOMER and also a comprehensive framework to show how optimal sizes of HRES's equipment is determined by HOMER are described in this section.

2.1. Input data

HOMER requires six types of data for simulation and optimization including meteorological data, load profile, equipment characteristics, search space, economic and technical data. These data are described in details in the following subsections.

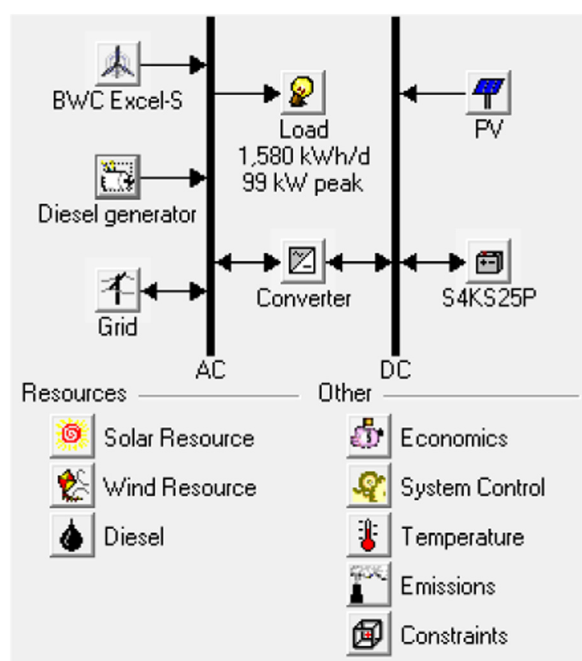

Fig. 1. Typical schematic of a HRES in HOMER.

2.1.1. Meteorological data

The meteorological data are wind speed, solar radiation, temperature, and stream flow which are fed into the software in the form of monthly averages or time series data. HOMER uses these inputs data to calculate the output power of WT, PV array and hydropower.

Table 1
Search space for a hypothetical case study.

Component	WT (number)	PV array (kW)	Battery (number)	Converter (kW)
Maximum	4	40	40	40
Minimum	0	0	0	0
Step	1	10	10	20

2.1.2. Load profile

Load profile of each region is the most important factor in the simulation and optimization. Some locations such as universities, hospitals, hotels, and industrial towns have real load consumption data, which are appropriate for simulation. These real data are fed into HOMER as time series data. However, in some regions especially remote and rural areas that the real load consumption data are not available, the load profile should be forecasted with notice to the specification of that region. These data are fed into HOMER as daily profile and HOMER uses them in power balance constraint.

2.1.3. Equipment characteristics

According to the characteristics of each equipment, which is modeled in HOMER, efficient operation of it in HRES is determined. The characteristics of HRES's equipment are described in [11].

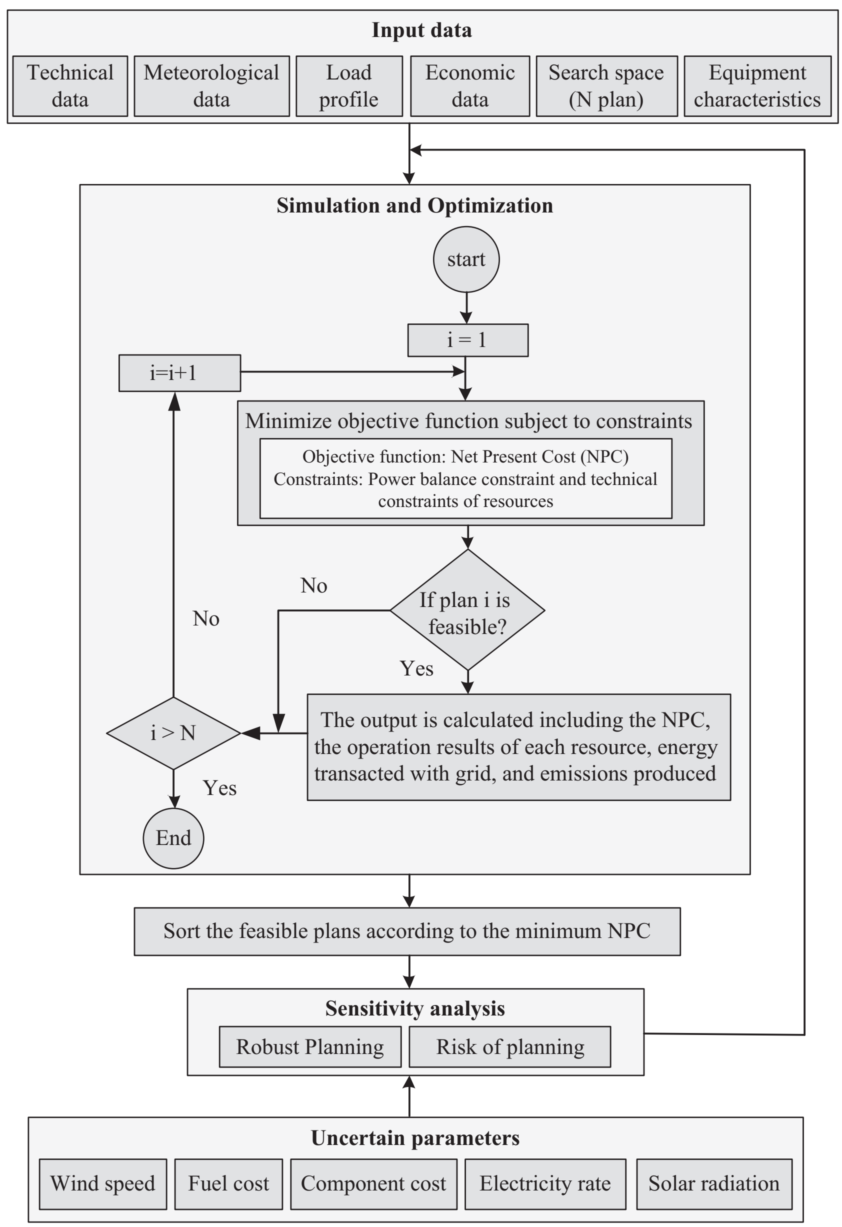

Fig. 2. The comprehensive framework of HOMER optimization procedure.

Table 2
Peak and types of different loads in the articles.

Ref.	Peak load (kWp)				Location	Country
	Electrical		Thermal	Hydrogen		
	Primary	Deferrable				
[14]	498,000	–	–	–	TGS	Canada
[15]	4.73	–	–	–	Remote area	Canada
[16]	12	–	–	–	Remote area	Cameroon
[17]	356	–	–	–	Remote area	Canada
[18]	61	–	–	–	Rural	Bangladesh
[19]	8.3	–	–	–	Remote villages	Cameroon
[20, 21]	24	–	–	–	Rural	Senegal
[22]	7.5	–	–	–	Village	Cameroon
[23]	Unknown	–	–	–	Village	Portuguese
[24]	5.6	–	–	–	Remote area	China
[25]	16	–	–	–	EML	Greece
[26]	6	–	–	–	Remote area	Jordan
[27]	7109	–	–	–	Island	Malaysia
[28]	966	–	–	–	Hotel	Australia
[29]	11	–	–	–	Residential area	Canada
[30]	4	–	–	–	Remote area	Greece
[31]	4200	–	–	–	Remote area	K.S.A.
[32]	159	–	–	–	Commercial building	K.S.A.
[33]	13.4	–	–	–	Village	Iran
[34]	4231	–	–	–	Village	K.S.A.
[35]	966	–	–	–	Hotel	Australia
[36]	8080	–	–	–	Island	Greece
[37]	42	1.05	–	–	Remote area	Ethiopia
[38]	1183	–	51.07	–	Rural community	Canada
[39]	4370	–	–	–	Village	K.S.A.
[40]	0.626	–	–	–	Rural areas	Algeria
[41]	81	1.8	–	–	Rural	Ethiopia
[42]	239	–	–	–	University	Turkey
[43]	7700	–	–	–	Arid region	Algeria
[44]	159	–	–	–	Village	India
[45]	11	–	–	–	Remote areas	Bangladesh
[46]	32	–	–	–	Remote area	Bangladesh
[47]	297.2	–	–	–	Hotels	Australia
[48]	77	–	–	–	University	Malaysia
[49]	9.97	–	–	–	Hotel	Jordan
[50]	36	–	–	–	University	Turkey
[51]	4400	–	–	–	Remote area	K.S.A.
[52]	265	–	Unknown	–	Residential district	Italia
[53]	9.3	–	–	–	Residential consumers	K.S.A.
[54]	23	–	–	–	Island	Bangladesh
[55]	34	–	–	–	Urban area	UK
[56]	84	–	–	–	Remote area	Malaysia
[57]	Unknown	–	–	–	Island	Brazil
[58]	2.3	–	–	–	Remote area	India
[59]	4.2	–	–	–	Kolkata city	India
[60]	110.9	–	–	–	Remote area	Malaysia
[61]	15	–	–	–	Remote area	South Africa
[62]	Unknown	–	–	–	Island	Thailand
[63]	Unknown	–	–	–	Remote area	Canada
[64]	1030	–	–	–	University	Iran
[65]	7100	–	–	–	University	Malaysia
[66]	982	–	–	–	Industry area	Malaysia
[67]	197	–	–	–	Island	Malaysia
[68]	325	–	–	–	Residential consumers	Hypothetical
[69]	5300	–	–	–	Island	USA
[70]	91	–	–	–	Island	Indonesia
[71]	65.1	–	–	–	Village	Iran
[72]	9.6	133	–	–	desert agricultural area	Egypt
[73]	27	–	–	–	Remote island	Hong Kong
[74]	56	–	–	–	Village	Indonesia
[75]	1137, 2300 and 11,000 for three cases	–	–	–	Remote areas	UAE
[76]	495	–	–	–	Renewable energy site	Iran
[77]	1.1	–	–	–	Urban areas	India
[78]	550	–	–	–	Island	South Korea
[79]	44.4	–	–	–	Village	Bangladesh
[80]	92	–	–	–	Island	Scotland
[81]	537	–	–	–	Remote areas	Canada
[82]	9.4	–	–	–	Rural	South Africa
[83]	8	–	–	–	Remote area	DRC
[84]	83	–	–	–	Remote areas	Ghana
[85]	1.4	–	–	–	Urban area	India

Table 2 (*continued*)

Ref.	Peak load (kWp)				Location	Country
	Electrical		Thermal	Hydrogen		
	Primary	Deferrable				
[86]	13	–	–	–	Village	Algeria
[87]	3.8 and 5.6	–	–	–	Rural	South Africa
[88]	2700	–	–	–	Island	Malaysia
[89]	50	–	–	–	Island	Malaysia
[90]	25	–	–	–	Rural area	Bangladesh
[91]	236	–	–	–	Rural areas	Nigeria
[92]	2,213,000	–	–	–	Urban area	K. S. A.
[93]	2,213,000	–	–	–	Urban area	K. S. A.
[94]	175	–	–	–	Island	Iceland
[95]	2.8	–	–	–	Remote area	Norway
[96]	Unknown	–	–	–	Rural areas	Canada
[97]	5665	–	10,305	–	Urban areas	Serbian
[98]	211	–	–	–	Urban area	Somali
[99]	1.3	–	–	–	Remote area	India
[100]	Unknown	–	–	–	Rural area	Algeria
[101]	Unknown	–	–	–	Coastal site	Algeria
[102]	52	–	–	–	Rural areas	India
[103]	25	–	–	–	Rural areas	Sri Lanka
[104]	Unknown	–	–	–	Rural areas	Nigeria
[105]	135	–	–	–	Island	Turkey

2.1.4. Search space

Since HRESs' components including WT, PV array, generator, battery, and converter have different sizes, there is a search space that is considered in simulation and optimization. For example, the equipment of a hypothetical HRES which have different sizes is illustrated in Table 1. So, the search space includes $5\times5\times5\times3=375$ plans (combination of different equipment) that the simulation and optimization stages will be done for each of them.

2.1.5. Economic data

Each equipment in HRES has some cost data such as operation and maintenance, capital, and replacement cost. Fuel price, price of transaction electricity with the grid, real interest rate, project lifetime, system fixed capital cost, system fixed operation and maintenance cost, and emissions penalty are the other economic data that can be considered in HOMER. These costs are considered in simulation and optimization stages and based on them, the Net Present Cost (NPC) of each plan is calculated.

2.1.6. Technical data

For simulation, HOMER requires some technical data including dispatch strategy, MACS, MREF, and operating reserve, which are described in [11].

2.2. HOMER optimization procedure

After the input data are fed into HOMER, which was described in previous section, optimal sizes of HRES's equipment are determined in three stages including simulation, optimization, and sensitivity analysis as described in Fig. 2. These stages are introduced in the following subsections. Simulation and optimization stages are done simultaneously.

2.2.1. Simulation and optimization

For each plan from search space the optimization and simulation stages are done. The objective function is minimized subject to the constraints. The objective function of each plan is the total NPC which is the present value of the sum of costs minus the sum of revenues. The costs are the cost of energy purchased from the grid, initial cost, replacement cost, operation and maintenance

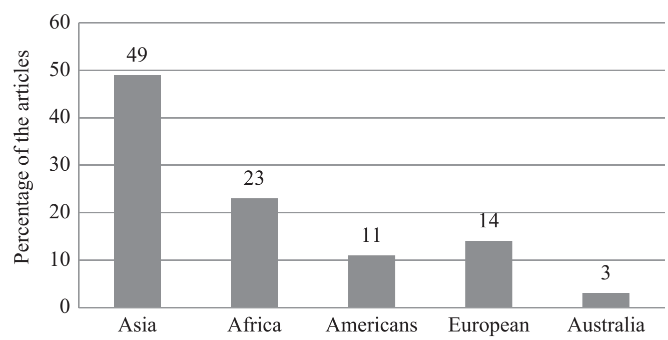

Fig. 3. Percentage of the articles done in different continent.

cost as well as the fuel cost. The revenues are the revenue from energy sold to the grid and the salvage value. Constraints are power balance constraint, charging and discharging constraints of battery, constraints of transaction energy with grid, technical constraints of generators and so on. For the feasible plans the required output is calculated including the NPC, operation results of resources such as generator, battery, and converter in each time step, the energy transacted with the grid, and the emissions produced. Feasibility means that the power balance constraint is satisfied in each time step. In fact, the demand of each time step is supplied. At the end, the feasible plans are sorted according to the minimum NPC so that the first plan has the minimum NPC and is considered as the best plan.

2.2.2. Sensitivity analysis

In optimal sizing procedure of HRES's equipment, some parameters such as fuel cost, wind speed, solar radiation, electricity price, and components cost have not deterministic values. So, the uncertainty of these parameters has effect on simulation and optimization stages. These parameters are fed into HOMER with different values. When the simulation and optimization stages are done and the feasible plans are sorted according to the minimum NPC, the sensitivity analysis is done as shown in Fig. 2. For each uncertain parameter the simulation and optimization stages are repeated and the new feasible and best plans may be obtained. To

Table 3
Components considered in different articles.

Ref.	Non-dispatchable resources			Dispatchable resources			Converters		Storages	
	PV	WT	Hydro	Gen.	Boiler	Grid	Converter	Electrolyzer	Battery	Hydrogen tank
[14]	–	✓	–	✓	–	–	–	–	–	–
[15]	✓	✓	–	✓	–	–	✓	✓	✓	✓
[16]	✓	–	✓	✓	–	–	✓	–	✓	–
[17]	–	✓	–	✓	–	✓	–	✓	–	✓
[18]	✓	✓	–	–	–	–	–	–	✓	–
[19]	✓	–	✓	✓	–	–	–	–	✓	–
[20,21]	✓	–	–	✓	–	–	✓	–	✓	–
[22]	✓	–	✓	✓	–	–	✓	–	✓	–
[23]	✓	✓	✓	–	–	✓	✓	–	✓	–
[24]	✓	✓	–	–	–	–	✓	–	✓	–
[25]	✓	–	–	✓	–	–	✓	✓	✓	✓
[26]	✓	–	–	✓	–	–	✓	–	✓	–
[27]	✓	✓	–	✓	–	–	✓	✓	✓	✓
[28]	✓	✓	–	–	–	✓	✓	–	✓	–
[29]	✓	✓	–	–	–	✓	✓	–	✓	–
[30]	✓	–	–	✓	–	–	✓	✓	✓	✓
[31]	✓	–	–	✓	–	–	✓	–	✓	–
[32]	✓	–	–	✓	–	–	✓	–	✓	–
[33]	✓	✓	–	✓	–	✓	✓	–	✓	–
[34]	–	✓	–	✓	–	–	–	–	–	–
[35]	✓	✓	–	✓	–	–	✓	–	✓	–
[36]	✓	✓	–	✓	–	–	✓	✓	–	✓
[37]	✓	✓	–	✓	–	–	✓	–	✓	–
[38]	✓	✓	✓	✓	✓	✓	✓	–	✓	–
[39]	✓	✓	–	✓	–	–	✓	–	–	–
[40]	✓	✓	–	✓	–	–	✓	–	✓	–
[41]	✓	✓	✓	✓	–	–	✓	–	✓	–
[42]	✓	✓	✓	✓	–	✓	✓	✓	–	✓
[43]	✓	✓	–	–	–	✓	✓	–	–	–
[44]	✓	✓	✓	✓	–	–	✓	–	✓	–
[45]	✓	✓	–	✓	–	–	✓	–	✓	–
[46]	✓	✓	–	–	–	–	✓	–	✓	–
[47]	✓	✓	–	✓	–	–	✓	–	✓	–
[48]	✓	✓	–	✓	–	–	✓	–	✓	–
[49]	✓	✓	–	–	–	✓	✓	–	✓	–
[50]	✓	–	–	✓	–	✓	✓	✓	✓	✓
[51]	✓	–	–	✓	–	–	✓	–	✓	–
[52]	✓	✓	–	✓	✓	✓	✓	✓	✓	✓
[53]	✓	–	–	✓	–	–	✓	–	✓	–
[54]	✓	✓	–	✓	–	–	✓	–	✓	–
[55]	✓	✓	✓	✓	–	✓	✓	–	✓	–
[56]	✓	–	–	✓	–	–	✓	–	✓	–
[57]	✓	–	–	✓	–	–	✓	✓	✓	✓
[58]	–	✓	–	✓	–	–	✓	✓	✓	✓
[59]	✓	–	–	✓	–	–	✓	✓	✓	✓
[60]	✓	–	–	✓	–	–	✓	–	✓	–
[61]	✓	–	✓	✓	–	–	✓	–	✓	–
[62]	✓	✓	–	✓	–	–	✓	–	✓	–
[63]	✓	✓	–	✓	✓	–	✓	–	✓	–
[64]	✓	✓	–	✓	–	✓	✓	–	✓	–
[65]	✓	–	–	✓	–	–	✓	–	–	–
[66]	✓	–	–	–	–	✓	✓	–	–	–
[67]	✓	✓	–	✓	–	–	✓	–	✓	–
[68]	✓	✓	–	–	–	✓	✓	–	✓	–
[69]	✓	✓	–	–	–	–	✓	–	✓	–
[70]	✓	–	–	✓	–	–	✓	–	✓	–
[71]	✓	✓	–	✓	–	–	✓	✓	✓	✓
[72]	✓	✓	–	✓	–	–	✓	–	✓	–
[73]	✓	✓	–	–	–	–	✓	–	✓	–
[74]	✓	✓	–	–	–	–	✓	–	✓	–
[75]	✓	✓	–	✓	–	–	✓	–	✓	–
[76]	✓	✓	–	–	–	–	✓	–	✓	–
[77]	✓	✓	–	–	–	–	✓	–	✓	–
[78]	✓	✓	–	✓	–	✓	✓	–	✓	–
[79]	✓	✓	–	✓	–	–	✓	–	✓	–
[80]	✓	✓	✓	✓	–	–	✓	–	✓	–
[81]	–	✓	–	✓	–	–	✓	–	✓	–
[82]	✓	–	✓	✓	–	–	✓	–	✓	–
[83]	✓	–	–	✓	–	–	✓	–	✓	–
[84]	✓	✓	–	✓	–	–	✓	–	✓	–
[85]	✓	✓	–	–	–	✓	✓	–	✓	–
[86]	✓	✓	–	✓	–	–	✓	–	✓	–
[87]	✓	✓	✓	✓	–	–	✓	–	✓	–

Table 3 (*continued*)

Ref.	Non-dispatchable resources			Dispatchable resources			Converters		Storages	
	PV	WT	Hydro	Gen.	Boiler	Grid	Converter	Electrolyzer	Battery	Hydrogen tank
[88]	✓	✓	✓	✓	–	–	✓	–	✓	–
[89]	✓	–	–	✓	–	–	✓	–	✓	–
[90]	✓	–	–	✓	–	–	✓	–	✓	–
[91]	✓	–	–	✓	–	–	✓	–	✓	–
[92]	✓	–	–	–	–	✓	–	–	✓	–
[93]	✓	–	–	✓	–	–	✓	–	✓	–
[94]	–	✓	–	✓	–	–	✓	✓	–	✓
[95]	–	–	–	✓	–	–	✓	–	✓	–
[96]	–	✓	–	✓	–	–	–	–	–	–
[97]	✓	✓	✓	✓	–	–	✓	–	✓	–
[98]	✓	✓	–	✓	–	–	✓	–	✓	–
[99]	✓	✓	–	✓	–	✓	✓	✓	✓	✓
[100]	✓	–	–	✓	–	–	✓	–	✓	–
[101]	✓	✓	–	–	–	✓	–	–	–	–
[102]	✓	✓	✓	✓	–	–	✓	–	✓	–
[103]	✓	✓	–	✓	–	–	✓	–	✓	–
[104]	✓	✓	–	✓	–	–	✓	–	✓	–
[105]	✓	✓	–	✓	–	–	✓	✓	✓	✓

evaluate the effect of uncertain parameters on the results, two criteria including robust planning and risk of planning are proposed in [12,13]. These criteria can be calculated by the researchers according to the methodologies which are described in [12,13] and HOMER software is not able to calculate them. HOMER also produces appropriate figures to show how the best plans' output will be changed with uncertain parameters.

3. Equipment modeled in HOMER

In this section, various HRES's equipment modeled in HOMER and used in different articles is presented. Loads, components, and grid are three types of the HRES's equipment, which are modeled in HOMER.

3.1. Loads

HRES should meet the load requirements in each time step. Electrical, thermal, and hydrogen loads are modeled in HOMER. Electrical loads are primary and deferrable loads. Primary loads are the electrical load that must be met in certain time while deferrable load is the electrical load that must be met within some time period, but the exact time is not important. Peak and types of different loads that are used in different articles are listed in Table 2. Also, Table 2 shows the locations and countries which are considered in each article. Locations that are listed for each article, such as remote area, rural, and village are exactly mentioned in the same article. Since there are some peak loads data that have not mentioned in the articles, these data are shown in Table 2 as unknown data.

Table 2 shows that the wide range of the peak loads from 0.626 kW to 2,213,000 kW are modeled in the articles. The most loads that are modeled in the articles are electrical loads; while thermal and hydrogen loads are modeled in few ones.

Fig. 3 shows the percentage of the articles published in different continent of the world. As illustrated in Fig. 3, the most articles are done in Asia. Sixty percent of the world population is living in Asia and 57.8% of these people are living in rural and remote areas and also most countries of the Asia are developing countries. So, these countries have severe need for electrical energy. Taking these issues into account, large number of the researches about HRES is done in Asia especially in remote areas.

3.2. Component

In HOMER, each part of HRES that can produce, deliver, convert, or save energy is named as a component. Ten components are modeled in the HOMER. WT, PV, and small hydropower are three renewable energy and non-dispatchable resources. Generators, grid, and boiler are three dispatchable resources. Converter and electrolyzer are components that convert electrical energy to other forms. AC and DC power are converted to each other using converters and electrolyzers consume AC or DC power and generate hydrogen through electrolyzing water. Batteries and hydrogen tanks are components that store energy. HRES that are modeled in the articles have used different components for simulation as given in Table 3. In some articles, fuel cells are used as generators. These HRESs with fuel cell have electrolyzer as converter and hydrogen tank as energy storage as illustrated in Table 3.

Since different combinations of the component that are considered in the articles are listed in Table 3, this table can be used by each researcher who intends to design HRES with a specific combination in his/her regions. PV is the most common resource from non-dispatchable resources in HRESs that are used in 91.2% of the studies. In recent papers new resources are considered such as biogas is used as the fuel resource for generators in [96,102] and flywheel is used as energy storage in [93].

3.3. Grid

Grid is modeled in the HOMER in three modes, namely, grid-connected, stand-alone, and compare stand-alone system with grid extension. Table 4 shows different modes of HRESs used in the articles. In grid connected mode price and sell back of electricity should be fed into HOMER in two types, real time prices and scheduled rates. In compare stand-alone system with grid extension mode, breakeven grid extension distance will be calculated using three inputs including capital, operation and maintenance cost and grid power price. The breakeven grid extension distance

Table 4
Grid modes in the articles.

Ref.	Grid connected	Stand-alone	Breakeven grid extension distance (km)
[14]	–	✓	–
[15]	–	✓	–
[16]	–	✓	37.4 and 15.4 for two cases
[17]	✓	–	–
[18]	–	✓	17
[19]	–	✓	12.9 and 15.2 for two cases
[20,21]	–	✓	–
[22]	–	✓	3.3
[23]	✓	✓	31.6
[24]	–	✓	–
[25]	–	✓	–
[26]	–	✓	–
[27]	–	✓	–
[28]	✓	–	–
[29]	✓	–	–
[30]	–	✓	–
[31]	–	✓	–
[32]	–	✓	–
[33]	✓	✓	5.92
[34]	–	✓	–
[35]	–	✓	–
[36]	–	✓	–
[37]	–	✓	–
[38]	✓	✓	153
[39]	–	✓	–
[40]	–	✓	–
[41]	–	✓	–
[42]	✓	–	–
[43]	✓	–	–
[44]	–	✓	–
[45]	–	✓	–
[46]	–	✓	10.10
[47]	–	✓	–
[48]	–	✓	–
[49]	✓	–	–
[50]	✓	✓	–
[51]	–	✓	–
[52]	✓	–	–
[53]	–	✓	–
[54]	–	✓	–
[55]	✓	✓	–
[56]	–	✓	–
[57]	–	✓	–
[58]	–	✓	–
[59]	–	✓	–
[60]	–	✓	–
[61]	–	✓	3.07
[62]	–	✓	–
[63]	–	✓	–
[64]	✓	–	–
[65]	–	✓	–
[66]	✓	–	–
[67]	–	✓	–
[68]	✓	–	–
[69]	–	✓	–
[70]	–	✓	–
[71]	–	✓	–
[72]	–	✓	–
[73]	–	✓	–
[74]	–	✓	–
[75]	–	✓	31, 38 and 180 for three cases
[76]	–	✓	–
[77]	–	✓	–
[78]	✓	✓	–
[79]	–	✓	–
[80]	–	✓	–
[81]	–	✓	–
[82]	–	✓	1.1 for the best plan
[83]	–	✓	–
[84]	–	✓	–
[85]	✓	–	–
[86]	–	✓	–
[87]	–	✓	1.76 and 1.1 for two cases
[88]	–	✓	–
[89]	–	✓	–
[90]	–	✓	–
[91]	–	✓	–
[92]	✓	–	–
[93]	–	✓	–
[94]	–	✓	–
[95]	–	✓	–
[96]	–	✓	–
[97]	–	✓	–
[98]	–	✓	–
[99]	✓	–	–
[100]	–	✓	–
[101]	✓	–	–
[102]	–	✓	–
[103]	–	✓	–
[104]	–	✓	–
[105]	–	✓	–

is the minimum distance from the grid that makes a stand-alone system cheaper than extending the grid. As illustrated in Table 4, most of HRESs in the articles are simulated in standalone modes.

4. Sensitivity analysis

To evaluate the effect of uncertain parameters on optimal sizing of HRES's equipment, sensitivity analysis should be done. Uncertain parameters may differ with notice to the location and type of the components. Uncertain parameters considered in different articles are listed in Table 5. Wind speed, solar radiation, fuel price, component cost, and primary load are the most uncertain parameters considered in the researches.

In most articles the effect of uncertain parameters on NPC, operation results of resources, production of emissions and other parameters of best plans are evaluated. Moreover, sensitivity analysis is done in details in recent papers. Effects of real interest rate, fuel price, and primary load on output results is investigated through different scenarios in [89]. The simultaneous effects of wind speed and solar radiation on CoE is studied in [103]. To investigate the effect of uncertain parameters on the NPC, an appropriate spider graph is presented in [98]. However, as mentioned before, to evaluate uncertain parameters and their effect on optimal sizing of HRES's equipment, two appropriate criteria including robust planning and risk of planning should be considered as proposed in [12,13]. Scenario technique is one of the appropriate approaches in dealing with the uncertainties in planning of HRES. To this end, at first, uncertain parameters and their different values that may occur in the future is determined and based on them, the scenarios can be constructed. For example, in one project the uncertain parameters and their different values may be considered as shown in Table 6. As illustrated in Table 6, there are three uncertain parameters with different values. Considering these different values, there are $5 \times 6 \times 4 = 120$ scenarios that should be considered in HOMER. The first scenario will occur when the wind speed is 4, diesel price is 0.2 and solar radiation is 4.5 and the last scenario will occur when wind speed is 8, diesel price is 0.7 and solar radiation is 6. Simulation and optimization stages are repeated for each scenario.

When each scenario is considered, even the best plan may differ. So, the best plan in base scenario may be changed into other scenarios. The robust plan is the one with the minimum NPC in most scenarios [12,13].

When one plan is considered as the best one in base scenario, its parameters such as NPC and production of emissions in other

Table 5
Type of uncertain parameters considered in different articles.

Ref.	Sensitivity analysis
[14]	Wind speed – Fuel price
[15]	Wind speed – Solar radiation – Fuel price – Component cost
[16]	–
[17]	–
[18]	–
[19]	Component cost
[20,21]	–
[22]	–
[23]	Sellback rate – Component cost
[24]	Wind speed – Solar radiation – Primary load
[25]	Fuel price - Solar radiation - Primary load
[26]	Solar radiation – Fuel price – MREF – MACS – PVEOR
[27]	Fuel price
[28]	Emission penalty – Electricity price – Component cost – Rate of return
[29]	Wind speed – Primary load
[30]	Fuel price – Component cost
[31]	–
[32]	–
[33]	–
[34]	Wind speed – Fuel price – MREF – MACS – WEOR
[35]	Battery efficiency – Payback time – Number of battery
[36]	–
[37]	–
[38]	Unmet energy – Fuel price
[39]	Wind speed – Solar radiation
[40]	–
[41]	–
[42]	Component cost – MACS – Electricity price
[43]	Wind speed – Solar radiation - Electricity price
[44]	Fuel price – Wind speed – Flow rate
[45]	Solar radiation – MACS – MREF – Wind speed – Fuel price
[46]	Wind speed – Solar radiation
[47]	Carbon tax – Fuel price
[48]	–
[49]	Electricity price
[50]	–
[51]	–
[52]	–
[53]	–
[54]	–
[55]	–
[56]	Solar radiation – Fuel price
[57]	–
[58]	–
[59]	Solar radiation
[60]	–
[61]	–
[62]	–
[63]	–
[64]	Primary load – Solar radiation – Wind speed – Fuel price – Interest rate – CO_2 penalty
[65]	–
[66]	–
[67]	Solar radiation – Wind speed – Fuel price
[68]	–
[69]	–
[70]	Primary load – Fuel price
[71]	–
[72]	–
[73]	Solar radiation – Wind speed – Primary load
[74]	–
[75]	Solar radiation – Wind speed – Fuel price
[76]	–
[77]	Capacity shortage
[78]	Solar radiation – Wind speed – Fuel price
[79]	–
[80]	Primary load
[81]	Wind speed – Fuel price
[82]	–
[83]	–
[84]	Solar radiation – Wind speed – Fuel price
[85]	Component cost
[86]	–
[87]	–
[88]	Primary load – Fuel price – Annual interest rate – Stream flow
[89]	Primary load – Fuel price – Annual interest rate
[90]	Investment costs – Biogas production rate
[91]	Solar radiation – Fuel price – Annual interest rate – Component cost
[92]	Photovoltaic array size – Converter size
[93]	–
[94]	–
[95]	Fuel price
[96]	Component size
[97]	Maximum CO_2 emission
[98]	Primary load – Wind speed – Solar radiation – Fuel price – Component cost
[99]	Primary load – Wind speed – Solar radiation – Fuel price
[100]	Primary load – Solar radiation – Fuel price – Annual interest rate
[101]	Wind speed – Solar radiation – Grid electricity price
[102]	–
[103]	Wind speed – Solar radiation – Component cost
[104]	–
[105]	Wind speed – Solar radiation – Annual interest rate

Table 6
Different scenarios for a case study.

Uncertain parameter	Different values
Wind speed (m/s)	4, 5, 6 , 7, 8
Diesel price ($/Liter)	0.2, 0.3, 0.4, 0.5, 0.6, 0.7
Solar radiation (kWh/m^2/day)	4.5, 5, 5.5, 6

scenarios may be changed. So, to evaluate these changes an appropriate criterion, namely risk assessment should be considered. Risk of planning is evaluated via NPC in base scenario and in other scenarios [12,13].

5. Discussion on HOMER's outputs

After all required data are fed into HOMER and the simulation and optimization stages are done, the results of each plan including the NPC ($), the initial capital cost ($), the operation cost ($/yr), renewable fraction (percent), CoE ($/kWh), and emissions produced (kg/yr) are calculated. Although best plan is determined according to the minimum NPC by HOMER, the best plan may be selected with notice to the other criteria considering the investors' perspective. This issue is discussed in details in [79].

CoE is an appropriate criterion to choice the best plan that is used in the literature. This criterion indicates the average cost per kWh of each plan to supply the demand. Table 7 shows the CoE for best plans which are obtained in the literature. Since in some articles the value of CoE for the best plans is not mentioned, these data is shown in Table 7 as unknown data. The CoE is high in some cases due to high investment cost of component, high fuel prices, high distance from the main grid and so on. For electrification to remote and rural areas which have high distance from the main grid, there are two main solutions including the extension of the main grid and using of HRESs. Although extension of the main grid may lead to lower NPC in comparison with HRESs, it has several disadvantages including power losses, low power quality, and high operation and maintenance cost. Moreover, in some cases the grid extension in not possible with notice to the topography of region. On the other hand, in urban areas the CoE for best plans is higher than the grid electricity prices. Therefore, to encourage the private investors to invest on HRESs in rural and urban areas, the governments should determine attractive regulations to give more

Table 7
CoE for the best plans which are determined in literature.

Ref.	CoE ($/kWh)	Ref.	CoE ($/kWh)	Ref.	CoE ($/kWh)	Ref.	CoE ($/kWh)
[14]	0.034	[38]	0.071	[62]	0.554	[85]	0.488
[15]	0.427	[39]	0.212	[63]	Unknown	[86]	Unknown
[16]	0.296	[40]	1.19	[64]	Unknown	[87]	0.265
[17]	0.16	[41]	0.101	[65]	0.272	[88]	0.145
[18]	0.363	[42]	0.307	[66]	0.095	[89]	0.569
[19]	0.352	[43]	0.379	[67]	0.216	[90]	0.048
[20,21]	0.425	[44]	0.42	[68]	0.191	[91]	0.348
[22]	0.234	[45]	0.37	[69]	0.172	[92]	Unknown
[23]	0.774	[46]	0.47	[70]	Unknown	[93]	0.369
[24]	1.045	[47]	Unknown	[71]	0.317	[94]	0.295
[25]	0.65	[48]	0.436	[72]	0.1	[95]	0.306
[26]	0.297	[49]	Unknown	[73]	0.595	[96]	Unknown
[27]	1.104	[50]	0.256	[74]	0.751	[97]	0.078
[28]	Unknown	[51]	0.19	[75]	0.2	[98]	0.288
[29]	Unknown	[52]	0.727	[76]	1.655	[99]	0.997
[30]	0.871	[54]	0.42	[77]	0.575	[100]	0.142
[31]	0.17	[55]	1.3	[78]	0.174	[101]	2.79
[32]	0.149	[56]	0.275	[79]	0.344	[102]	0.085
[33]	0.369	[57]	1.072	[80]	0.2	[103]	0.336
[34]	0.044	[58]	0.785	[81]	0.487	[104]	0.324
[35]	Unknown	[59]	0.672	[82]	0.189	[105]	0.83
[36]	0.231	[60]	Unknown	[83]	0.707		
[37]	0.332	[61]	0.197	[84]	0.281		

incentives to investors. These issues are discussed in recent papers and appropriate solutions are introduced [75,79,80,90,96,103].

6. Conclusion

HRESs are appropriate solution to meet the local loads in rural, remote, and special urban regions, e.g., universities and hospitals. Determining the optimal sizes of HRES's equipment is the major concern of researchers. HOMER software is a powerful tool used by many researchers around the world for optimal planning of HRES. According to the ability and widespread use of this software, the present paper reviewed those articles that have used HOMER for the optimal planning of HRES. The most remarkable conclusions from this review are listed as follows:

- The software has been used in developing countries more than other regions, especially in remote and rural areas.
- The software has been used for wide range of load from 0.626 kW to 2,213,000 kW.
- Many combinations of dispatchable/Non-dispatchable resources, storages and converters have been modeled in the articles.
- PV is the popular resource considered by many researchers.
- HRESs have been modeled in stand-alone mode more than grid connected mode.
- Wind speed, solar radiation, fuel price, component cost, and primary load are the most uncertain parameters referred to in the articles.

References

[1] Erdinc O, Uzunoglu M. Optimum design of hybrid renewable energy systems: overview of different approaches. Renew Sustain Energy Rev 2012;16:1412–25.
[2] Bajpai P, Dash V. Hybrid renewable energy systems for power generation in stand-alone applications: A review. Renew Sustain Energy Rev 2012;16:2926–39.
[3] Bernal-Agustín JL, Dufo-López R. Simulation and optimization of stand-alone hybrid renewable energy systems. Renew Sustain Energy Rev 2009;13:2111–8.
[4] Bhattacharyya SC. Review of alternative methodologies for analysing off-grid electricity supply. Renew Sustain Energy Rev 2012;16:677–94.
[5] Fathima AH, Palanisamy K. Optimization in microgrids with hybrid energy systems—a review. Renew Sustain Energy Rev 2015;45:431–46.
[6] Kaundinya DP, Balachandra P, Ravindranath NH. Grid-connected versus stand-alone energy systems for decentralized power—a review of literature. Renew Sustain Energy Rev 2009;13:2041–50.
[7] Mahesh A, Sandhu KS. Hybrid wind/photovoltaic energy system developments: critical review and findings. Renew Sustain Energy Rev 2015;52:1135–47.
[8] Shivarama Krishna K, Sathish Kumar K. A review on hybrid renewable energy systems. Renew Sustain Energy Rev 2015;52:907–16.
[9] Upadhyay S, Sharma MP. A review on configurations, control and sizing methodologies of hybrid energy systems. Renew Sustain Energy Rev 2014;38:47–63.
[10] 〈http://www.nrel/gov/HOMER〉.
[11] Lambert T, Gilman P, Lilienthal P. Micropower system modeling with homer. Integration of alternative sources of energy. John Wiley & Sons, Inc.; 2006. p. 379–418.
[12] Andrews CJ. Evaluating risk management strategies in resource planning. IEEE Trans Power Syst 1995;10:420–6.
[13] Haimes YY. Risk modeling, assessment, and management. John Wiley & Sons; 2005.
[14] Blackler T, Iqbal MT. Pre-feasibility study of wind power generation in Holyrood, Newfoundland. Renew Energy 2006;31:489–502.
[15] Khan MJ, Iqbal MT. Pre-feasibility study of stand-alone hybrid energy systems for applications in Newfoundland. Renew Energy 2005;30:835–54.
[16] Nfah EM, Ngundam JM, Vandenbergh M, Schmid J. Simulation of off-grid generation options for remote villages in Cameroon. Renew Energy 2008;33:1064–72.
[17] Weis TM, Ilinca A. The utility of energy storage to improve the economics of wind–diesel power plants in Canada. Renew Energy 2008;33:1544–57.
[18] Nandi SK, Ghosh HR. A wind–PV–battery hybrid power system at Sitakunda in Bangladesh. Energy Policy 2009;37:3659–64.
[19] Nfah EM, Ngundam JM. Feasibility of pico-hydro and photovoltaic hybrid power systems for remote villages in Cameroon. Renew Energy 2009;34:1445–50.
[20] Camblong H, Sarr J, Niang AT, Curea O, Alzola JA, Sylla EH, et al. Micro-grids project, Part 1: analysis of rural electrification with high content of renewable energy sources in Senegal. Renew Energy 2009;34:2141–50.
[21] Alzola JA, Vechiu I, Camblong H, Santos M, Sall M, Sow G. Microgrids project, Part 2: Design of an electrification kit with high content of renewable energy sources in Senegal. Renew Energy 2009;34:2151–9.
[22] Kenfack J, Neirac FP, Tatietse TT, Mayer D, Fogue M, Lejeune A. Microhydro-PV-hybrid system: Sizing a small hydro-PV-hybrid system for rural electrification in developing countries. Renew Energy 2009;34:2259–63.
[23] Ramos JS, Ramos HM. Sustainable application of renewable sources in water pumping systems: Optimized energy system configuration. Energy Policy 2009;37:633–43.
[24] Li C, Ge X, Zheng Y, Xu C, Ren Y, Song C, et al. Techno-economic feasibility study of autonomous hybrid wind/PV/battery power system for a household in Urumqi, China. Energy 2013;55:263–72.
[25] Karakoulidis K, Mavridis K, Bandekas DV, Adoniadis P, Potolias C, Vordos N. Techno-economic analysis of a stand-alone hybrid photovoltaic–diesel–battery-fuel cell power system. Renew Energy 2011;36:2238–44.
[26] Hrayshat ES. Techno-economic analysis of autonomous hybrid photovoltaic–diesel–battery system. Energy Sustain Dev 2009;13:143–50.

[27] Ashourian MH, Cherati SM, Mohd Zin AA, Niknam N, Mokhtar AS, Anwari M. Optimal green energy management for island resorts in Malaysia. Renew Energy 2013;51:36–45.
[28] Dalton GJ, Lockington DA, Baldock TE. Feasibility analysis of renewable energy supply options for a grid-connected large hotel. Renew Energy 2009;34:955–64.
[29] Iqbal MT. A feasibility study of a zero energy home in Newfoundland. Renew Energy 2004;29:277–89.
[30] Tzamalis G, Zoulias EI, Stamatakis E, Varkaraki E, Lois E, Zannikos F. Techno-economic analysis of an autonomous power system integrating hydrogen technology as energy storage medium. Renew Energy 2011;36:118–24.
[31] Shaahid SM, El-Amin I. Techno-economic evaluation of off-grid hybrid photovoltaic–diesel–battery power systems for rural electrification in Saudi Arabia—a way forward for sustainable development. Renew Sustain Energy Rev 2009;13:625–33.
[32] Shaahid SM, Elhadidy MA. Technical and economic assessment of grid-independent hybrid photovoltaic–diesel–battery power systems for commercial loads in desert environments. Renew Sustain Energy Rev 2007;11:1794–810.
[33] Asrari A, Ghasemi A, Javidi MH. Economic evaluation of hybrid renewable energy systems for rural electrification in Iran—a case study. Renew Sustain Energy Rev 2012;16:3123–30.
[34] Rehman S, El-Amin IM, Ahmad F, Shaahid SM, Al-Shehri AM, Bakhashwain JM, et al. Feasibility study of hybrid retrofits to an isolated off-grid diesel power plant. Renew Sustain Energy Rev 2007;11:635–53.
[35] Dalton GJ, Lockington DA, Baldock TE. Feasibility analysis of stand-alone renewable energy supply options for a large hotel. Renew Energy 2008;33:1475–90.
[36] Giatrakos GP, Tsoutsos TD, Mouchtaropoulos PG, Naxakis GD, Stavrakakis G. Sustainable energy planning based on a stand-alone hybrid renewableenergy/hydrogen power system: application in Karpathos island, Greece. Renew Energy 2009;34:2562–70.
[37] Bekele G, Palm B. Feasibility study for a standalone solar–wind-based hybrid energy system for application in Ethiopia. Appl Energy 2010;87:487–95.
[38] Hafez O, Bhattacharya K. Optimal planning and design of a renewable energy based supply system for microgrids. Renew Energy 2012;45:7–15.
[39] Rehman S, Mahbub Alam M, Meyer JP, Al-Hadhrami LM. Feasibility study of a wind–pv–diesel hybrid power system for a village. Renew Energy 2012;38:258–68.
[40] Saheb-Koussa D, Koussa M, Haddadi M, Belhamel M. Hybrid options analysis for power systems for rural electrification in Algeria. Energy Procedia 2011;6:750–8.
[41] Bekele G, Tadesse G. Feasibility study of small hydro/PV/wind hybrid system for off-grid rural electrification in Ethiopia. Appl Energy 2012;97:5–15.
[42] Türkay BE, Telli AY. Economic analysis of standalone and grid connected hybrid energy systems. Renew Energy 2011;36:1931–43.
[43] Saheb-Koussa D, Koussa M, Belhamel M, Haddadi M. Economic and environmental analysis for grid-connected hybrid photovoltaic–wind power system in the arid region. Energy Procedia 2011;6:361–70.
[44] Sen R, Bhattacharyya SC. Off-grid electricity generation with renewable energy technologies in India: an application of HOMER. Renew Energy 2014;62:388–98.
[45] Mondal AH, Denich M. Hybrid systems for decentralized power generation in Bangladesh. Energy Sustain Dev 2010;14:48–55.
[46] Nandi SK, Ghosh HR. Prospect of wind–PV-battery hybrid power system as an alternative to grid extension in Bangladesh. Energy 2010;35:3040–7.
[47] Dalton GJ, Lockington DA, Baldock TE. Case study feasibility analysis of renewable energy supply options for small to medium-sized tourist accommodations. Renew Energy 2009;34:1134–44.
[48] Ngan MS, Tan CW. Assessment of economic viability for PV/wind/diesel hybrid energy system in southern Peninsular Malaysia. Renew Sustain Energy Rev 2012;16:634–47.
[49] Aagreh Y, Al-Ghzawi A. Feasibility of utilizing renewable energy systems for a small hotel in Ajloun city, Jordan. Appl Energy 2013;103:25–31.
[50] Dursun B. Determination of the optimum hybrid renewable power generating systems for Kavakli campus of Kirklareli University, Turkey. Renew Sustain Energy Rev 2012;16:6183–90.
[51] Rehman S, Al-Hadhrami LM. Study of a solar PV–diesel–battery hybrid power system for a remotely located population near Rafha, Saudi Arabia. Energy 2010;35:4986–95.
[52] Beccali M, Brunone S, Cellura M, Franzitta V. Energy, economic and environmental analysis on RET-hydrogen systems in residential buildings. Renew Energy 2008;33:366–82.
[53] Shaahid SM, Elhadidy MA. Economic analysis of hybrid photovoltaic–diesel–battery power systems for residential loads in hot regions—a step to clean future. Renew Sustain Energy Rev 2008;12:488–503.
[54] Kumar Nandi S, Ranjan Ghosh H. Techno-economical analysis of off-grid hybrid systems at Kutubdia Island, Bangladesh. Energy Policy 2010;38:976–80.
[55] Prodromidis GN, Coutelieris FA. Simulation and optimization of a stand-alone power plant based on renewable energy sources. Int J Hydrog Energy 2010;35:10599–603.
[56] Lau KY, Yousof MFM, Arshad SNM, Anwari M, Yatim AHM. Performance analysis of hybrid photovoltaic/diesel energy system under Malaysian conditions. Energy 2010;35:3245–55.
[57] Silva SB, de Oliveira MAG, Severino MM. Economic evaluation and optimization of a photovoltaic–fuel cell–batteries hybrid system for use in the Brazilian Amazon. Energy Policy 2010;38:6713–23.
[58] Bajpai P, Kumar S, Kishore NK. Sizing optimization and analysis of a stand-alone WTG system using hybrid energy storage technologies. In: Proceedings of the 2010 international conference on energy and sustainable development: issues and strategies (ESD); 2010. p. 1–6.
[59] Bajpai P, Prakshan NP, Kishore NK. Renewable hybrid stand-alone telecom power system modeling and analysis. In: Proceedings of the 2009 IEEE region 10 conference on TENCON 2009; 2009. p. 1–6.
[60] Barsoum N, Wong Yew Y, Tan K, Goh WC. Modeling and cost simulation of stand-alone solar and biomass energy. In: Proceedings of the 2008 AICMS 08s Asia international conference on modeling & simulation; 2008. p. 1–6.
[61] Kusakana K, Munda JL, Jimoh AA. Feasibility study of a hybrid PV-micro hydro system for rural electrification. In: Proceedings of the AFRICON, 2009 (AFRICON '09); 2009. p. 1–5.
[62] Chun-Che F, Rattanongphisat W, Nayar C. A simulation study on the economic aspects of hybrid energy systems for remote islands in Thailand. In: TENCON'02 Proceedings 2002 IEEE region 10 conference on computers, communications, control and power engineering, vol. 3; 2002. p. 1966–9.
[63] Mizani S, Yazdani A. Design and operation of a remote microgrid. In: Proceedings of the 2009 IECON'09 35th annual conference of IEEE industrial electronics; 2009. p. 4299–304.
[64] Bahramara S, Jafari F, Rahimi-Kian A, Lesani H. Planning of a grid-connected smart micro-power system. In: Proceedings of the 2012 IEEE innovative smart grid technologies – Asia (ISGT Asia); 2012. p. 1–5.
[65] Sunderan P, Singh B, Mohamed NM, Husain NS. Techno-economic analysis of an off-grid photovoltaic natural gas power system for a university. In: Proceedings of the 2011 3rd international symposium & exhibition on sustainable energy & environment (ISESEE); 2011. p. 129–35.
[66] Anwari M, Rashid MIM, Hui HI, Yee TW, Wee CK. Photovoltaic power system simulation for small industry area. In: Proceedings of the 2011 international conference on electrical, control and computer engineering (INECCE); 2011. p. 263–68.
[67] Razak NAbA, bin Othman MM, Musirin I. Optimal sizing and operational strategy of hybrid renewable energy system using homer. In: Proceedings of the 2010 4th international power engineering and optimization conference (PEOCO); 2010. p. 495–501.
[68] Vuc G, Borlea I, Barbulescu C, Prostean O, Jigoria-oprea D, Neaga L. Optimal energy mix for a grid connected hybrid wind 2014; Photovoltaic generation system. In: Proceedings of the 2011 IEEE 3rd international symposium on exploitation of renewable energy sources (EXPRES); 2011. p. 129–32.
[69] Rui H, Low SH, Ufuk T, Chandy KM, Clarke CR. Optimal design of hybrid energy system with PV/wind turbine/storage: A case study. In: Proceedings of the 2011 IEEE international conference on smart grid communications (SmartGridComm); 2011. p. 511–6.
[70] Purwadi A, Haroen Y, Zamroni M, Heryana N, Saryanto A. Study of hybrid PV-diesel power generation system at Sebira Island–Kepulauan Seribu. In: Proceedings of the 2012 international conference on power engineering and renewable energy (ICPERE); 2012. p. 1–7.
[71] Rohani A, Mazlumi K, Kord H. Modeling of a hybrid power system for economic analysis and environmental impact in HOMER. In: Proceedings of the 2010 18th Iranian conference on electrical engineering (ICEE); 2010. p. 819–23.
[72] Kamel S, Dahl C. The economics of hybrid power systems for sustainable desert agriculture in Egypt. Energy 2005;30:1271–81.
[73] Ma T, Yang H, Lu L. A feasibility study of a stand-alone hybrid solar–wind–battery system for a remote island. Appl Energy 2014;121:149–58.
[74] Hiendro A, Kurnianto R, Rajagukguk M, Simanjuntak YM, Junaidi. Techno-economic analysis of photovoltaic/wind hybrid system for onshore/remote area in Indonesia. Energy 2013;59:652–7.
[75] Rohani G, Nour M. Techno-economical analysis of stand-alone hybrid renewable power system for Ras Musherib in United Arab Emirates. Energy 2014;64:828–41.
[76] Shiroudi A, Rashidi R, Gharehpetian GB, Mousavifar SA, Akbari Foroud A. Case study: simulation and optimization of photovoltaic-wind-battery hybrid energy system in Taleghan–Iran using homer software. J Renew Sustain Energy 2012;4.
[77] Rawat R, Chandel S. Simulation and optimization of solar photovoltaic–wind stand alone hybrid system in hilly terrain of India. Int J Renew Energy Res 2013;3:595–604.
[78] Kim H, Baek S, Park E, Chang HJ. Optimal green energy management in Jeju, South Korea – on-grid and off-grid electrification. Renew Energy 2014;69:123–33.
[79] Bhattacharyya SC. Mini-grid based electrification in Bangladesh: technical configuration and business analysis. Renew Energy 2015;75:745–61.
[80] Chmiel Z, Bhattacharyya SC. Analysis of off-grid electricity system at Isle of Eigg (Scotland): lessons for developing countries. Renew Energy 2015;81:578–88.
[81] Bhattarai PR, Thompson S. Optimizing an off-grid electrical system in Brochet, Manitoba, Canada. Renew Sustain Energy Rev 2016;53:709–19.
[82] Kusakana K, Vermaak HJ. Cost and performance evaluation of hydrokinetic-diesel hybrid systems. Energy Procedia 2014;61:2439–42.
[83] Hurtado E, Peñalvo-López E, Pérez-Navarro Á, Vargas C, Alfonso D. Optimization of a hybrid renewable system for high feasibility application in non-connected zones. Appl Energy 2015;155:308–14.

[84] Adaramola MS, Agelin-Chaab M, Paul SS. Analysis of hybrid energy systems for application in southern Ghana. Energy Conver Manag 2014;88:284–95.
[85] Bhattacharjee S, Acharya S. PV–wind hybrid power option for a low wind topography. Energy Conver Manag 2015;89:942–54.
[86] Baghdadi F, Mohammedi K, Diaf S, Behar O. Feasibility study and energy conversion analysis of stand-alone hybrid renewable energy system. Energy Conver Manag 2015;105:471–9.
[87] Kusakana K. Techno-economic analysis of off-grid hydrokinetic-based hybrid energy systems for onshore/remote area in South Africa. Energy 2014;68:947–57.
[88] Basir Khan MR, Jidin R, Pasupuleti J, Shaaya SA. Optimal combination of solar, wind, micro-hydro and diesel systems based on actual seasonal load profiles for a resort island in the South China Sea. Energy 2015;82:80–97.
[89] Lau KY, Tan CW, Yatim AHM. Photovoltaic systems for Malaysian islands: effects of interest rates, diesel prices and load sizes. Energy 2015;83:204–16.
[90] Khan EU, Martin AR. Optimization of hybrid renewable energy polygeneration system with membrane distillation for rural households in Bangladesh. Energy 2015;93(Part 1):1116–27.
[91] Adaramola MS, Paul SS, Oyewola OM. Assessment of decentralized hybrid PV solar-diesel power system for applications in Northern part of Nigeria. Energy Sustain Dev 2014;19:72–82.
[92] Ramli MAM, Hiendro A, Sedraoui K, Twaha S. Optimal sizing of grid-connected photovoltaic energy system in Saudi Arabia. Renew Energy 2015;75:489–95.
[93] Ramli MAM, Hiendro A, Twaha S. Economic analysis of PV/diesel hybrid system with flywheel energy storage. Renew Energy 2015;78:398–405.
[94] Chade D, Miklis T, Dvorak D. Feasibility study of wind-to-hydrogen system for Arctic remote locations – Grimsey island case study. Renew Energy 2015;76:204–11.
[95] Sarker S. Feasibility analysis of a renewable hybrid energy system with producer gas generator fulfilling remote household electricity demand in Southern Norway. Renew Energy 2016;87(Part 1):772–81.
[96] Mudasser M, Yiridoe EK, Corscadden K. Cost-benefit analysis of grid-connected wind–biogas hybrid energy production, by turbine capacity and site. Renew Energy 2015;80:573–82.
[97] Batas Bjelic I, Ciric RM. Optimal distributed generation planning at a local level – a review of Serbian renewable energy development. Renew Sustain Energy Rev 2014;39:79–86.
[98] Abdilahi AM, Mohd Yatim AH, Mustafa MW, Khalaf OT, Shumran AF, Mohamed Nor F. Feasibility study of renewable energy-based microgrid system in Somaliland's urban centers. Renew Sustain Energy Rev 2014;40:1048–59.
[99] Margaret Amutha W, Rajini V. Techno-economic evaluation of various hybrid power systems for rural telecom. Renew Sustain Energy Rev 2015;43:553–61.
[100] Rezzouk H, Mellit A. Feasibility study and sensitivity analysis of a stand-alone photovoltaic–diesel-battery hybrid energy system in the north of Algeria. Renew Sustain Energy Rev 2015;43:1134–50.
[101] Koussa DS, Koussa M. A feasibility and cost benefit prospection of grid connected hybrid power system (wind–photovoltaic) – case study: an Algerian coastal site. Renew Sustain Energy Rev 2015;50:628–42.
[102] Chauhan A, Saini RP. Renewable energy based off-grid rural electrification in Uttarakhand state of India: technology options, modelling method, barriers and recommendations. Renew Sustain Energy Rev 2015;51:662–81.
[103] Kolhe ML, KMIU Ranaweera, Gunawardana AGBS. Techno-economic sizing of off-grid hybrid renewable energy system for rural electrification in Sri Lanka. Sustain Energy Technol Assess 2015;11:53–64.
[104] Olatomiwa L, Mekhilef S, Ohunakin OS. Hybrid renewable power supply for rural health clinics (RHC) in six geo-political zones of Nigeria. Sustain Energy Technol Assess 2016;13:1–12.
[105] Kalinci Y, Hepbasli A, Dincer I. Techno-economic analysis of a stand-alone hybrid renewable energy system with hydrogen production and storage options. Int J Hydrog Energy 2015;40:7652–64.