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Review

Trends in Hybrid Renewable Energy System (HRES) Applications: A Review

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Abstract: Microgrids and hybrid renewable energy systems play a crucial role in today's energy transition. They enable local power generation and distribution, reducing dependence on large centralized infrastructures, can operate independently or connected to a grid, and can provide backup power, thus increasing system resilience. In addition, they combine multiple renewable energy sources, such as solar, wind, hydro, and biomass, to maximize the efficiency and reliability of the supply, and are also adaptable to location-specific conditions, taking advantage of locally available energy resources and reducing the need for energy imports. Moreover, they contribute to decarbonization goals by offering a cleaner and more sustainable alternative. In this article, a documentary review is presented on the interaction of Homer Pro software 3.16.2 (July 2023), used for the design of hybrid renewable energy systems (HRES), with other methods of optimization or sizing. Allusion is made to the type of architecture in the most prominent clean and fossil source configurations, the levelized cost, net annual cost, and maintenance and capital investment cost. A comparison is made among the works reported in the last five years regarding the use of this software tool, based on load demand, geographical area, renewable energy sources, fossil sources, and objective functions, applied to the educational, rural, and industrial sectors. It is shown that India is one of the countries that has reported the most number of HRES techno-economic environmental analysis works, and that the case studies have focused approximately 47% on rural areas, 20% on educational agencies, 14% on commerce and industry, and 29% on urban buildings.

Keywords: techno-economic analysis; Homer Pro; energy dispatch; hybrid energy system; sensitivity analysis

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1. Introduction

Currently, crude oil, coal, and natural gas are used as conventional energy sources to meet about 70% of the world's energy demand [1]. Energy demand is soaring in response to the world's growing economy and population. Consequently, the consumption of fossil fuels is also increasing significantly. Stocks of conventional fuels are limited and rapidly diminishing, requiring immediate action and long-term solutions to avoid a potential energy disaster in the coming years. In addition, fossil fuels are potential sources of dangerous emissions, such as greenhouse gases, which are major contributors to global warming [2].

The increase in these gases (especially CO_2), which has occurred since approximately 1990 from the excessive use of fossil fuels and electricity production [3], has caused an increase in droughts and seasonal mismatches (short winters, long summers) [4]; for this reason, the governments of a large number of countries have seen the need to take action to mitigate this problem, being fundamental to the sustainability of the environment, and have opened fiscal opportunities and incentives for energy investment, giving way to renewable energy as part of the solution to this global problem.

According to the World Economic Outlook 2020, some 940 million people (13% of the world's population) live without electricity [5], while it is estimated that the world population will reach approximately 9.3 billion by 2050, which is a rapid increase and is expected to increase global energy demand by 1.5 to 3 times [6].

Hybrid renewable energy systems (HRES) have become an option for stand-alone or grid-connected models [7]. This design of different renewable energies can temporarily harmonize the demand for electricity with the availability of renewable resources [8]. Researchers' interest in HRES has grown tremendously in the last two decades [9]. Furthermore, as a reaction to the accelerated growth of energy consumption, they have emerged as an option for reducing the harmful effects derived from the use of fossil fuels in traditional power plants and their harmful consequences for the natural environment, and with advances in power–electronics interfaces, a better integration of renewable energies has been achieved [10–12]. HRES are, therefore, generating important transformations in the paradigm of conventional energy systems. The traditional unidirectional flow of energy between power plants and users has evolved into a bidirectional flow, improving the energy transition [13,14].

Renewable energy sources (RES), such as solar, wind, and biomass, have been developed as an option with which to mitigate global warming, alleviate energy security issues, create new business opportunities, and provide other benefits. Thus, a hybrid system integrating multiple energy resources is more efficient and cost-effective [15].

Data have been reported in the literature on global electricity generation by subregions, for Latin America and the Caribbean, 1551 TWh (5.79%); North America, 4930 TWh (18.41%); Africa, 844 TWh (3.15%); the Middle East, 1265 TWh (4.72%); Asia and Australia, 12,919 TWh (48.25%); Europe 3871, TWh (14.46%); and the Commonwealth of Independent States, 1397 TWh (5.22%) [16]. That is why hybrid renewable energy systems play an important role in the energy transition process; in addition, the signing of the Paris Agreement in 2015 has encouraged nations to seek sustainable strategies to ensure energy security, techno-industrial development, decarbonization, and to reduce energy costs [17].

The integration of renewable energy storage devices and power electronic devices in hybrid systems has led to optimization processes using traditional, hybrid, or artificial intelligence methodologies to find better results for their design and cost analysis. In this analysis process, it is important to classify the objective functions of cost, air quality, technical aspects, supply reliability, grid autonomy, and whether it is an isolated configuration, grid connected, or both [18].

According to what has been provided in the research, the software tools are compared considering the input data (load requirement, details of supplies, details of components, among others) and output data (optimal sizing, evaluation of technological aspects environmental review, financial assessment, among others) required for an HRES analysis. Figure 1 shows the proportion of these requirements that these tools have. It can be seen that Homer Pro is an outstanding tool in certain aspects [19].

HOMER software performs three main functions: simulation, optimization, and sensitivity analysis. During the simulation, HOMER models the operation of a specific configuration of an energy microsystem for each hour of the year in order to determine its technical feasibility and life cycle cost. During the optimization process, HOMER evaluates multiple system configurations with the objective of finding the one that meets the technical requirements at the lowest possible cost over its lifetime. For the sensitivity analysis, HOMER performs various optimizations by varying the input assumptions to examine how uncertainty or changes in the input data may affect the results [20].

A hybrid electrification system in a remote area with multiple components is a complex system that requires careful planning. To produce a reliable and cost-effective system, the concept of optimal planning is critical. A renewable hybrid system is the most cost-effective way to store and utilize natural energy without interruption. Because of its reliability and cost-effectiveness in supplying energy to rural and remote areas, researchers have increasingly focused their attention on HRES integrated with ESS [21].

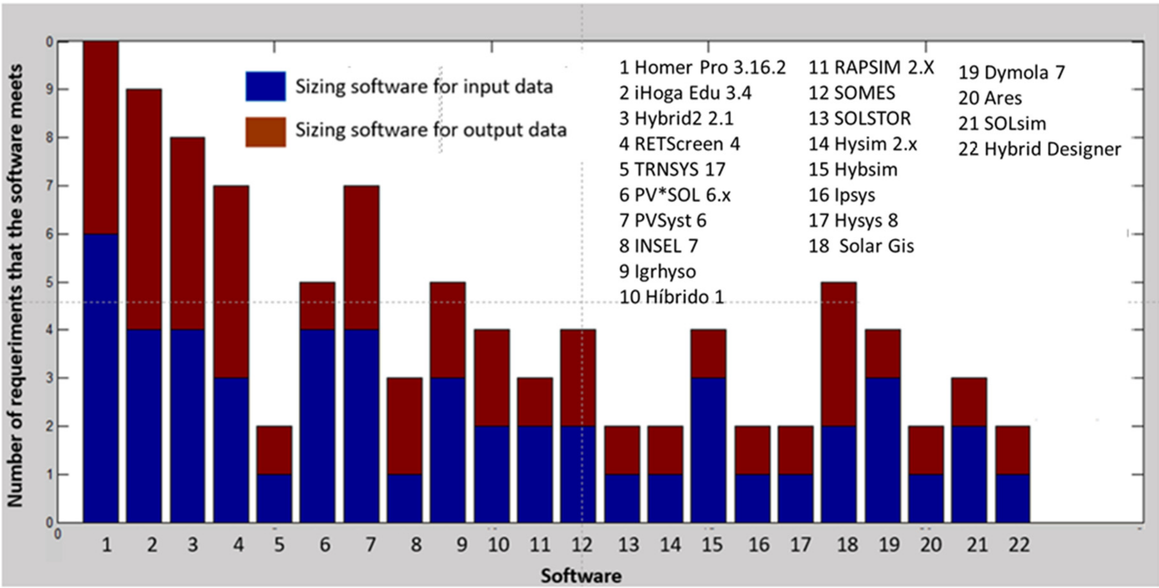

Figure 1. Comparative chart of minimum input data requirements for HRES sizing.

Several studies have examined resource utilization and techno-economic performance. The most common schematic diagram of an HRES plant is shown in Figure 2 below, in which the load is powered mainly by solar and wind generators, with the biogas generator serving as the backup. The battery ensures the balance of the energy flow in the system, as well as optimization [22].

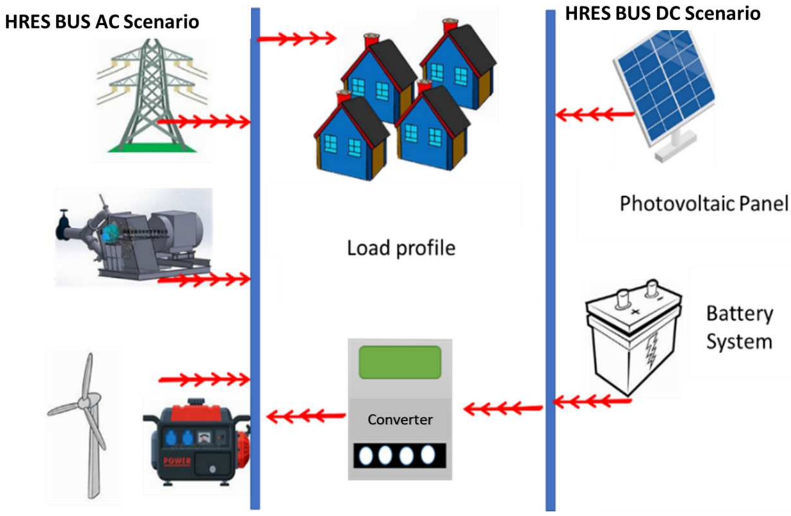

Figure 2. Schematic diagram of an HRES system.

As described, when building a hybrid renewable energy system, the most pointed elements to consider are cost and reliability; however, these variables are related to emissions and technological challenges. In addition, it is necessary to consider the different categories of target functions. Nowadays, most researchers focus on the central parameters in the study of HRES; these parameters are shown in Figure 3 [23].

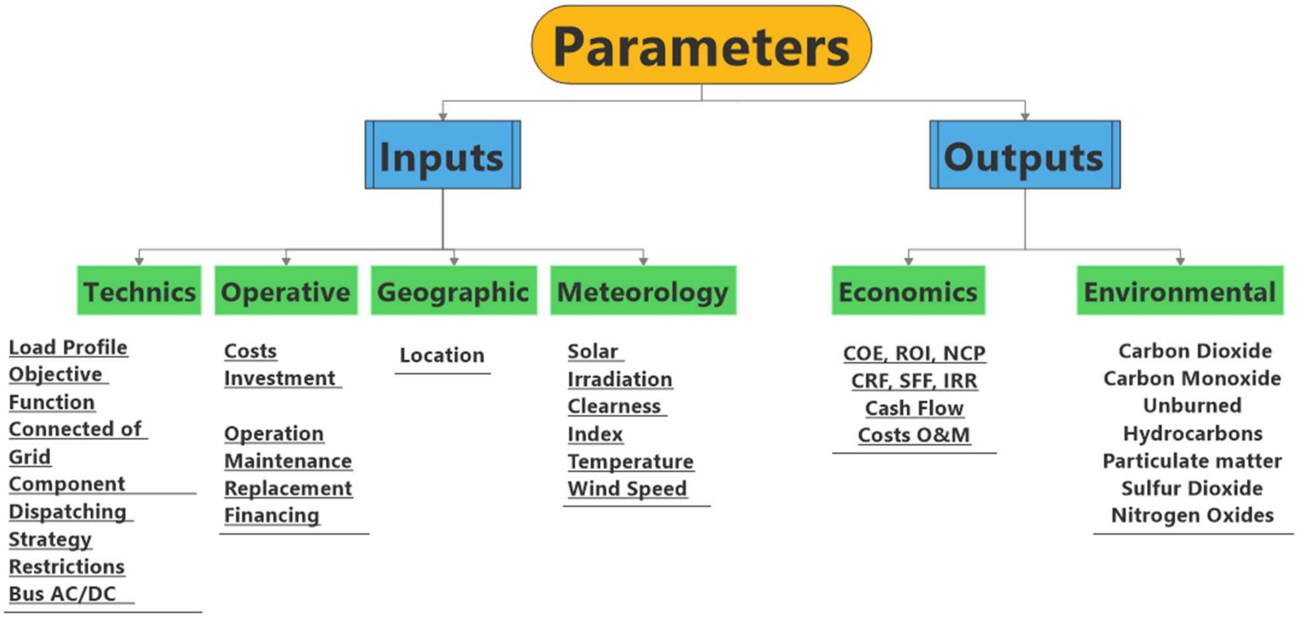

Figure 3. Schematic diagram of the parameters. Data are taken from the objective function block diagram in [24].

The financial targets include the net present cost (NPC), levelized cost of energy (LCOE), total annual cost (TAC), simple payback period (SPP), and internal rate of return (IRR or IRR). One study described the NPC for a diesel generator, where it was calculated by summing all the current capital, maintenance, replacement, recovery, and fuel consumption costs. The capital recovery factor is multiplied by the NPC over the annual energy consumption of the system to determine the LCOE. To calculate the TAC, annual construction and maintenance costs are combined with annual fuel prices. The SPP measures how long it will take for annual earnings to cover component capital expenditures. The discount rate at which the net present value (NPV) of all future cash flows is zero is known as the IRR [25,26].

Some of the most common measures and target functions for the reliability of an HRES system described by [27] are as follows:

1. Loss of power supply probability (LPSP).
2. Expected energy not supplied (EENS).
3. Loss of load expectation (LOLE).
4. Loss of energy expectation (LOEE).
5. System average interruption frequency index (SAIFI).
6. System average outage interruption duration index (SAIDI).
7. LPSP is the probability of an unmet load over the entire energy demand of a stand-alone or grid-connected hybrid renewable energy system.
8. EENS is the energy that a hybrid renewable energy system is supposed to provide.
9. LOLE is also known as loss of load probability.
10. LOLP is the number of hours per year that energy exceeds the capacity of the HRE generation system.
11. The LOEE represents the total energy not delivered by the grid-connected or stand-alone hybrid renewable energy system.

Estimating the hybrid system component sizes reduces system costs and increases system reliability. Oversizing can increase system cost, while under sizing can lead to power failure or inadequate power being supplied to the load [28].

The purpose of this document is to review the current state regarding the trend of hybrid renewable energy systems with the use of Homer pro software. This paper analyzes work related to sizing, optimization, and sensitivity analysis with algorithmic methods and the use of this software, and it seeks to obtain information on the trend of applications in industry, rural areas, commerce, and education.

2. Method

The techno-economic–environmental analysis of hybrid renewable energy systems is a fundamental part of the decision-making process for optimization and sizing. It evaluates parameters, such as technical characteristics, operating costs, maintenance, and meteorological and geographic data, in order to obtain comparative data that can deliver the high reliability of integrated systems, low costs in sizing or optimization, the capacity to cover the electrical load demand, and improve energy management or energy dispatch.

Recent works have mentioned the challenges faced by HRES in relation to energy management, system sizing and demand response [29]. A variety of researchers have performed HRES analyses with different methodologies, with various renewable energy configurations, in different areas or geographical zones, for cases of the integration of storage and backup components, stand-alone or grid-connected systems, and with various optimization methods, including MOPSO (Multi-Objective Particle Swarm Optimization), MOGA (Multi-Objective Genetic Algorithm), Fuzzy satisfaction, NSGA-II (Non-dominated Sorting Genetic Algorithm II), MOSADEA (Multi-Objective Shuffled Differential Evolution Algorithm), IFOA (Invasive Footprint Optimization Algorithm), NSGA-II (Non-dominated Sorting Genetic Algorithm II), and PSO (Particle Swarm Optimization), where certain objective functions are mentioned [18].

Sensitivity analysis studies have been reported, such as in Morocco, with variations in wind speed and solar radiation in the meteorological input, and the interest rate and fuel cost in the economic input, and have applied modeling and optimization algorithms, including HHO (Harris Hawks Optimization), AEFA (Adaptive Enhanced Firefly Algorithm), EO (Estimation of Distribution Algorithm), and energy management strategies [30].

The literature search and review were performed for different scientific social networks, such as academia.edu and researchGate.net; we also searched in journals published in Elsevier, IEEE, MDPI, and SpringerLink. This query was based on the keywords Homer Pro, techno-economic–environmental analysis, and Smart Grid with the HRES approach published from 2019 to 2023. Figure 4 shows the comparison of the results for the number of articles by keyword.

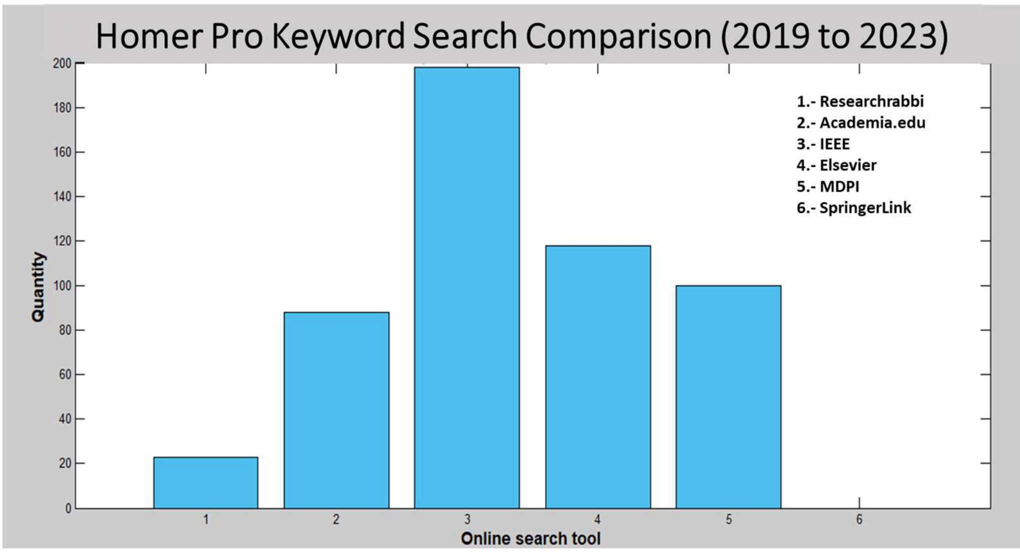

Figure 4. Comparative data for the quantity of works published from 2019 to 2023 for the keyword Homer Pro.

Figure 5 shows the block diagram of the methodology. The results were filtered by scientific research specialty in the area of energy, for 3074 articles, and were subsequently delimited by the period from 2019 to 2023, and to those that exclusively presented a techno-economic and environmental analysis with the Homer tool. Using the Google Scholar search engine and research social networks, such as Academia and ResearchGate, the filtered papers were downloaded, for 110 in total.

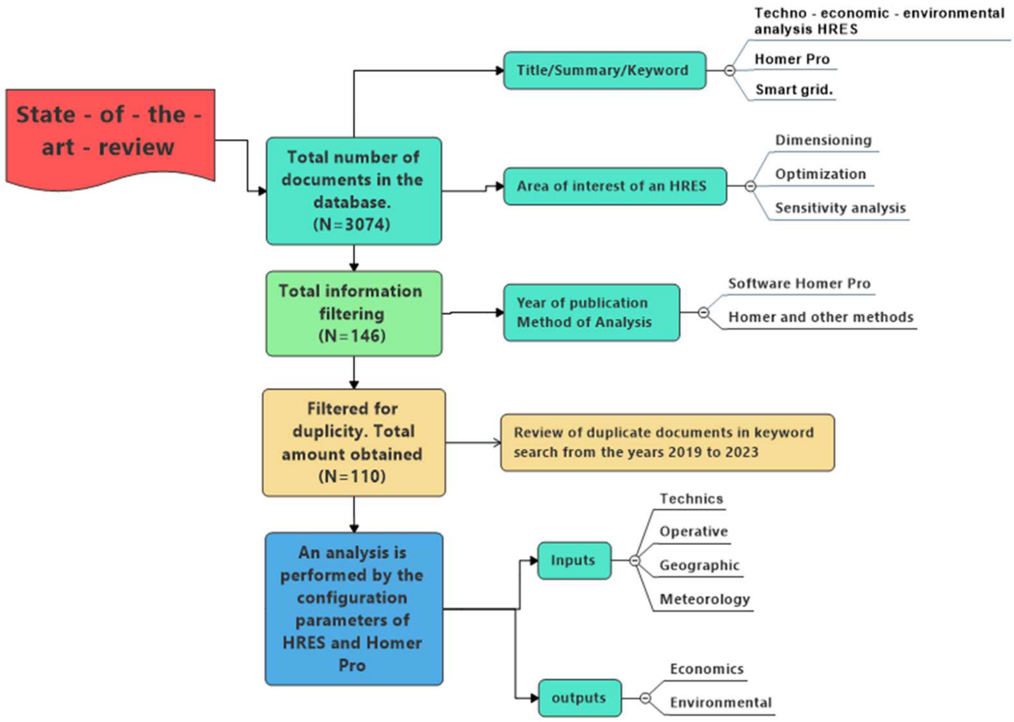

Figure 5. Block diagram of criteria for literature selection.

Subsequently, repeated articles were filtered out from the database obtained from Science Direct, Elsevier, IEEExplore, MDPI, and Springer Link. The 110 articles, which are examined in this HRES study with the use of Homer, are detailed by year in Table 1; considering these data as percentages, the publication behavior can be observed as a bar graph, as shown in Figure 6.

Table 1. Number of publications per year.

Year	Quantity	Percentage
2019	11	10%
2020	17	15%
2021	29	26%
2022	33	30%
2023	20	18%
Total	110	100%

The architectures of the technologies involved were identified for the photovoltaic panel (PV), wind turbine (WT), biomass (BM), diesel generator (DG), batteries source (BS), hydrogen tank (HT), biodiesel (BD), nuclear generator (NG), converter (Conv), hydrogen pump source (HPS), hydropower system (HS), grid system (GS), hydrogen reformer (HR), fuel cell (FC), and electrolyzed (EL).

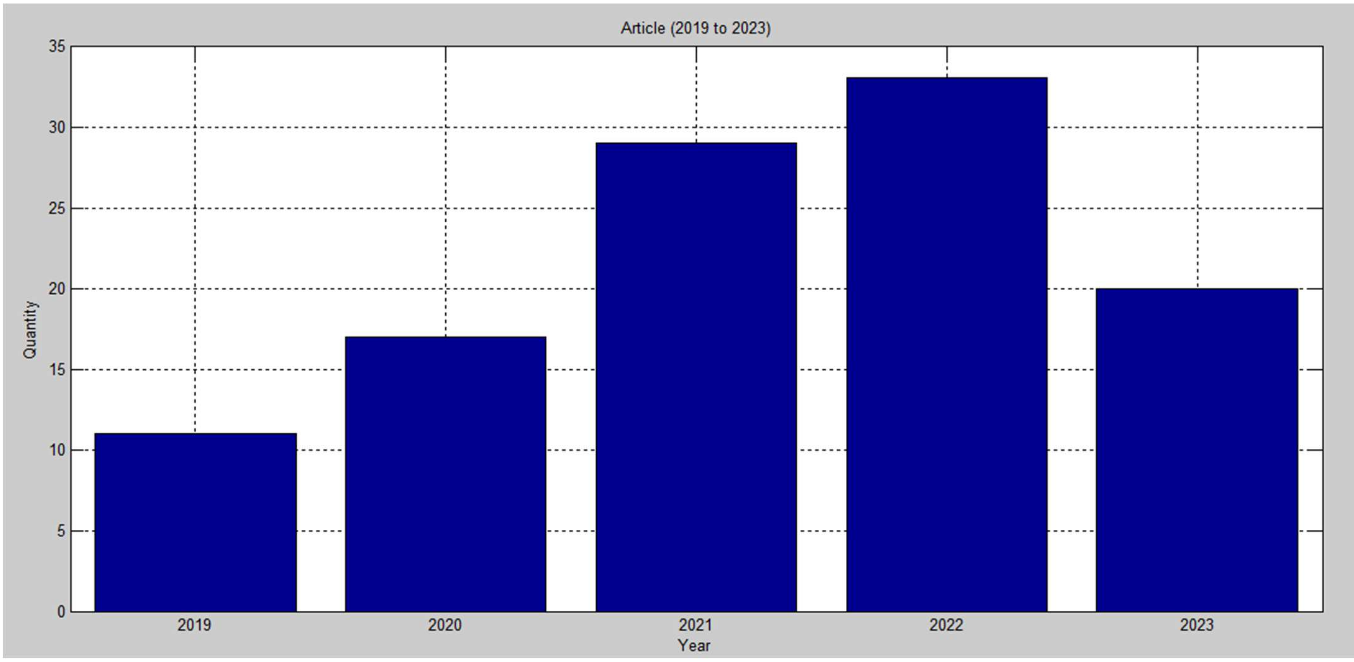

Figure 6. Comparative graph of articles of interest versus year of publication.

From the literature surveyed, the publications were organized by location, with 31 countries reporting works on sizing, optimization, and sensitivity analyses. Figure 7 shows the geographical description, and shows India as one of the countries where studies are being applied to these systems with the help of Homer Pro.

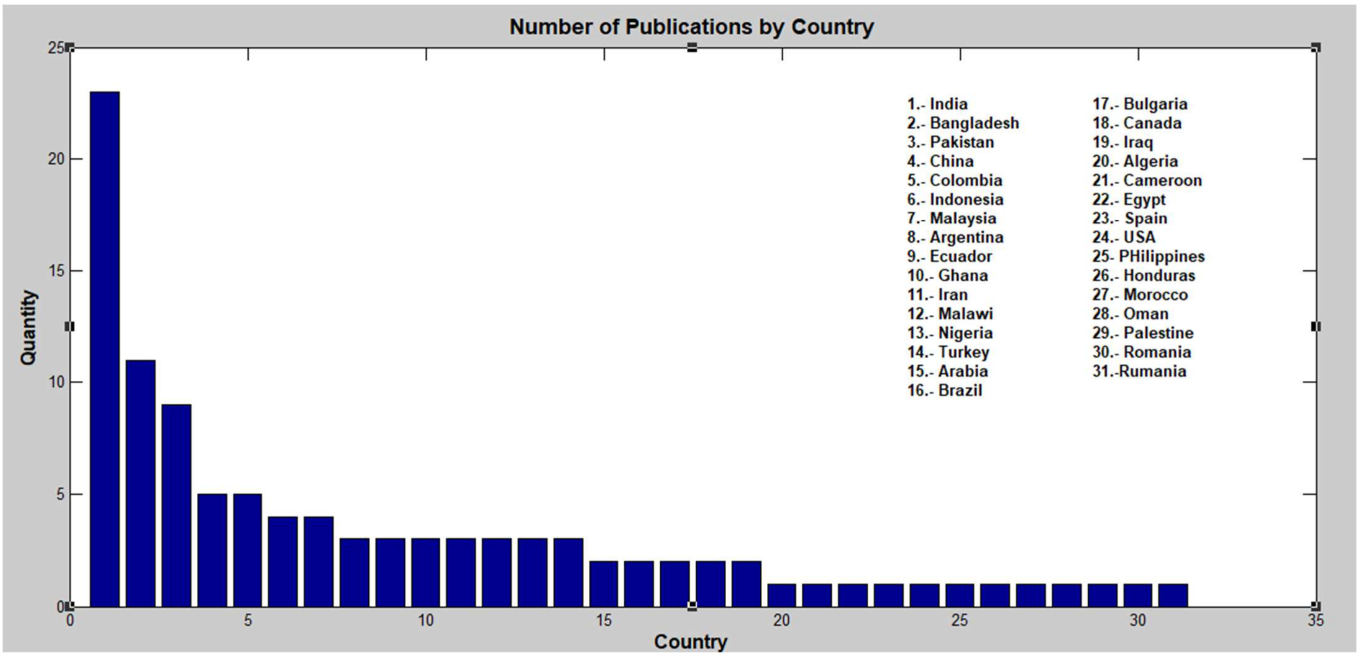

Figure 7. Comparative graph of the percentage of countries' interest in publishing on the subject.

According to the articles investigated, the general perception of the application of these systems is to cover the lack of energy for residential use in rural areas. Another specific application that represents an energy demand is in educational and industrial areas. Figure 8 shows the trend in applications of HRES systems. Given the important challenge of bringing electricity to remote and difficult-to-access areas, these systems are presented as an ideal solution for this purpose.

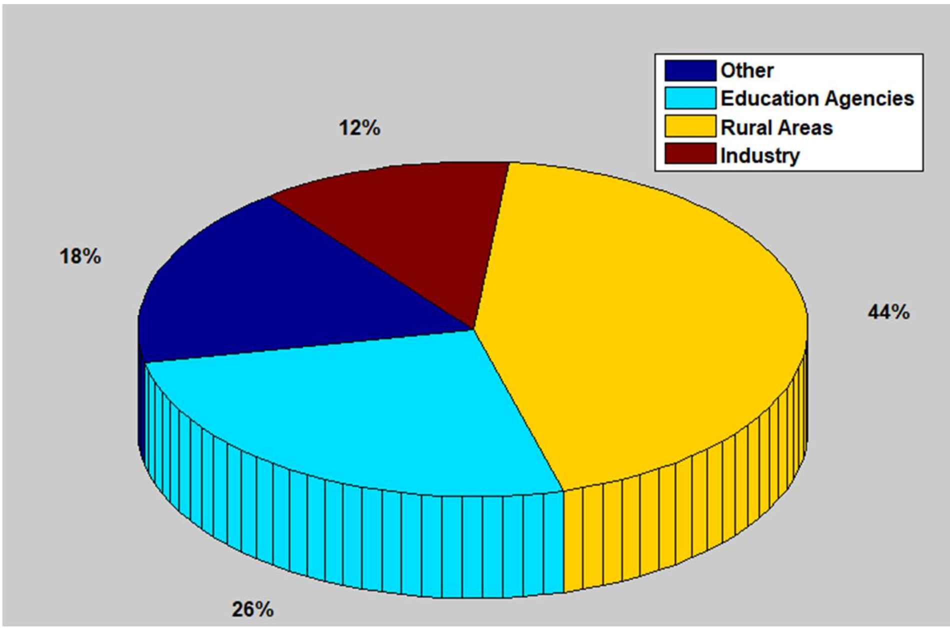

Figure 8. Applications for which HRES are most frequently used.

Another important point is to know the type of scenario regarding the hybrid system configurations; for this study, the information was ordered based on the most reported configurations. Figure 9 shows the percentage of each configuration in the case studies of the analyzed articles. The most used configuration is the one with solar energy, a diesel generator, battery bank, and converter (PV/DG/BS/CONV).

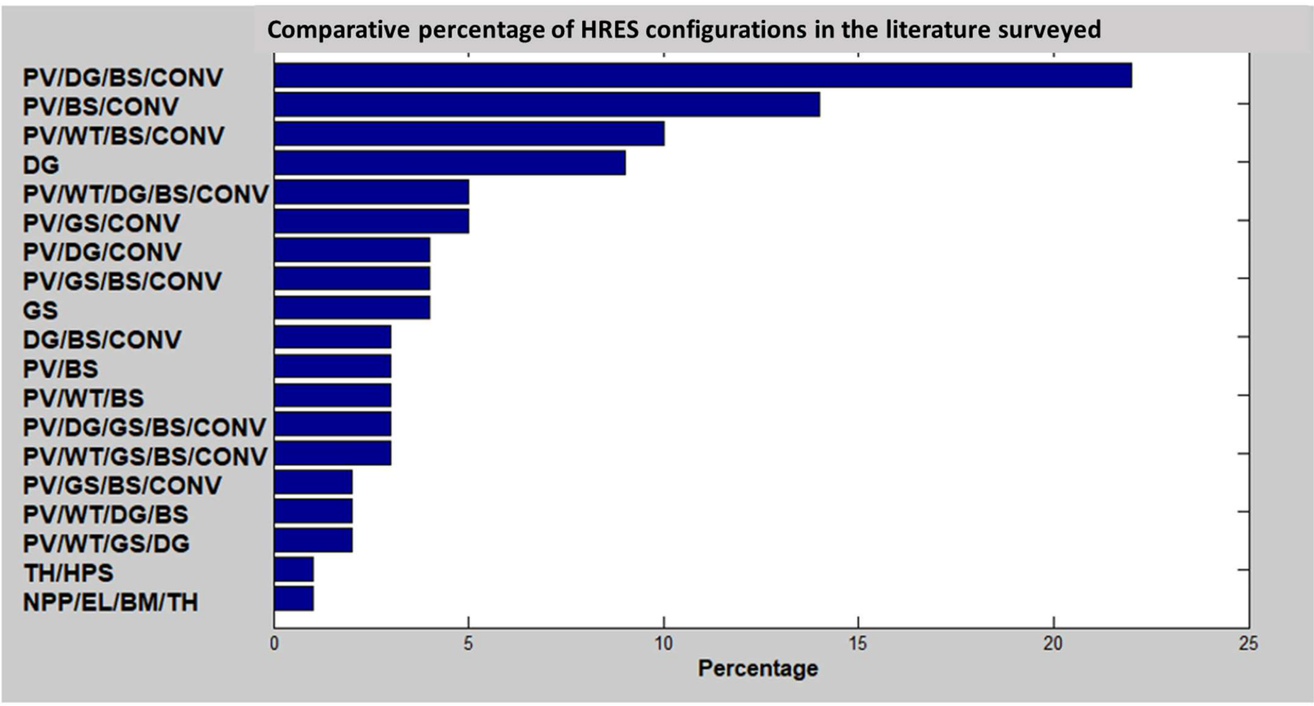

Figure 9. Comparative percentage of HRES configurations in the literature surveyed. PV: photovoltaic panels; WT: wind turbine; BM: biomass; DG: diesel generator; HT: hydrogen tank; NG: nuclear generator; BS: batteries; CONV: converter and inverter; GS: electricity grid system.

On the other hand, information was obtained about the storage, backup, and power electronics technologies used with these systems. Figure 10 shows a bar chart comparing the times which the use of these technologies was mentioned.

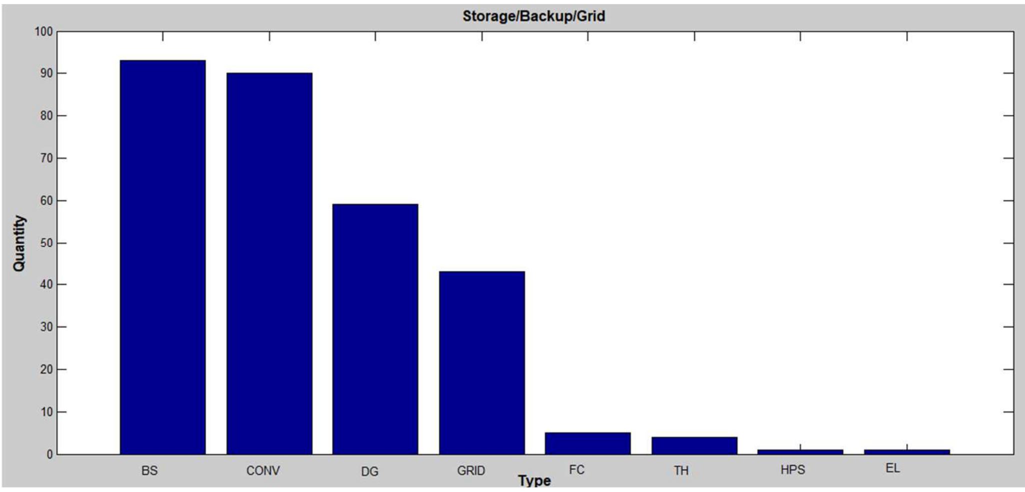

Figure 10. Percentage graph of backup systems used in the last 5 years. BS: batteries; CONV: converter; DG: diesel generator; Grid: electricity grid system; FC: fuel cell, TH: hydrogen tank; HPS: hydraulic pump system; EL: electrolyzer.

The Homer Pro financial indicators are determined relationships that are intended to be compared; they are born from the information that is collected from investments in a project, and allows one to approximate the current value of a project and its future projection. The financial measures allow one to know the financial situation of an entity, but should be categorized and taken into account only by those that can best evaluate them, since the use of many indicators negatively affects the functionality of the models, since it requires financial, administrative, and legal information about the entity that is not always available to users of the information. Therefore, it is necessary to consider the categories of indicators that allow one to evaluate the financial situation of companies, in order to have an idea about what are considered the vital signs of the financial health of a project, that is to say, about liquidity, profitability, and indebtedness.

3. Results

Table 2 shows the 22 publications reported chronologically from the last five years in which Homer Pro software was applied to cases involving educational institutions. The focus of most of these publications was a techno-economic analysis to reduce the cost of billing and the environmental impact. The dimensioning for rural schools was recorded to meet the academic need. The percentages of the configurations reported in the literature for this type of case study are shown in Figure 11. It can be seen that the technology combination of two renewable sources, such as solar and wind, used by academic institutions, most often tends to be the PV/DG/BS/CONV configuration.

As can be seen, studies on India have reported an outstanding amount of work related to their application to educational organizations; also, a high load demand of 48,194.08 kWh/d has been reported in Malaysia, and a minimum of 1.5 kWh/d. Homer Pro has been instrumental in these cases for the cost results (COE, NCP, O&M, and initial cost); their prices are tabulated in each country's currency and, in some cases, the cost-effective fraction is reported. The graph presented in Figure 12 shows 10 combinations of technologies used to cover the electric load demand, according to the investigated works. The highest demand is covered with the combination of CV/GS/CONV.

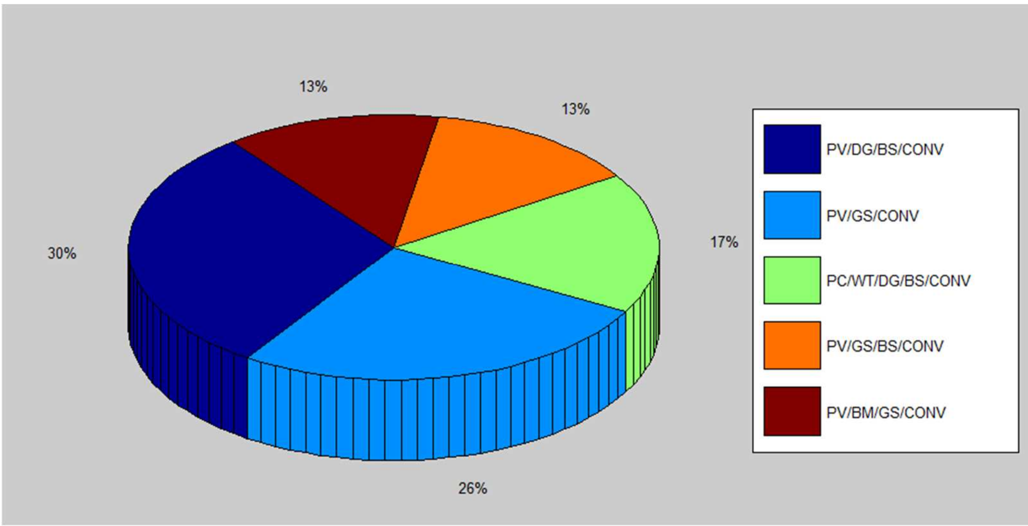

Figure 11. Percentage of combinations most reported in the studies investigated.

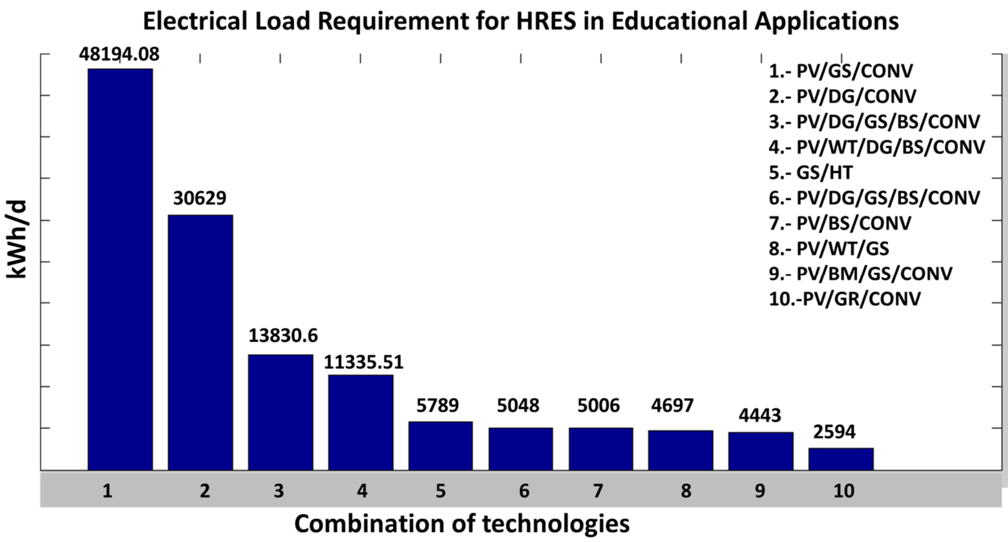

Figure 12. Graph of the 10 highest electrical load demands in the researched works.

In Table 3, there are 44 publications sorted by year; most of these publications performed an analysis for an off-grid system. The most mentioned configurations are PV/DG/BS/CONV, PV/BS/CONV, and PV/WT/DG/BS/CONV, as can be seen from Figure 13. The trend of HRES configurations was determined using Homer Pro. In this scenario, there is one paper that reported the highest demand of 24.61 kWh/d, in which the PV/HT/BS/CONV combination was used, see Figure 14. It is also possible to see the average daily load demand for the 10 systems, which reported the highest amounts for this application in rural areas. It can be seen that the combination of PV/WT/GR/BS/BS/CV was applied twice to cover this high demand.

Table 2. HRES and Homer Pro publications about applications used by educational institutions.

Ref	Year	Configurations	Electrical Data	Country	COE USD/kW·h	NPC USD	O&M USD/kW/a	C.I. USD	RF (%)
[31]	2019	PV/BM/GS/CONV PV/BM/GS/CONV PV/BM/BS/GS	4443.15 kWh/d 2005.11 kW	India	6.43 M 6.92 M 6.47 M	168 M 169 M 170 M	6.43 M 6.92 M 6.47 M	85 M 79.6 M 86.3 M	87 85 87
[32]	2019	PV1/PV2/BS/CONV PV1/PV2/GS/BS/CONV PV3/DG/BS/CONV PV4/DG/GS/BS/CONV	5005.95 kWh/d 967 kW	Bangladesh	0.216 0.203 0.157 0.153	5.11 M 5.39 M 3.62 M 3.63 M		3.3 M 2.21 M 825,625 850,125	
[33]	2019	PV/DG/CONV PV/DG/BS/CONV	30,629 kWh/d 2838.34 kW	Egypt	0.251 0.2	35.9 M 28.5 M		21.58 M	2.6 50.9
[34]	2019	PV/WT/DG/BS/CONV	1.5 kWh/d 0.47 kW	Argentina	4.65	597,256	3881	95,500	91.5
[35]	2020	PV/DG/BS/CONV PV/WT/DG/BS/CONV	6.87 kWh/d 3.3 kW	Bangladesh	0.125 0.216	6191 10,696		2450 7451	82.5 88.7
[36]	2020	PV/BS/GS/CONV PV/GS/CONV GS BS/GS/CONV PV/GS/BS/CONV PV/GS/CONV GS BS/GS/CONV	11.27 kWh/d 2.39 kW	India	3.03 3.60 7.50 9.87 3.16 3.71 7.5 9.87	21,166 27,238 39,883 52,495 214,695 277,002 398,935 524,952	3366 17,784 30,852 32,862 3418 18,037 30,852 32,869		99 60 0 0 99 58 0 0
[37]	2020	PV/GS/CONV PV/BS/GS/CONV GS BS/GS/CONV	48,194.08 kWh/d 3731.56 kW	Malaysia	0.179 0.181 0.434 0.438	56,633,560 56,941,060 97,535,030 98,479,890	1,576,152 1,756,303 7,629,846 76,680,556	36,485,045 35,929,942 0 456,394	
[38]	2021	PV/DG/GS/BS/CONV PV/DG/GS/BS/CONV	13,830.6 kWh/d 420.7 MWh/a 5048.2 MWh/a 1488.52 kW	India	4.37 2.3		234,514,437.4 229,285,321.1	525,520,706.4	17 17
[39]	2021	PV/WT/DG/BS/CONV PV/DG/BS/CONV PV/WT/BS PV/BS	11,335.51 kWh/d 1769.87 kW	India	0.1266 0.1268 0.1338 0.1338	28.94480 28.9811403 0.589540 30.601110	256,761.50 256,590.00 278,395.30 278,866.30	14.7531469 14.7989397 15.2021237 15.1876606	99.9 99.9 99.9 99.9
[40]	2021	PV/GS/CONV PV/GS/BS/CONV	77.6 kWh/d 20.06 kW	Indonesia	382.78 487.58	145 M 183 M	3.1 M 4.66 M	105 M 123 M	
[41]	2021	GS PV/GS WT/GS PV/WT/GS	4696.98 kWh/d 579.50 kW	India	6.35 5.57 5.4 4.71				

Table 2. *Cont.*

Ref	Year	Configurations	Electrical Data	Country	COE USD/kW·h	NPC USD	O&M USD/kW/a	C.I. USD	RF (%)
[42]	2021	PV/WT/BM/BS/CONV	256.33 kWh/d 71.37 kW	India	0.159	184,687	6154	106,015	
[43]	2022	PV/GS	45 kW	Morocco	0.41				
[44]	2022	PV/DG/BS/CONV	633 kW	Colombia	≈0.55	≈500,000	52,111	329,400	
[45]	2022	PV/WT/GS/BS/CONV PV/GS/BS/CONV WT/GS/BS/CONV	96.97 kWh/d 15.00 kW	Pakistan	0.0344 0.0384 0.0365	13,510 1427 3351		15,700 11,146 855	
[46]	2022	PV/DG/BS/CONV PV/DG/CONV DG DG/BS/CONV	95.32 kWh/d	Ecuador	0354 0.796 0.871 0.880	159,659.7 358,191.8 392,089.5 396,020.1	8752.753 26,703.06 29,943.07 30,049.22	46,508.33 12,987.5 5000 7558.333	
[47]	2022	PV/DG/BS/CONV PV/BS/CONV	1.823 kWh/d 1.821 kWh/d	Colombia	0.54 0.84	190 405	4974.51 2113.81	111,737.24 196,815.6	
[48]	2022	GS/PT PV/GS/PT/WT/mCHP/CONV PV/GS/PT/mCHP/CONV	643.00 kWh/d 69.00 Kw 5789 kWh/d 1588.86 kW	Romania	0.115	396,397	21,020		
[49]	2022	PV/BS/CONV PV/WT/GS/BS/CONV PV/DG/BS/CONV WT/BS/CONV WT/DG/BS/CONV PV/WT/DG/BS/CONV	11.27 kWh/d 2.39 kW	India	0.66 0.0895 0.439 5.98 0.716 0.434				
[50]	2023	DG/GS PV/DG/GS/CONV PV/BM/GS/CONV PV/WT/BM/GS/CONV BM/GS PV/GS/BS/CONV	334.750 kWh/d 23.70 kW	Malawi	0.01397 0.1244 0.09508 0.103 0.1054 0.1428	116,853 104,064 79,511 86,099 88,954 118,475	7752.3 5771.75 3985.9 4061.33 5701.53 4515.19	9500 24,137 24,319 29,858 10,000 55,949	
[51]	2023	PV/GS/CONV PV/DG1/DG2/BS1/BS2/CONV	200 kWh/d 52.95 kW	Iraq	0.058	77,680	1460	59,018	
[52]	2023	GS WT/GS PV/GS/CONV PV/WT/GS/CONV	2594 kWh/d 196.22 kW	Romania	0.2 0.201 0.184 0.185	2190 2200 2020 2030	189.362 188.836 165.954 165.428	0 15.000 100.000 115.000	

Table 3. HRES and Homer Pro Publications for rural applications.

Ref	Year	Configurations	Electrical Data	Country	COE USD/kW·h	NPC USD	O&M USD/kW/a	C.I. USD	RF (%)
[53]	2019	PV/WT/BS PV/BS WT/BS	50.50 kWh/d 13.9 kW 100.23 kWh/d 17.5 kW 17.53 kWh/d 5.0 kW	India	0.288 M 0.302 M 0.746 M	0.228 M 0.242 M 0.591 M	4994 5480 10880	0.166 M 0.176 M 0.450 M	
[54]	2019	PV/BS/CONV	10.28 kW 0.77 kW	Pakistan	0.199	9650.0	332.39	5353	
[55]	2019	DG/BS/CONV	84 kWh/d 14 kW	Malaysia	0.511		25,607	32,000	
[56]	2019	WT/GS WT/GS PV/GS WT/GS PV/GS	2687.54 kWh/d 394.98 kW 1521.37 kWh/d 233.4 kW	Bangladesh	0.037 0.43 0.006 0.053 0.071	1,877,869 2,049,735 1,850,822 1,690,032 1,884,952			89.4 89 68 96.8 73.5
[57]	2019	PV/DG/BS/CONV PV/DG/BS/CONV PV/DG/BS/CONV	30.00 kWh/d 5.05 kW	Argentina	0.345 0.307 0.017	32.880 29.179 120.750	1.536 1.330 1.777	19.524 17.615 100.000	88.2 90.6 74.4
[58]	2019	PV/WT/BS/CONV PV/BS/CONV	197.74 kWh/d 27.87 kW	Pakistan	0.137 0.15	127,345 140,048	4.522 5.640	68,882 67,132	100% 100%
[59]	2020	DG PV/DG/BS1 PV/DG/BS2 WT/DG/BS/ PV/WT/DG/BS	5416.6 kWh/d	USA	0.644 0.229 0.304 0.18 0.16	658,092 234,219 310,362 184,253 164,048		87,136	0 93 90.3 78.7 83.1
[60]	2020	PV/WT/DG/BS PV/DG/BS WT/DG/BS PV/WT/BS PV/BS WT/BS DG/BS DG	170 kWh/d	India	0.24932 0.3982 0.5296 0.1293 0.1240 0.7273 0.4266 0.6263	199,850.8 319,414.8 424,570.3 103,661.7 99,427.02 583,120.8 342,131.3 502,348.3	11,081.2 13,700.6 21,335.1 1635.06 1758.8 9893.3 25,224.1 37,969.2		64.8 57.8 28.8 100 100 100 0 0
[61]	2020	DG PV/DG/BS PV/BS DG DG/BS PV/DG PV/DG/BS PV/BS DG	63. 81 kWh/d 21.86 kW 166.92 kWh/d 22.81 kW 453 kWh/d 50.42 kW 722. 85 kWh/d 72.4 kW	Bangladesh	0.449 0.3 0.34	135,337 235,953 769,966	15,000 92,749 203,420	9309 11,078 91,413	

Table 3. *Cont.*

Ref	Year	Configurations	Electrical Data	Country	COE USD/kW·h	NPC USD	O&M USD/kW/a	C.I. USD	RF (%)
[62]	2020	DG1/DG2 PV/DG1/DG2/BS PV/WT/DG1/DG2/BS PV/WT/DG1/DG2/HT/BS	3853 kWh/d 421.89 kW	Nigeria	0.1055 0.106 0.119 0.271 0.921	1 M 100,799 1.14 M 2.58 M 8.70 M	383,820	91,339 183,377 112,686 344,390 464,975	
[63]	2020	PV/WT/BM/BG/EL/BS/FC/CONV PV/WT/BM/BG/EL/FC/CONV PV/WT/BM/BG/EL/BS/CONV PV/WT/BM/BG/EL/CONV	724.83 kWh/d 149.21 kW	India	0.163 0.425	890,013 856,013			
[64]	2020	PV/HT/BS/CONV	24,861 kWh/d 3000.9 kW	Cameroon	0.1666	26.39 M	11.7 M	14.1 M	
[65]	2020	GS	13.93 kWh/d 0.73 kW	Bulgaria:	0.1				
		PV/GS/BS/CONV	13.93 kWh/d 0.73 kW	Vidin Montana Vratsa Pleven Lovech Sofia Pernik Kyustendil Pazardzhik Gabrovo Veliko Ruse Stara Plovdiv Haskovo Yambol Kardzali Smolyan Silistra	0.218 0.211 0.215 0.211 0.212 0.220 0.210 0.212 0.212 0.216 0.313 0.195 0.217 0.217 0.212 0.217 0.213 0.219 0.209				67.8 68.8 68.1 68.7 68.6 68.8 68.9 68.6 68.8 68 68.6 71.1 68 68 68.7 68 68.5 67.7 69.1
		PV/WT/GS/BS/CONV	13.93 kWh/d 0.73 kW	Blagoevgrad Razlog Targovishte Shumen Sliven Burgas Varna Dobrich	0.212 0.219 0.198 0.197 0.201 0.216 0.196 0.198				75.4 67.7 78.6 79 78 79.4 77.3 78.6
[66]	2020	DG PV/DG/BS/CONV PV/WT/DG/BS/CONV	189.800 kWh/d 13.989 kW	Indonesia	0.1968 0.1154 0.1555	283,965 224,233 224,334	13.63 M 8.1 M 8.1 M		

Table 3. *Cont.*

Ref	Year	Configurations	Electrical Data	Country	COE USD/kW·h	NPC USD	O&M USD/kW/a	C.I. USD	RF (%)
[67]	2020	PV/BD/CONV PV/WT/BS/CONV WT/BS/CONV	3.00 kWh/d 0.36 kW	India	0.637 1.19 2.86	9009 16,830 40,470	85.11 188.23 589.91	7909 14,397 32,844	
[68]	2021	PV/BS PV/HPS PV/BS/PS WT/BS WT/HPS WT/BS/HPS PV/PV/WT/BS WT/HPS PV/WT/BS/HPS	255.6 kWh/d	China					
[69]	2021	PV/WT/DG/BS/CONV PV/DG/BS/CONV PV/WT/BS/CONV PV/BS/CONV DG	234.00 kWh/d 25.6 kW	Indonesia	0.276 0.284 0.322 0.326 0.499	414,951 426,966 482,468 488,567 749,792		152,664 144,142 200,129 196,824 24,500	
[70]	2021	PV/WT/BS PV/WT/FC PV/WT/DG PV/WT/BS/FC PV/WT/DG/BS PV/WT/DG/FC PV/WT/DG/BS/FC	13,68 kWh/d 2,16 kW	Iran	0.322 0.617 0.286 0.403 0.151 0.306 0.231	24,662 47,233 21,913 30,854 11,576 23,388 17,648		18,381 32,727 6895 24,170 6930 14,370 12,127	100 100 28.3 100 72.2 59.8 66.1
[71]	2021	PV/WT/DG/BS/CONV PV/WT/DG/BS/CONV PV/WT/DG/BS/CONV PV/WT/DG/BS/CONV PV/WT/DG/BS/CONV PV/WT/DG/BS/CONV	110 Kwh/d 11.04 kW	India	0.321 0.326 0.295 0.345 0.289 0.266	166,400 169,461 153,131 178,815 149,990 138,197	9692 9911 8732 10,305 8683 8085	41,100 41,335 40,253 45,603 37,736 33,674	
[72]	2021	PV/DG/BS/CS DG/BS/CS PV/BS/CS DG PV/DG/CONV	183.68 kWh/d 37.81 kW 40.38 kWh/d 6.75 kW	Ghana	0.399 0.523 0.782 0.902 0.998	296,552 388,358 580,170 669,394 740,800	20,569 35,458 16,252 70,992 71,516	109,846 66,500 435,646 25,000 91,650	40 0 100 0 0
[73]	2021	PV/WT/BS/CONV	30 kWh/d 1.6 kW	Iraq	0.117 0.118	14,800 14,988	541 539	8590 8810	
[74]	2021	PV/FC/HT/EL		China			133,000	2,180,000	
[75]	2021	PV/WT/BS/CONV PV/BS/CONV	197.74 kWh/d 27.84 kW	Pakistan	0.137 0.15	127,345 140,048	4522 5640	68,882 67,132	100 100
[76]	2021	PV/WT/BS CONV	11.27 kWh 2.39 kW	Turkey	0.521 0.495 0.420 0.409	94,705 89,992 76,542 74,436	974.3 929.51 809.71 800.06	48,750 46,150 38,350 36,700	100

Table 3. *Cont.*

Ref	Year	Configurations	Electrical Data	Country	COE USD/kW·h	NPC USD	O&M USD/kW/a	C.I. USD	RF (%)
[77]	2021	PV/GS/BS/CONV GS	542.60 kWh/d 58.17 kW	India	1.77 5.66	9.22 M 17 M	124,389 1.31 M	7.68 M 0	66.8 0
[78]	2021	PV/DG/BS/CONV WT/DG/BS/CONV PV/WT/DG/BS/CONV PV/WT/BS/CONV	346.43 kWh/d 68.9 kW 80.87 kWh/d 7.44 kW	India	0.223 0.410 0.223 0.361	449,574 827,473 449,573 727,327	89,659	208,988	91.6 1.06 91.6 100
[79]	2021	PV/WT/DG/BS/CONV WT/DG/BS/CONV PV/DG/BS/CONV DG WT/DG PV/WT/BS/CONV PV/DG/CONV PV/BS/CONV	135 kWh/d 18 kW	Iran	1.058 1.072 1.079 1.18 1.308 1.338 1.444 1.478	284,724 288,338 290,343 317,394 351,877 360,023 388,569 397,453	14,583 29,695 24,391 45,253 46,622 5309 44,187 4656	205,000 126,000 157,000 70,000 97,000 331,000 147,000 372,000	64 29 37 0 12 100 27 100
[80]	2021	PV/WT/BS/CONV PV/BS/CONV PV/BS/CONV	14.53 kW 8.09 kW 6.4 kW	Malawi	0.635 0.625 0.734	325,509 167,213 185,611	6219 3470 4170	228,700 113,200 120,700	
[81]	2021	PV/GS/BS/CONV	1.26 kWh/a 1537 kWh/a	Honduras Zambia	0.06 0.48	256,133 564,697	4.45 160	181,733 429,400	
[82]	2021	PV/WT/BS/CONV		Malesia		221,329.97	294,156		
[83]	2022	PV/DG/BS/CONV MH/DG	5.3 kWh/d 0.78 kW 5 kWh/d 0.78 kW	Indonesia	122,237 19,715		4675 M 2885 M		
[84]	2022	PV/DG/BS/CONV PV/WT/DG/BS/CONV PV/BS/CONV PV/WT/BS/CONV	22 kWh/d 2.5 kW	Iran	371 379 536 547	27,020 2728 33,972 34,652	333	13,582 14,492 23,900 24,525	
[85]	2022	PV/WT/BS/CONV PV/WT/DG/BS/CONV PV/WT/BS/HG/FC/CONV	980.76 kWh/d 99.02 kW	Pakistan	0.0446 0.0416 0.0489	206,161 192,353 226,420	2813 2913 2997	169,800 154,690 187,670	100 100
[86]	2022	PV/BS/CONV PV/DG/BS/CONV PV/WT/BS/CONV PV/WT/DG/BS/CONV	530.00 kWh/d 55.66 kW	Bangladesh	6476 10,900 11,909 13,355	478,008 565,690 569,914 658,652	336,463 336,463 319,453 377,786		
[87]	2022	PV/BS/CONV PV/DG/BS/CONV DG/BS/CONV PV/DG/CONV	3.40 kWh/d 1.26 kW	Nigeria	0.25 0.258 0.672 3.18	4003 4146 10,785 51,093			100 97.1 0 ---
[88]	2023	PV/DG/BS/CONV PV/BS/BV	11.27 Kwh/d 2.39 kW	Congo	0.11 0.89				

Table 3. *Cont.*

Ref	Year	Configurations	Electrical Data	Country	COE USD/kW·h	NPC USD	O&M USD/kW/a	C.I. USD	RF (%)
[89]	2023	PV/WT/GS	13.26 kWh/d 6.20 kW	Turkey	0.01 0.051	2540 8951		3379.7 8140.1	40 87
		PV/WT/DG/BS			0.198 0.346	23,372 40,858	341	1552.1 6312.5	20 91
[90]	2023	PV/DG/BS/CONV	50.5 kWh/d 9.28 kW	Colombia	0.442	104,270	1385	21,700	32
[91]	2023	PV/DG/BS PV/DG/BS PV/BS PV/WT/DG/BS/CONV PV/BS/CONV PV/DG/BS/CONV PV/WT/DG/BS/CONV PV/DG/BS/CONV PV/BS/CONV PV/BS/CONV PV/BS/CONV PV/DG/BS/CONV PV/BS/CONV PV/DG/BS/CONV PV/DG/BS/CONV PV/WT/DG/BD/CONV	1312.0 kWh/d 144.0 kW	Amdjarass Am Timan Ari Bagrai Biltine Bol Fada Goz Beida Koumra Lai Mao Massakory Massenya Mongo Moussoro Pala Arabia	0.389 0.367 0.380 0.416 0.38 0.389 0.406 0.375 0.370 0.373 0.397 0.379 0.375 0.373 0.388 0.369	2.52 M 2.38 M 2.46 M 2.69 M 2.46 M 2.52 M 2.63 M 2.43 M 2.40 M 2.42 M 2.57 M 2.45 M 2.43 M 2.42 M 2.51 M 2.39 M	439 2.40 0 646 0 439 692 2.10 0 0 0 1.8 0 2.10 439 2.40	1.63 M 1.53 M 1.6 M 1.7 M 1.61 M 1.63 M 1.63 M 1.8 M 1.56 M 1.56 M 1.71 M 1.59 M 1.55 M 1.56 M 1.63 M 1.54 M	99.2 100 100 97.6 100 99.2 97.3 100 100 100 100 100 100 100 99.2 100
[92]	2023	PV/WT/GS/BS/CONV	12,742.40 kWh/d 1821.05 kW 15,928 kWh/d 2276.28 kW	Indonesia	1.241 1.264	74.7 B 95.0 B		5.36 B 5.36 B	
[93]	2023	PV/DG/BS/CONV	21,589.04 kWh/d 3209.49 kW	India	9.77 9.86	995 M 1 B	128.41 M	679 M	90 90

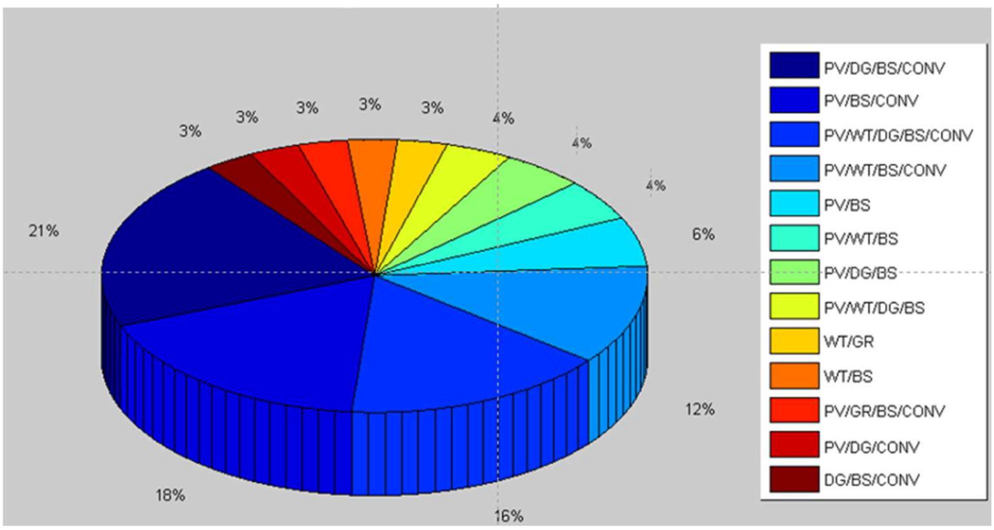

Figure 13. Percentage of combinations most reported in the studies investigated, educational applications.

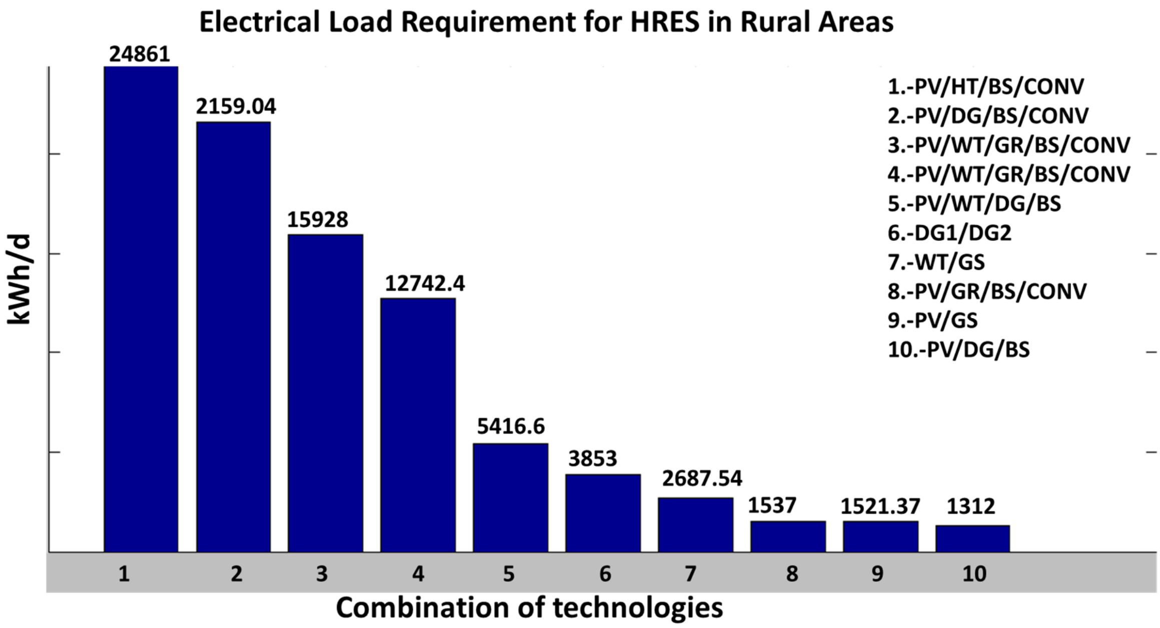

Figure 14. Graph of the 10 highest electrical load demands in the researched works (rural areas).

In Table 4, only publications with an HRES and Homer Pro analysis focused on industrial applications, such as water purification, cement plants, field irrigation, and commerce, were listed. For this case, the configurations that were reported most frequently in the analysis of the papers are as follows: PV/BS/CONV, PV/WT/BS/CONV, and WT/BS/CONV. The highest load demand was 27,523.34 kWh/d with an HRES technology of PV/BM/BS/CONV. Figure 15 shows a pie chart, where we can see the proportions of the applications of the technologies involved that covered the needs of industry or commerce. The average daily load demand is also described; for the cases in which the system had a greater supply than load, see Figure 16.

Table 4. HRES and Homer Pro Publications for industry applications.

Ref	Year	Configurations	Electrical Data	Country	COE USD/kW·h	NPC USD	O&M USD/kW/a	C.I. USD	RF (%)
[94]	2019	PV/WT/DG/BS/CONV	250 kWh/d 16 kW Max	Spain	0.404 0.408	473,013 560,247	17,993 23,448	243,000 260,000	96 92
[95]	2020	PV/BS/CONV PV/WT/BS/CONV WT/BS/CONV PV/BS/CONV PV/WT/BS/CONV WT/BS/CONV	32.43 kWh/d 4.44 kW 60.11 kWh/d 4.55 kW	Canada	0.425 0.585 1.03	64,969 89,512 157,555	47,932 70,563 133,474	1318 1466 1863	100 100 100
[96]	2020	PV/DG/BS/CONV PV/BS/CONV PV/DG/CONV DG DG/BS/CONV	300 kWh/d 43.98 kW 48.70 kWh/d 13.11 kW	Palestine	0.438 0.521 0.568 0.609 0.666	636,150 731,927 820,902 962,084 10.7 M			84% 87%
[97]	2021	PV/DG/BS/CONV PV/BS/CONV PV/DG/CONV	54.00 kWh/d 15.07 kW	India	0.655 0.813 0.364	165,137 197,152 91,676			
[98]	2022	HYD/BS HYD/HPS PV/HRY/BS PV/HYD/HPS PV/HPS	1500 kWh/d 205 kW	Ghana	0.06 0.10 0.14 0.16 0.31	509,202 787,523 1.14 M 1.34 M 2.53 M	18,318 32,185 22,606 32,296 85,700	272,391 849,298	
[99]	2022	PV/HYD/FC/CONV DG PV/BS/CONV PV/DG/CONV	432 MWh/d 816 MWh/d 888 MWh/d 432 MWh/d 744 MWh/d	Pakistan	0.266 0.248 0.248 0.49 0.248	575 M 1010 1100 540 M 923 M	40.8 M 61.1 M 66.1 M 32.5 M 55.6 M	14.8 M 175 M 190 M 94.5 M 159 M	
[100]	2022	PV/BM/BS/CONV	27,523.34 kWh/d 4602.2 kW	Nigeria	0.4128	116.73 M	2.17 M		
[101]	2022	PV/DG/BS/CONV PV/BS/CONV	1006.0 kWh/d 112.84 kW	Argentina	0.329 0.517	2.42 M 1.31 M		902,460 902,460	93.5 100
[102]	2022	PV/EL/FC/TH/CONV	47 kWh/d 5.4 kW	Argerlia	0.259	64,384	19.26	35,850	
[103]	2023	PV/DG/GS/BS/CONV	18 MW 34 MW 37 MW 18 MW 32 MW	Pakistan	0.24	519.6 M 981.4 M 1 B 519.6 M 894.8 M			

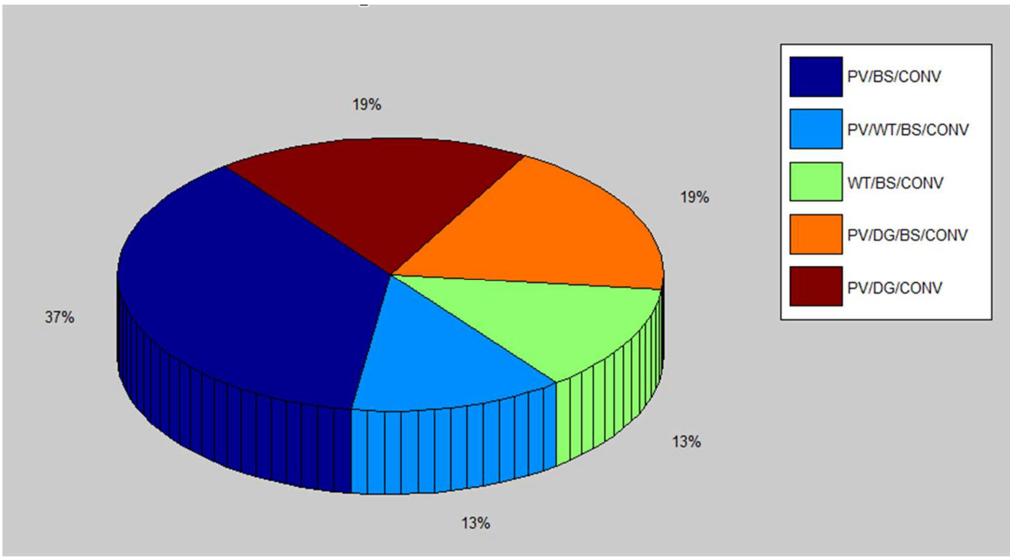

Figure 15. Percentage of combinations most reported in the studies investigated, rural areas.

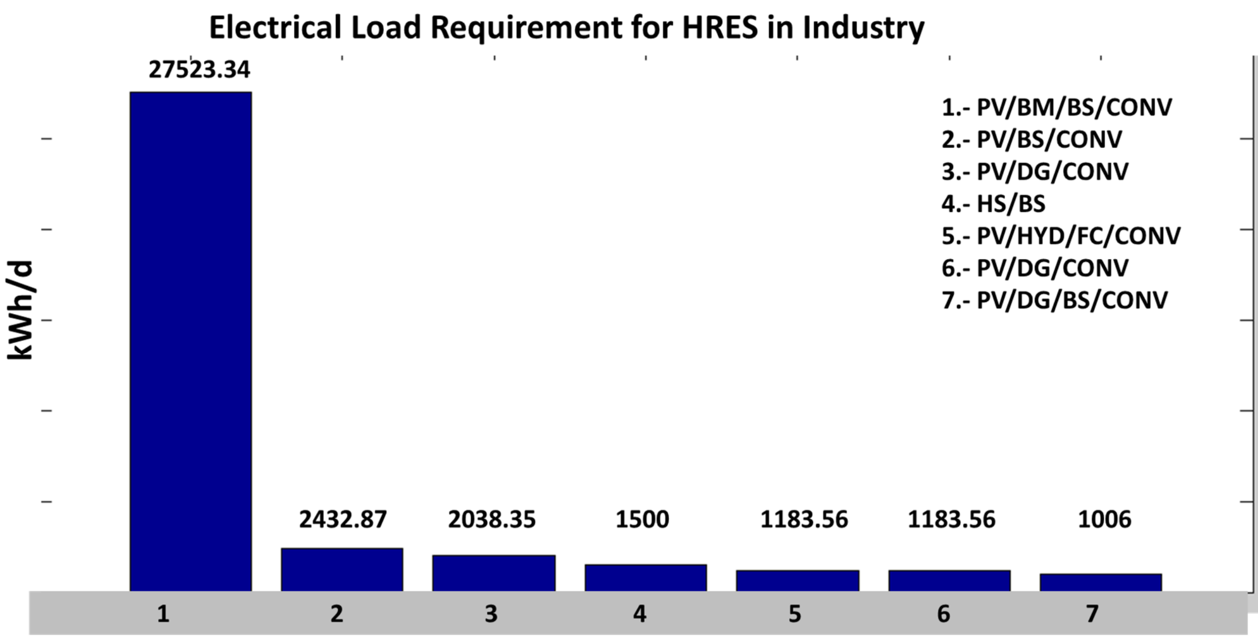

Figure 16. Requirement chart for electrical load demand (industry).

Table 5 shows articles on the simulation, sizing, and optimization of HRES with the use of Homer Pro for residential applications, lighting in squares, laboratories, health centers and others; the most reported configurations in these documents are PV/GS/BS/CONV, PV/DG/BS/CONV, PV/GS/CONV, and PV/WT/DG/BS/CONV. The importance of the grid power system energy source for this scenario is observable, as seen in Figure 17.

Table 5. HRES and Homer Pro Publications for general research applications in urban residential areas for optimization.

Ref	Year	Configurations	Electrical Data	Country	COE USD/kW·h	NPC USD	O&M USD/kW/a	C.I. USD	RF (%)
[104]	2020	PV/GS/CONV PV/WT/GS/CONV	823.25 kWh/d 106.14 kW	Brazil	0.469 0.548	3.74 4.38	161,253 163,626	567,023 116 M	55.6% 56.6%
[105]	2020	PV/WT/GS/CONV	24,000 kWh/h 1833.4 kW	Colombia	0.2	11.8 M	94,410	9.3 M	
[106]	2020	PV/GS	14,887 kWh/d 1310.47 kW	Bangladesh	5.3		15 M	23.2 M	
[107]	2021	PV/DG/BS/CONV PV/BS/CONV PV/GS/BS/CONV	112.49 kW/d 26.88 kW	Ecuador	0.83 0.67 0.85 1.72 0.09 0.32	183.52 319.69 406.16 824.71 44.74 271.91	12.51 13.92 15.06 30.65 3.74 10.55	37.32 157.05 230.2 466.44 1.03 148.64	
[108]	2021	PV/DG/BS/CONV	14,767.33 kWh/d 1294.20 kW	India	0.3965	309,432.90	70,361.33	255,549.5	
[109]	2021	PV/GS/BS/CONV	5333.93 kWh/d 514.05 kW	Brazil	0.1000 0.0999 0.0999	1.81 M 1.82 M 1.82 M			
[110]	2021	PV/WT/BS/CONV	50.77 kWh/d 10.45 kW	Canada	0.48	34,149.8	9578.77	23,064.72	100
[111]	2021	PV/WT/GS/BS/CONV	165.44 kWh/d 20.46 kW	Pakistan	0.3	180,026	18,116		
[112]	2021	PV/WT/GS/BS/CONV	13.93 kWh/d 0.73 kW	Bulgaria		20,800			69
[113]	2021	DG PV/DG/BS/CONV PV/WT/DG/BS/CONV	165.44 kWh/d 47.57 kW	Bangladesh	3.94 1.07 1.01	3.08 M 833,844 791,531	23,5621 44,235 39,866	31,800 261,991 276,164	0 86 88.5
[114]	2021	PV/DG//BS/CONV PV/WT/BS/CONV DG/BS/CONV PV/BS/CONV DG	23 kWh/d 3 kW	Nigeria	0.258 0.45 0.30 0.37 0.41			11,000	
[115]	2022	PV/GS/CONV PV/GS/BS/CONV GS/BS GS	24,961.08 kWh/d 1461.40 kW	Saudi Arabia	0.115 0.117 0.163 0.163	14.20 15.30 19.10 19.20	1 M	3 M	44.6 48.6 0 0
[116]	2022	PV/WT/DG/BM/EL/BS/FC/CONV	2426.44 kWh/d 405.71 k	India	0.138	1.58 M	182,039	940,932	
[117]	2022	DG/CONV PV/WT/DG/CONV	25.55 kWh/d 2.9 kW 105.00 kWh/d 8.03 kW	Ghana	0.487 0.39	150,486 118,788	22,292 12,658	59,986	

Table 5. *Cont.*

Ref	Year	Configurations	Electrical Data	Country	COE USD/kW·h	NPC USD	O&M USD/kW/a	C.I. USD	RF (%)
[118]	2022	PV/WT/DG/BS	21 kWh/d5.9 kW	Iraq	0.225	22,302	3448	10,520	100
[119]	2022	PV/WT/DG/BS/CONV	241,022.37 kWh/d 2105.55 kW 908.91 kWh/d 70.18 kW	Hungry	3.22		29,403		
[120]	2022	PV/DG/GS/BS/CONV PV/WT/GS/DG/BS/CONV1 WT/DG/GS/BS/CONV PV/WT/GS/DG/BS/CONV2	11.26 kWh/d 2.09 kW	Malaysia	0 0.377 0.051	7256.74 −299,762.16 −637,870.28 −642,247.46	−8689.23 −522,416.71	17,564 203,121.5	
[121]	2022	PV/GS/CONV	18.00 kWh/d	Turkey	0.562		38,310.04	10,645.88	
[122]	2022	PV/WT/BS/CONV PV/BS/CONV DG/BS/CONV PV/WT/DG/BS/CONV PV/DG/BS/CONV		China		129,765 211,083 3.84 M 140,836 227,898	≈2905.4 3383 3468 4182.6 4864.2	94,198 174,974 19,484 90,122 206,448	
[123]	2022	DG PV/DG/CONV PV/BS/CONV PV/DG/BS/CONV PV/WT/DG/BS/CONV PV/GS/BS/CONV	61.33 kWh/d 5.76 kW	India	58.55 44.77 10.99 9.29 7.94 1.65	16.9 M 13 M 3.18 M 2.69 M 2.3 M 1.65 M	280,320 1.52 M 2.5 M 2 M 1.71 M 1.97 M	83,200 188,512 0 5120 4672 ----	0 11.1 100 97.5 98.2 80.1
[124]	2022	PV/GS/CONV PV/HT/CONV	11.26 kWh/d 2.09 kW	India	6.4 4.15			44.4 100	
[125]	2022	PV/DG/DG1/DG2/BS/CONV	19,424.65 kWh/d 2734.84 kW	India	18.06	1.65 B	182.39 M	12.93 B	73
[126]	2022	DG PV/WT/DG/BS/CONV PV/DG/BS/CONV PV/WT/BS/CONV	843.29 kWh/d	Malawi	0.541 0.198 0.209 0358	515,071 188,814 198,969 340,809	23,628 4907 4774 3410	0 81,854 94,892 266,462	
[127]	2023	PV/GS/CONV	11.26 kWh/d	Ecuador	1.828				
[128]	2023	PV/HG/BM/BS PV/HG/BM/GS/BS		India	0.106			17 M	
[129]	2023	PV/WT/DG PV/WT/GT PV/BG PV/DG WT/NG HT/DG/EL PV/HT/DG PV/CONV PV/HT		China	0.164 7.89 0.094 0.178 0.142 0.07 0.087 0.67 0.092	10,015 244.9 M 20,184 98,911 87.7 M 92,441 179,741 5 B 3.2 M			

Table 5. *Cont.*

Ref	Year	Configurations	Electrical Data	Country	COE USD/kW·h	NPC USD	O&M USD/kW/a	C.I. USD	RF (%)
[130]	2023	PV/WT/DG/BM/BS/CONV	300 kWh/d 12.5 kW	Iraq	0.1192		32.01	2875	
[131]	2023	PV/GS/BS/CONV	2139.7 kWh/d 163.44 kW	Oman					
[132]	2023	PV/DG/BS/HT /CONV/HR PV/DG/BS/HT /CONV/EL/HR PV/DG/BS/HT /CONV/HR/HT PV/DG/BS/HT /CONV/EL/HR/HT PV/WT/DG/BS /HT/CONV/HR PV/WT/DG/BS /HT/CONV/HR	2426.45 kWh/d 405.71 kW	Bangladesh	0.271 0.273 0.273 0.275 0.278	3.11 M 3.13 M 3.13 M 3.15 M 3.18 M	62,297 62,327 62,307 61,855 60,899	2.3 M 2.32 M 2.33 M 2.35 M 2.41 M	
[133]	2023	PV/GS/BS/CONV	200 kWh/d 21.9122 kW	Saudi Arabia	0.00257	10.4 M	−8.37 M	108 M	88.6
[134]	2023	PV/DG/BS	3250 kWh/d 240 kW 570 kWh/d 71.25 kW	Bangladesh	0.0445 0.0291 0.0198 0.0512 0.0449 0.283	3,464,268 2,301,523 1,539,620 3,717,828 3,463,741 10,354,990			80.1 79.5 78.2 80.9 76.7 78.1
[135]	2023	PV/WT/GS/BS/CONV PV/GS/BS/CONV PV/WT/DG/GS/BS/CONV PV/DG/GS/BS/CONV PV/BS/CONV	1940 kWh/d 424.80 kW 645 kWh/d 147.70 kW	Bangladesh	0.0714 0.0720 0.0812 0.082 0.269	1.82 M 1.81 M 1.81 M 1.81 M 5.56 M	815,883 788,618 569,575 588,011 1.81 M		54.3 54.2 42.7 42.3 100

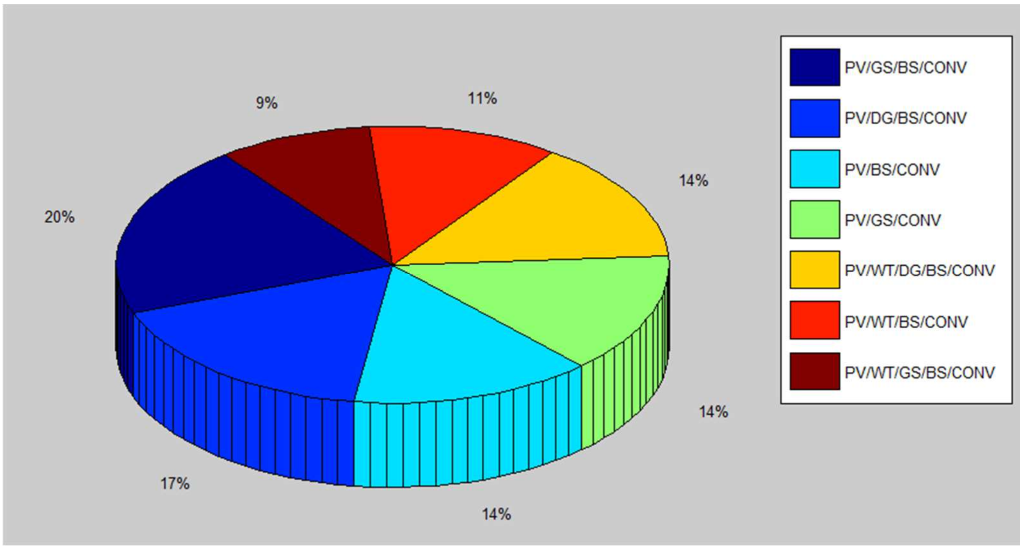

Figure 17. Percentage of combinations most reported in the studies investigated, industry.

On the other hand, the maximum load demand recorded was 24,022.37 kWh/d, and its renewable energy and fossil source arrangement was PV/WT/DG/BS/CONV. The countries that reported the highest number of publications were India and Bangladesh, see Figure 18.

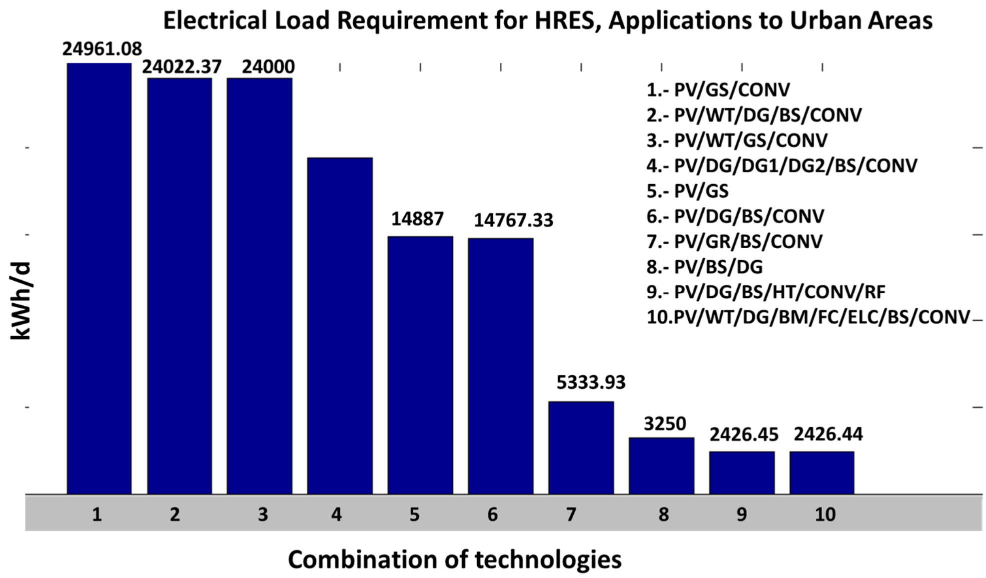

Figure 18. Requirement chart for electrical load demand (urban areas).

The predominant objective function of the researched literature was the cost of energy (COE) or levelized cost of energy (LCOE). The cost of electricity can be applied using the net present cost (NPC). Figure 19 visualizes the trend of four economic parameters in an operation analysis with Homer, for this review of the last 5 years.

In Table 6, a summary of the equations that Homer Pro integrates for the calculation of financial indicators, such as the net annual cost and the levelized cost of energy, are shown.

The net present cost (NPC or NPV (net present value)) of an HRES system is the present value of all capital expenditures (Capex), the maintenance and operating expenses (Opex) of the system over the life of the project, plus the present value of imported energy (if the HRES is grid-connected), minus the present value of all exported energy over the life of the project. The NPC operation is the energy balance with the grid in the grid-connected mode, or the fuel consumption cost in the stand-alone mode. The equations for calculating NPC are shown below.

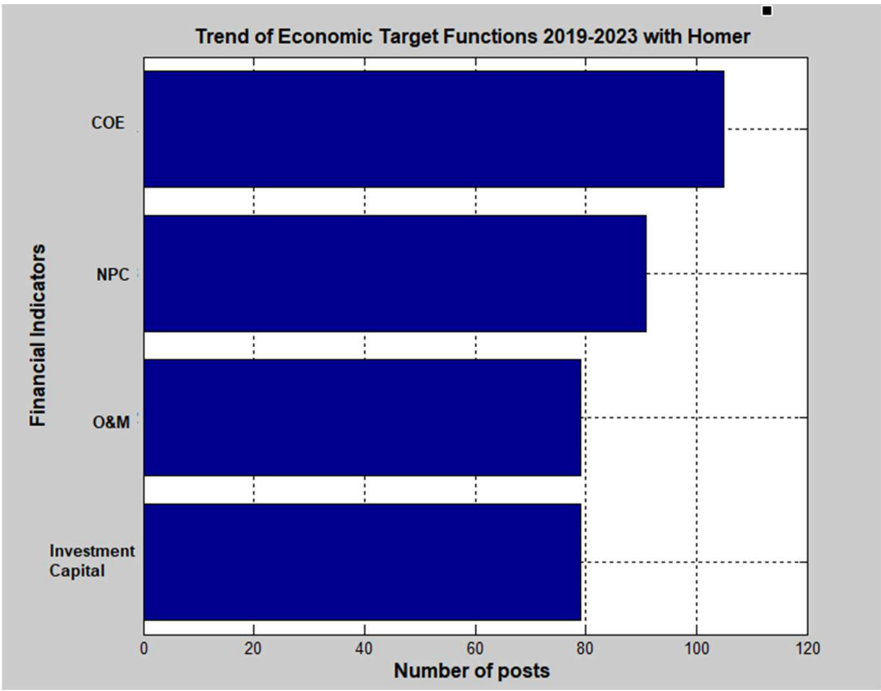

Figure 19. Financial indicators as objective functions in the literature reviewed.

Table 6. Summary of financial indicator equations in Homer Pro [136].

Financial Indicators	Equation	Description
Net Present Cost	$NPC_t = NPC_C + NPC_O$	Where NPC_C = Net Present Cost of Components NPC_O = Net Present Cost of Operation PC_C = Caplex Present Cost PC_b = Present Cost Opex PC_m = Maintenance Cost PC_r = Replacement Cost C_m = Fixed Annual Maintenance Cost C_r = Annual Fixed Replacement Cost M = Component Life Time i = Interest Rate n = Project Life Time r = Real Interest Rate, after taking into account the inflation rate, over the interest rate of the fuel and energy supply cost C_0 = Annual Cost Connected or off − grid RP = Retail Price FiT = Feed Rate P_i = Power Imported to the Grid P_e = Power for Export to Grid FC = Fuel Cost P_g = Power Output $T = 8750h$, represents the annual operation of the system
	$NPC_C = PC_C + PC_b$	
	$PC_b = PC_m + PC_r$	
	$PC_r = C_m \frac{(1+i)^M - 1}{i(1+i)^M}$	
	$PC_r = C_r \sum_{t=1}^{t<M} \frac{1}{(1+i)^t}$	
	$NPC_0 = \frac{(1+r)^n - 1}{r(1+r)^n}$	
	$r = \frac{i-e}{1+e}$	
	$C_0 \sum_{t=1}^{T} (RP(t).P_i(t) - FiT(t).P_e(t))$	
	$C_0 \sum_{t=1}^{T} (FC(t).P_g(t))$	
Levelized cost of energy	$LCOE = \frac{NPC_t.CRF}{E_1}$	Where CRF = Capital Recovery Factor E_1 = Annual Energy Demand d = Discount Rate
	$CRF = \frac{d(1+d)^n}{(1+d)^n - 1}$	

The levelized cost of energy (LCOE) is the ratio of annual net payment to annual net electricity consumption, calculated based on the electricity component data and NPC.

The cost of energy (COE), as already mentioned, is an important metric for the economic study of renewable energy projects. Figure 20 shows the average of this value for different countries where more techno-economic–environmental analysis documents have been reported.

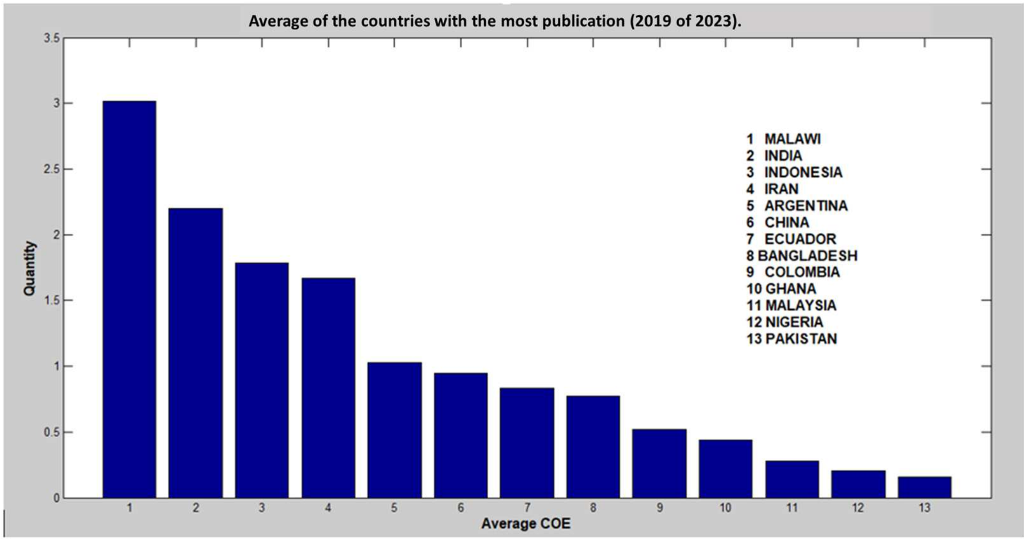

Figure 20. Graph of energy costs averages for countries with more reported publications.

4. Energy Dispatch Strategies

A dispatch strategy is a set of rules that are used to control generator and storage bank operation whenever there is insufficient renewable energy to supply the load.

Load following: Under a cyclic load strategy, whenever a generator is required, it runs at full capacity and the surplus energy charges the battery bank. Cyclic charging (CC) tends to be optimal in systems with little or no renewable energy.

Cycle load (LF): When a generator needs to serve as the primary load, it operates at full power. Surpluses are directed to lower priority targets, such as deferral charging, charging the storage bank, and serving the electrolyze.

Homer Pro MATLAB Link (ML): Homer Pro MATLAB Link allows you to write your own dispatch algorithm for Homer Pro using MATLAB. Homer interacts with MATLAB R2023a software to execute MATLAB functions during simulation.

Combined dispatch: Uses the cycle load dispatch strategy when the net load is low and the following load dispatch strategy when the net load is high.

Predictive dispatch: Homer Pro knows the upcoming electrical and thermal demand, as well as the upcoming availability of solar and wind resources. It will often produce results with lower system operating costs compared to other dispatch strategies. Homer Predictive has a 48 h forecast and uses this knowledge to operate batteries economically.

Generator order: Homer Pro follows a defined order of generator combinations and uses the first combination in a list that meets the operating capacity. It only supports systems with generators, PV, wind turbines, a converter, and/or storage components. It does not run systems that include thermal or CHP components, hydrogen components, the grid, the hydroelectric component, or the hydro kinetic component [137].

Table 7 shows the type of dispatch and sensitivity analyses that are mentioned in the literature; the main uses are noted as cycle load and load following. On the other hand, the literature reports little information on comparative dispatch analysis between load following and cycle loading with Homer Matlab Link.

Table 7. Reported sensitization analyses.

Ref.	Year	Dispatch	Sensitivity Analysis
[31]	2019	LF	Based on wind and irradiation profiles.
[94]	2019	LF	To study the impact of diesel price only on the optimal system design and also on the TNPC. Interest rate of 6%. Five values were considered: 0.31 USD/L, 0.50 USD/L, 0.7 USD/L, 0.8 USD/L, and 0.9 USD/L.
[56]	2019	CC	The model defined the results according to the initial costs, NPC, COE, capacity shortage, dispatch types, and penetration and fraction of renewables.
[59]	2020	CC	The life cycle cost (LCC). It consists of all maintenance and operating costs, including installation and the initial capital cost over the life of the system. Different scenarios were considered.
[60]	2020	LF	A comparative analysis of various combinations of energy sources.
[61]	2020	CC	Changes in annual wind speed and biomass fuel prices.
[63]	2020	CC	Two types of scenarios. During daytime hours with a certain load and the other scenario was interrupted.
[64]	2020	LF	The greenhouse gas emissions of the system in single-family homes were investigated, comparing the difference with the dispatch strategy when using different work strategies, depending on the greenhouse gas emissions and choosing the adequate dispatch strategy adequate.
[105]	2020	LF	Daily load profile and renewable resource with an existing system of 13 generators.
[106]	2021	LF	System cost changes with a fluctuation in solar radiation, wind speed, diesel price, operation and maintenance costs, capital costs, and replacement costs.
[68]	2021	ML	The effect of changes in average solar radiation and average wind speed on the cost of energy and CO_2 emissions.
[69]	2021	CC	Examined the effect of the cost of diesel fuel, the intermittent nature of solar and wind energy, and the nominal discount rate, and determined the average scaled load per day.
[73]	2021	LF	For different values of annual average solar radiation, average temperature, oscillation in average WS, rise and fall of fuel prices, and changing multiplication value of capital costs, the RC and O&M costs of photovoltaic systems were realized.
[74]	2021	CC	The model defined the results according to the initial costs, NPC, COE, capacity shortage, dispatch and penetration types, and fraction of renewable energy.
[75]	2021	CC	Summer and winter load profile.
[78]	2021	CC	The sensitivity of the output systems was tested by varying wind speed and diesel pump rates.
[82]	2021	CC	The details of the system's battery storage status and energy flow were analyzed through the energy balance of various system configurations. This analysis showed the operating cost, fuel cost, COE, fuel consumption, and renewable fraction.
[113]	2022	LF	PV size sensitivity versus O&M costs.
[84]	2022	LF	Sensitivity to evaluate the behavior of the proposed system when the scaled annual average energy consumption per day is increased by 10% and 20%
[118]	2022	LF	Sensitivity based on net current cost and lowest electricity cost.
[85]	2022	LF	The lowest cost system can also be modified by adjusting the sensitivity settings.
[121]	2022	CC LF	Microgrid optimization based on the dispatch strategy.
[48]	2022	CC	Microgrid optimization based on the dispatch strategy.
[122]	2022	CC LF LF CC	Prices change, load grows, or technology improves, and how a system design might adapt to different markets.
[138]	2022	CC	The sensitivity variables for the simulation were the operating time of the diesel generators and the cost of fuel.

Table 7. *Cont.*

Ref.	Year	Dispatch	Sensitivity Analysis
[124]	2022	LF CC	Wind speed (m/s) and fuel consumption were considered as sensitivity variables.
[101]	2022	CC LF	Sensitivity analysis was performed based on the abundance of renewable resources, such as solar irradiance and wind speed.
[131]	2023	LF CC	Lowest and highest NPC values for each region.
[51]	2023	CC	Fuel prices of USD0.51/L and USD1.02/L.
[89]	2023	LF CC	It was carried out taking into account the different values of the inflation rate and the useful life of the project.
[90]	2023	CC	Simulation of renewable energy configurations.
[91]	2023	LF	The NPC, the system COE, and only diesel were considered for the sensitivity analysis.

5. Conclusions

In this bibliographic review, it was found that most of the case studies (47%) focused on localities which did not have electricity, suffered from electrical resilience or, in other cases, had very high tariffs. Therefore, sizing, optimization, design, and decision-making studies were developed based on the information on technologies, economics, and social and environmental impact. In addition, energy policies vary from country to country. On the other hand, 14% of the analyzed works focused on the industrial area. The trend of this work shows the impact of HRES sizing on isolated communities, and how the software facilitates simulation and financial analysis, for different loads and climatic conditions.

In general, the publications analyzed reported their techno-economic–environmental analysis with Homer Pro, considering financial indicators such as COE, NCP, O&M, and initial capital to be of greater importance.

Important configurations of renewable energies, fossil sources, storage, and backup were found, depending on the application to which the study was directed (for educational institutions, in rural areas, industry, and others). It was also observed that DC- and LF-type energy dispatches were the most reported, in approximately 50% of the publications; while ML dispatch is one of the least reported, it could be a relevant area of study.

The sensitivity analyses of 40 articles reported with Homer Pro works, from 2019 to 2023, and that were analyzed here, tended to be performed for the parameters of environmental profiles, load profiles, interest rate, isolated and connected costs, dispatch type, schedule type, price fluctuation, and probability of loss of energy supply; the most reported were analyses with a variation in solar irradiance and wind speed.

It was observed that there was the dimensioning for a PV/WT/DG/BS/CONV configuration, with the economic objective functions and a sensitivity study modifying the NCP based on the wind and solar profiles, together with the meteorological data for the locality based on local meteorological stations. In addition, to be able to find the profitable fraction, the penetration percentage of each technology and the pollution levels of the diesel generator need to be taken into consideration.

To cover an electrical load demand of 48,194.08 kWh/d, applied to an educational area, the technologies of photovoltaic panel systems connected to a grid and converter were combined. In the case of a rural area with a load of 24,861 kWh/d, the technologies of photovoltaic panel systems, a hydrogen tank, backup batteries, and a converter were combined. On the other hand, an application in industry reported a load of 27,523.34 kWh/d with a combination of photovoltaic panel systems, biomass, battery systems, and a converter. In the case of an urban application, a load of 24,961.08 kWh/d was reported, with a combination of photovoltaic panels and interconnected to the electrical system network; it was noted that for this case, there was a demand of 24,022.37 kWh/d with photovoltaic panels, a wind generator, diesel generator, storage batteries, and a converter.

The research on Homer Pro is a valuable tool in HRES analysis, and allows for an analysis of its current importance in the creation of detailed models of energy systems, such as microgrids, with a variety of renewable energy sources, energy storage and load profiles, and under different conditions and scenarios. It also concentrates the results data in publications that have simulated the operation of HRES under various conditions, such as changes in energy demand, interest rates, availability of renewable resources, among others, helping to evaluate the sizing, design optimization, and financial and environmental aspects.

In summary, Homer Pro plays a crucial role in techno-economic environment analysis by providing advanced tools to model, simulate, optimize, and evaluate the economic performance of these complex distributed energy infrastructures.

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