Software Tools for the Integration of Renewable-Based Hybrid Power Systems

J.J. Roberts*, P.O. Prado, A. Marotta Cassula, A. Mendiburu Zeballos, E. Leonardi

***Abstract*-- Globally, 770 million people still lack access to electricity, particularly in remote regions where grid extension is unfeasible. Hybrid Power Systems (HPS), which integrate renewable and non-renewable energy sources, offer a promising alternative due to their economic and environmental benefits. However, optimal HPS design is complex, requiring software tools to manage the stochastic nature of renewable resources and intricate system interactions. This paper presents a comprehensive review of software tools for HPS design, analyzing their capabilities, limitations, and applications. Tools like HOMER, iHOGA, and SAM are among the most referenced, offering features ranging from pre-feasibility analysis to detailed optimization of energy resources and control strategies. The study underscores that no single tool is universally optimal; instead, users should match tool features to project needs, considering energy sources, demand complexity, and data availability. Combining tools can further enhance system design and analysis. By summarizing findings in detailed tables and figures, this work provides a practical guide for researchers and practitioners to select suitable tools for renewable energy projects. The review aims to facilitate the adoption of HPS, contributing to sustainable electrification in underserved regions and advancing renewable energy integration globally.**

***Index Terms*— hybrid power systems, renewable energy integration, energy system design, optimization tools, electrification in remote areas**

I. NOMENCLATURE

HPS: Hybrid Power Systems
DG: diesel generator set
LAC: AC load
PV: solar photovoltaic generator
WT: wind turbine
BT: battery bank
CONV: bidirectional inverter

II. INTRODUCTION

ENERGY is considered a key factor in the development of humanity. Access to modern forms of energy, particularly electricity, brings social benefits that improve the quality of life of the population. However, there are still, in the 21st century, 770 million people (9.7% of the world's population) who do not have access to electricity, mostly in Africa and developing countries in Asia. Further, the impact of the pandemic has made the progress in electrification to be stalled between 2019 and 2021 globally, and the number of people without electricity access has actually increased [1]. In remote regions, the supply of electrical energy through traditional means such as the extension of the electrical grid is not viable due to the high cost involved in the construction of long transmission lines to supply a small group of consumers [2].

Currently, the most widely used alternative for serving isolated communities is thermal generation, mainly fossil-fueled electricity generators [3]. However, as energy demand grows, so does fuel consumption, increasing fuel logistics, transportation and storage costs. Additionally, there are environmental impacts derived from the burning of fossil fuels and the potential danger of spilling.

The supply of energy using autonomous power generation systems based on renewable sources is constituted as a viable alternative. Systems that integrate two or more generation sources, renewable or not, to supply different types of loads are called Hybrid Power Systems (HPS) [4] (See Fig. 1). HPS, when correctly dimensioned, have technical, economic and environmental advantages in relation to single-source energy systems or traditional systems. However, the optimal sizing of this systems is not a trivial task [5].

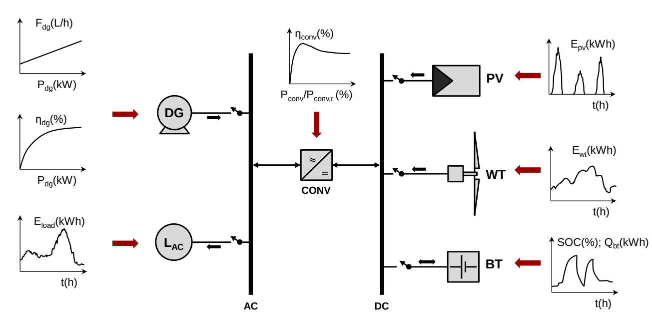

Fig. 1. Basic configuration of a HPS.

The main challenge in the design of HPS is to economically match energy production and consumption. This problem, which is relatively simple to solve in the case of systems based

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on dispatchable sources, becomes critical when renewable generation is included. The complexity of the problem lies in the stochastic behavior of the renewable resources (solar and wind) and the energy demand, in addition to the non-linear characteristics of the system components and the high interaction between the system variables.

Currently, there are a wide variety of software tools that can be used for the simulation, analysis and optimal design of HPS [6]. These tools have been developed to assess the technical and economic potential of HPS and simplify the system design process maximizing the use of the renewable resources, while balancing simplicity and ease of use, accuracy, precision, and representativeness of the results.

The most appropriate tool to assess a hybrid power system project depends on the type of renewable technology being considered, complexity of the project, complexity of the demand considered (the user), and the data available to perform de simulations [7]. The success of the energy project may depend on the results provided by the software employed, thus the importance of choosing the right tool.

In this paper the available software tools for the analysis of HPS are reviewed. We assess the technologies they evaluate, the scale and level of analysis, their modeling approach and limitations, data inputs required, and typical outputs.

Although good review papers have been published previously on the subject [6], [7], [8], [9], [10], none of them present the results in comprehensive tables and figures as here. With this study we aim to provide a basic insight to the potential users to identify and utilize suitable software tools effectively, as per the requirements for research and development studies related to HPS.

III. OVERVIEW OF EXISTING SOFTWARE TOOLS

During the bibliographic research for this work, 97 different software tools ranging from simple web-based tools to complex country level energy scenario simulation tools were identified. To organize the study, we classified the tools into five broad categories based on their type [11]:

1. *Pre-feasibility tool:* automate the calculations that an engineer would normally do by hand. It helps to determine whether the HPS makes sense for a specific application, both in terms of technical and economic aspects. These tools are usually geared towards a rough sizing but often have a comprehensive cost and financial analysis. Are typically used by vendors, system promoters, energy consultants, community planners, renewable energy financiers, and other people who need to assess the opportunity of a specific HPS application. According to Fig. 2, 3.0% of the software are of this type. Usually, prefeasibility and simulation are combined into one tool, 9.9% of the software have these two features.

2. *Sizing tool:* perform dimensioning of the system determining the optimal size of each of the different components of the system to meet a given energy requirement. Different optimization objectives may be considered, such us life-cycle cost of the system, energy loss, emissions, etc. These tools are generally small compiled software packages with a friendly user interface and are employed typically by most system installers. Sizing tools represent 10.9% of the studied software, given that the optimum dimensioning of power systems is a key aspect for energy planning, and the increase of computational power of personal computer which makes easier to implement complex optimization algorithm. Tools that implement simulation-based optimization (simulation & sizing) represent 9.9% of the studied packages (see Fig. 2).

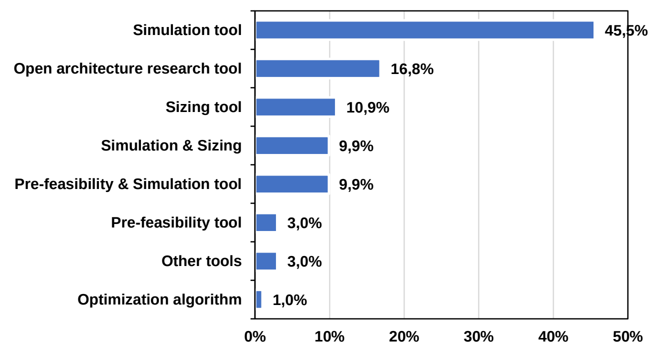


Fig. 2. Classification of software tools according to its type.

3. *Simulation tool:* different from the sizing tools, to run a simulation tools the user must specify the nature and size of each component. The tool then provides a detailed analysis of the performance of the system. The time resolution for the simulation may vary and depends on the level of detail required and the available input data (i.e. meteorological data, load demand). These tools can also be used for dimensioning, this requires the user to correctly identify the key variables and then repeatedly run the simulation in order to adjust the variables to converge on an acceptable system size. Also, some software are based on a simulation-optimization approach, thus combining a simulation model with an optimization algorithm. Simulation tools are usually compiled software developed and sold by universities and research centers. Fig. 2 shows that almost half (45.5%) of the software correspond to simulation tools, and in combination with other features, such as sizing and pre-feasibility, this percentage goes up to 65.3%. This is natural since this kind of tool have a broader target public.

4. *Open architecture research tool:* perform R&D at component and system level with high level of flexibility in the interaction of the components. While traditional simulation tools allow extensive sensitivity analysis, they generally do not allow the user to modify the algorithms that determine the behavior, interaction and control of the individual components. For this, an open architecture tool is required which consists of a selection of routines describing the components, and a platform linking these routines. These research tools can be either implemented within a commercially available general-purpose simulation package (i.e. MATLAB/Simulink, TRNSYS, INSEL) or programmed and compiled in a language such as C, Fortran or Pascal. The flexibility and power of open architecture research tools make them ideal for research purposes; their concomitant complexity limits their usefulness

for commercial system analysis, sizing and design. Open architecture research tools represent 16.8% of the studied software, this high share is logical since most of the available software are a subset of the routines of an open architecture package that are compiled and distributed commercially, usually as sizing and/or simulation tools.

5. Optimization algorithm: is a procedure which is executed iteratively by comparing various solutions till an optimum or a satisfactory solution is found. These algorithms are implemented within a commercially available general-purpose simulation package or programmed in a language and need to be combined with a simulation algorithm that provides the input data to find the best solution. These algorithms are usually implemented in universities and research centers. A low percentage of the software studied are exclusively optimization tools (1%), but usually are combined with a simulation model to optimally design the HPS.

In order to asses the historical evolution of these software tools, the plot shown in Fig. 3 was generated. It can be seen that the development of software tools related to HPS has increased since 1970, starting with simple tools based on spreadsheets to complex country level simulation optimization packages. Although most of the tools developed during the 70' and 80' are no longer available, they are the foundation of today's more complex software packages. The tools currently used were mainly developed in the 2000-2010 decade and are still in continuous improvement. In the last decade, almost no new tool has been developed, rather than improved version of already standard packages.

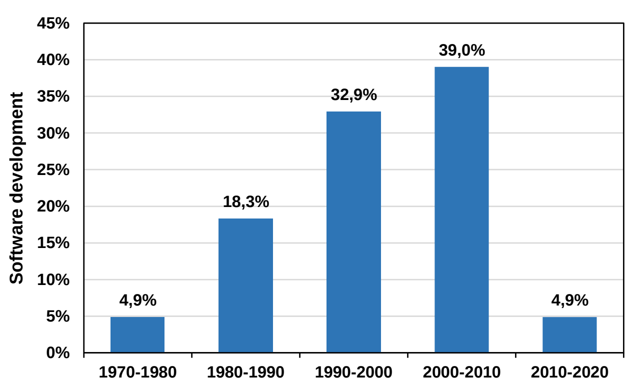


Fig. 3. Year of development of the tools.

Regarding the creators of the software tools, it is observed that most of them were developed by private companies (32%) and research laboratories (32%), either privately owned or state owned. Also, a big share of development comes from universities (25.8%), particularly from research groups working on these topics. Finally, government related institutions or organizations account for 10.3% of the software tools developed; further, in some cases the tools are the result of joint projects between various countries.

IV. SHARE OF REFERENCES

As mentioned before, during the initial bibliographic review we found 97 software tools, from these, 43 have at least 2 citations, while the rest of them are cited only once and almost no actual information was found. The number of references citing each of the 43 software is presented in Tab. I, the second column presents graphically the percentage of shear for each software. Clearly, HOMER is the most referenced tool with 9.6%, followed by HYBRID2 (6.7%), RETScreen (6.7%) and iHOGA/MOGA (5.7%), these four standard commercially available software are cited in 35.5% of the studied articles. Open architecture research tools represent 15.3% of the citations, with 7.5% for TRNSYS-based tools, 3.9% for MATLAB/SIMULINK-based tools and 3.9% for INSEL-based tools. The remaining 49.2% of the citations represent a wide range of software tools particularly useful for different applications. Within this share, there are included all the software tools that have only one citation.

TABLE I
SHARE OF REFERENCES FOR THE DIFFERENT SOFTWARE TOOLS STUDIED

Software	#	Share	Software	#	Share
HOMER	26	9,4%	RAMSES	1	0,4%
HYBRID2	18	6,5%	WASP	1	0,4%
RETScreen	18	6,5%	BCHP Screening tool	1	0,4%
iHOGA / MOGA	15	5,4%	EnergyPLAN	1	0,4%
TRNSYS	13	4,7%	IKARUS	1	0,4%
HYBRIDS	8	2,9%	MiniCAM	1	0,4%
INSEL	8	2,9%	WILMAR Planning Tool	1	0,4%
RAPSIM	8	2,9%	COMPOSE	1	0,4%
SOLSIM	7	2,5%	energyPRO	1	0,4%
SOMES	7	2,5%	INFORSE	1	0,4%
iGRHYSO	6	2,2%	NEMS	1	0,4%
ARES	5	1,8%	simREN	1	0,4%
Dymola/Modelica	4	1,4%	E4cast	1	0,4%
GAMS	4	1,4%	ENPEP-BALANCE	1	0,4%
HYBRID DESIGNER	4	1,4%	invert	1	0,4%
MATLAB/SIMULINK Hysys	4	1,4%	ORCED	1	0,4%
PV*SOL	4	1,4%	SIVAEL	1	0,4%
H2RES	3	1,1%	EMCAS	1	0,4%
HybSim	3	1,1%	GTMax	1	0,4%
HySim	3	1,1%	PERSEUS	1	0,4%
LINGO / LINDO	3	1,1%	STREAM	1	0,4%
MATLAB/SIMULINK	3	1,1%	PRIMES	1	0,4%
PV-DESIGNPRO	3	1,1%	PHOTO	1	0,4%
PVSYST	3	1,1%	RAPSYS	1	0,4%
SAM	3	1,1%	PVF-chart	1	0,4%
SOLSTOR	3	1,1%	ANFIS	1	0,4%
TRNSYS / HYDROGEMS	3	1,1%	FATE2-P	1	0,4%
AEOLIUS	2	0,7%	Ashling	1	0,4%
BALMOREL	2	0,7%	Vipor	1	0,4%
DER-CAM	2	0,7%	Supélec	1	0,4%
DIRECT	2	0,7%	Solar Pro	1	0,4%
DOIRES	2	0,7%	Off Grid Pro	1	0,4%
GSPEIS	2	0,7%	Simplorer (Ansys)	1	0,4%
IPSYS	2	0,7%	PowerSim	1	0,4%
LEAP	2	0,7%	Power Factory DIgSILENT	1	0,4%
MARKAL/TIMES	2	0,7%	Off Grid Sizer	1	0,4%
MATLAB/SIMULINK PVToolbox	2	0,7%	Sunny Design	1	0,4%
OptQuest	2	0,7%	PVS	1	0,4%
ORIENTE	2	0,7%	PolySun	1	0,4%
PVWATT	2	0,7%	CREST	1	0,4%
SimPhoSys	2	0,7%	Windographer	1	0,4%
WATSUN-PV	2	0,7%	windPro	1	0,4%
WDILOG2	2	0,7%	Helioscope	1	0,4%
ARENA	1	0,4%	Reopt	1	0,4%
RAPSODY	1	0,4%	Gatecycle	1	0,4%
EMINENT	1	0,4%	EAM	1	0,4%
MesapP PlaNet	1	0,4%	PVGIS	1	0,4%
ProdRisk	1	0,4%	PV*SOL-Online	1	0,4%
UniSyD3.0	1	0,4%	TRNSYS / UW-HYBRID	0	0,0%
EMPS	1	0,4%	TRNSYS / H2Demo	0	0,0%
MESSAGE	1	0,4%			

V. CHARACTERISITICS OF RELEVAT TOOLS

In this section we narrow the analysis to the 43 top cited tools shown in Tab. I. There are presented the main characteristics including information about the target users, scale of the projects that can handle, availability, computer platform, programming language, and further information source. It is found that most of the tools (51%) are developed to be used by Researchers and Educators (see Fig. 4a). This is in line with what was shown in Fig. 2 since a large share of the software are open architecture research tools. Further, most researchers act also as professors, thus the same tools used for research purposes are also used for teaching in university courses related to renewable energy, energy planning and power systems. Today, more and more Engineers require specialized software tools and apps to research and develop projects and their associated systems, thus a large share of the HPS software tools are targeted for engineers (25%). Some tools are specially designed to be used by developers and installers, these account for 11% and 7%, respectively. Electrical utilities also make use of these tools to simulate the integration of RE in their networks, accounting for 6% of the targeted users. Finally, only 1% of the cited software are intended to be used by policy makers. This may be because of the difficulty to develop user-friendly tools that take into account technical, economic, social and environmental aspects needed to make sound policy decisions.

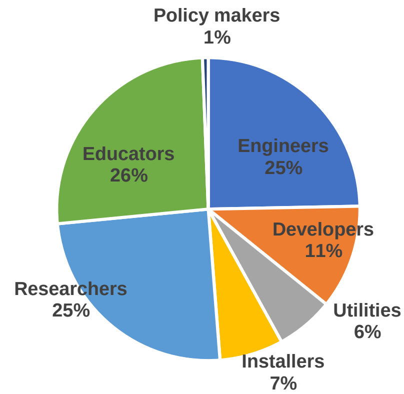
One of the characteristics assessed is related to the capability of the tools to model an energy sector, which can be used to group the tools into these categories [2] (see Figure 4b):

1. Multi-scale RE tools: they have the capability of modeling residential, as well as commercial buildings. These tools are well-rounded for many scales of modeling. Because of their flexibility they represent 67% of the studied tools.

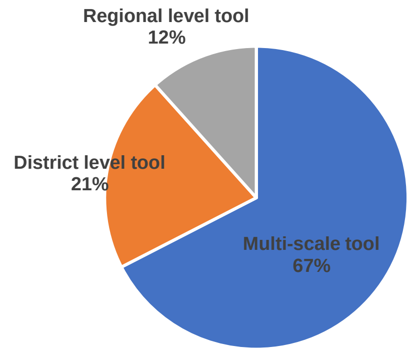
2. District level tools: these tools require a more sophisticated users that can provide more detailed data sets for results. They can analyze systems with greater detail than Multi-scale RE Tools due to the inputs and complexity of results. District level tools can also model higher scale projects, such as microgrids and larger gas turbines. According to Fig. 4b, 21% of the studied tools fall into this category.

3. Regional level tools: these tools are mainly focused on developments on a larger scale, such as regional or national. They require more advanced data sets in order to get more accurate results. This kind of tools need complex algorithms to represent the interaction of different energy sectors, only 12% of the tools include the features to be included in this category.

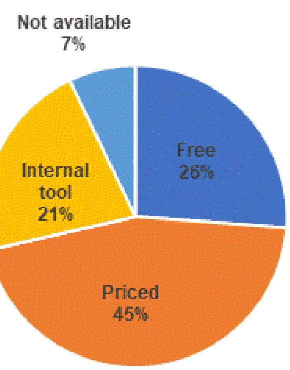
Other relevant information is related to the availability of the tools. As shown in Fig. 4c, most of the tools are priced (45%), though there is a good share of free tools available in the market (26%), further some of the paid software have a free version with fewer capabilities, usually for academic use. There is also a number of tools (21%) developed and used internally, usually for research purposes, in academic institutions. Lastly, for some of the tools there is no information about their availability (7%).



(a) Target users.



(b) Energy scale.



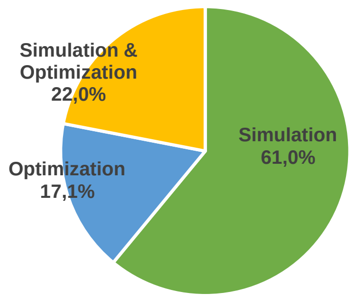
(c) Availability.

Fig. 4. Statistics on main characteristics.

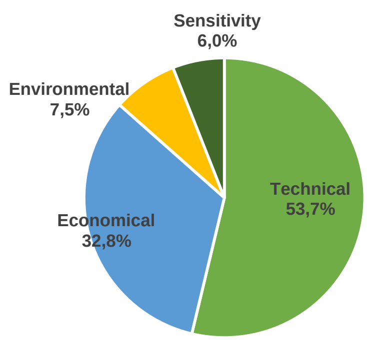
A. *Main features*

At the end of the paper Table II presents the main features of the studied software tools including type of model (simulation and/or optimization), configuration (hybrid or single source system), type of analysis (economic, technical, sensitivity, environmental), generation technology included and the ability to handle different control strategies. As it is, Tab. II provides a detailed matrix in which the 43 tools assessed in this paper are shown, along with 5 features that classify and make each tool unique. The tool having the specific feature is marked with an X, which represents a quick reference for comparing each tool discussed in this review paper.

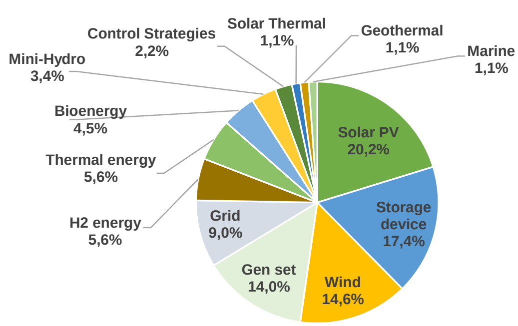
With the information provided in Tab. II, the plots in Fig. 6 where drawn. In Fig. 6a it is observed that the software are mainly simulation models (61%), a smaller share are exclusively optimization models (17.1%) and a 22% include both features in the form of simulation-based optimization models. Regarding the analysis they perform (see Fig. 6b), most of them include technical 53.7% and economic 32.8% calculations, but very few include environmental impact features (7.5%), and even less give the possibility of performing sensitivity analysis to assess the impact of uncertain variables (6%). Finally, regarding the generation technology, it is clear that solar PV, wind turbines, internal combustion generators and storage devices are the more common technologies since they are mature and affordable, see Fig. 6c.



(a) Model



(b) Anlaysis performed



(c) Technology included.

Fig. 5. Type of analysis and technology.

The tools in Tab. II are ordered according to the number of capabilities they present. In first place **HOMER** is the most complete tool in terms of features it offers. HOMER is a timestep simulator using hourly load and environmental data inputs for renewable energy system assessment; it facilitates the optimization of renewable energy systems based on Net Present Cost for a given set of constraints and sensitivity variables. HOMER consists of a library of components including photovoltaic generators, batteries, wind turbines, hydraulic turbines, AC generators, fuel cells, electrolyzers, hydrogen tanks, AC–DC bidirectional converters, and boilers. The loads can be AC, DC, and/or hydrogen loads, as well as thermal loads. It simulates the operation of a system by making energy balance calculations for each of the 8760 h in a year. For each hour, it compares the electric demand in the hour to the energy that the system can supply in that hour, and calculates the flows of energy to and from each component of the system. At the end of the simulation, the different system configurations are classified by their total NPCs [21–23]. It can do sensitivity analysis, which determines varying factors such as wind speed, solar radiation, fuel cost, interest rate, etc. Among its advantages is very flexible and has an easy interface that facilitates the layman user to model, analyze and optimize micropower systems. Its limitations include allowing only single objective function for minimizing the net present cost (NPC). Does not consider electrical aspects such as intra-hour variability or variations in bus voltage. For large search spaces the computational time can be excessive. It cannot analyze thermal systems. And it does not consider depth of discharge (DOD) of batteries [10].

Following the ranking is **iHOGA/MOGA** software, this tool presents almost the same capabilities as HOMER, with the main difference being the optimization algorithm used to size the hybrid systems. While HOMER uses an enumerative optimization algorithm (not specified by the developer), iHOGA implements genetic algorithms to perform the optimization, thus making the sizing process faster. Also, iHOGA allows to implement more complex control strategies with the possibility of optimizing the control parameters [24–28]. iHOGA optimization is achieved by minimizing total system costs throughout the whole of its useful lifespan, therefore financial (mono-objective). However, the program allows multi-objective optimization, where additional variables may also be minimized: CO2 emissions or unmet load, as selected by the user. iHOGA could simulate Net- metering of any case and includes an advanced battery aging model and auto optimization of PV panel slope [10]. Some limitations of the model are related to the fix 1-hour interval simulation time during which all of the parameters remained constant, the EDU free-version has limited use, the advanced algorithm is relatively time-taking, and it does not have analysis capability for Bio-energy system [29].

Third in the ranking of capabilities is the free software **SAM**; differently to HOMER and iHOGA, this is not an optimization model, but rather a simulation tool. It runs a performance model to calculate the electrical output of a power system and a financial model simulation to calculate the cash flow of an energy project [30–33]. Although you can use SAM for optimization, either by running several simulations to find the maximum or minimum value of an output metric in order to determine optimal value of an input parameter [34]. SAM incorporates some generation technologies not available in HOMER or iHOGA such as geothermal and marine energy. One interesting feature of SAM is that incorporates a scripting language that allows to automate repetitive or complex simulation tasks like read and write data to text files, run simulations, create graphs, among others. Its main limitations are related to not allowing hybrid system simulation and not including an optimization algorithm for system dimensioning.

Fourth in the ranking is **MATLAB/SIMULINK** which is a very powerful tool to simulate any kind of physical system, it allows to integrate electrical systems, mechanical systems, thermal systems and custom design systems [35]. Being an open architecture tool allows to model any kind technology, test different control strategies and find the optimal design of the system through the use of the optimization toolbox incorporated in MATLAB. Differently from HOMER, iHOGA and SAM, MATLAB/SIMULINK users need to have a deep understanding of the technologies and some programming background to produce accurate results, this constitutes its main limitation.

The last of the top five software is **HYBRID2**, this tool is a free probabilistic/time series computer model that uses statistical methods to account for inter time step variations and can perform detailed long-term performance and economic analysis and predict the performance of various hybrid systems [36–39]. HIDRID2 is a powerful simulation model dedicated to system design and allows the evaluation of important technical constraints, such as voltage level, and complex dispatch strategies. On the other hand, its limitations include several renewable technologies are not supported, and it does not include optimization or sensitivity analysis modules and is not flexible in defining the various components. Further, HYDRID2 only runs on Windows XP operating system and is no longer supported [40].

To complete the comparison between the top 5 software tools according to its capabilities, Tab. III presents the necessary information to be provided to the software in order to run (inputs) and the simulation results (outputs) provided by the software.

VI. Conclusion

In the present paper, an extensive review of available software tools for renewable-based Hybrid Power Systems (HPS) integration is performed. This work bridges a critical gap by presenting results through comprehensive tables and figures, offering users a practical guide for selecting the most appropriate tool for their energy projects.

The review highlights the essential role of these tools in overcoming the challenges posed by renewable energy's variability and the complexities of designing HPS. Simulation tools are key to matching energy production with consumption efficiently, especially for systems intended to provide solutions in remote or underserved areas where extending the traditional electrical grid is infeasible.

The study identified a wide range of tools cited in the literature, though many are no longer available. Among the prominent tools analyzed, HOMER emerged as the most versatile, providing detailed sizing options for district-level projects and user-friendly interfaces. Other notable tools, such as HYBRID2, RETScreen, iHOGA, and MATLAB/SIMULINK, also offer unique capabilities for design, analysis, and optimization of HPS.

Despite the variety of tools available, no single software meets all project needs. Thus, users are encouraged to thoroughly evaluate the components and energy sources of their HPS before selecting tools. Where necessary, combining complementary tools may ensure comprehensive design, analysis, and optimization.

By focusing on the capabilities, limitations, and specific applications of different tools, this review underscores their contribution to advancing the integration of renewable energy systems, particularly in addressing global energy access challenges. The information provided herein aims to assist users in selecting the most effective tool for their specific project requirements and supports the broader goal of facilitating the global transition to sustainable energy solutions.

TABLE II
MAIN FEATURES OF THE STUDIED SOFTWARE TOOLS

Software	**Simulation**	**Optimization**	**Hybrid**	**Single technology**	**Economic Analysis**	**Technical Analysis**	**Sensitivity Analysis**	**Environmental Analysis**	**Solar PV**	**Wind**	**Mini-Hydro**	**Gen set**	**Storage device**	**Bioenergy**	**H2 energy**	**Thermal energy**	**Solar Thermal**	**Geothermal**	**Marine**	**Grid**	**Control Strategies**
HOMER	X	X	X		X	X	X	X	X	X	X	X	X	X	X	X				X	X
iHOGA / MOGA	X	X	X		X	X	X	X	X	X	X	X	X	X	X	X				X	X
SAM	X			X	X	X	X	X	X	X		X	X	X	X		X	X	X	X	
MATLAB/SIMULINK	X		X			X			X	X	X	X	X	X	X	X	X		X	X	X
HYBRID2	X		X		X	X	X		X	X	X	X	X		X	X					X
H2RES	X	X	X		X				X	X	X	X	X	X				X		X	
SOLSIM	X	X	X		X	X			X	X		X	X	X		X					
TRNSYS / HYDROGEMS	X	X	X		X	X			X	X	X	X	X		X						
DER-CAM	X	X	X		X	X			X	X		X	X			X				X	
RETScreen	X			X	X	X		X	X	X			X	X		X					
TRNSYS	X		X		X	X			X	X		X	X		X	X					
iGRHYSO		X	X		X	X			X	X			X		X	X				X	
BALMOREL	X		X		X	X			X	X		X	X							X	
LEAP	X		X		X	X		X	X	X				X						X	
GSPEIS	X		X		X	X			X	X		X								X	
INSEL	X		X			X			X	X		X	X			X					
SOMES		X	X		X	X			X	X		X	X								
SOLSTOR		X	X		X	X			X	X		X								X	
IPSYS	X		X			X			X	X		X	X		X						
MARKAL/TIMES	X	X	X		X	X			X	X										X	
ORIENTE	X	X	X						X				X		X					X	
RAPSIM	X		X			X			X	X		X	X								
HySim	X		X		X	X			X			X	X								
HybSim	X		X		X	X			X			X	X								
ARES	X		X			X			X	X		X	X								
HYBRID DESIGNER		X	X			X			X	X		X	X								
WATSUN-PV	X		X			X			X			X	X							X	
PVWATT	X			X	X	X			X				X							X	
SimPhoSys	X		X			X			X			X	X								
PV-DESIGNPRO	X			X		X			X				X							X	
MATLAB/SIMULINK PVToolbox	X		X			X			X			X	X								
MATLAB/SIMULINK Hysys	X		X			X			X	X			X								
WDILOG2	X		X			X				X		X									
HYBRIDS	X		X			X			X				X								
Dymola/Modelica	X		X						X	X			X								
PVSYST	X			X	X				X				X								
OptQuest	X	X	X			X															
DOIRES		X	X		X	X															
PV*SOL	X			X		X			X												
LINGO / LINDO		X	X			X															
GAMS		X	X																		

TABLE III.
INPUTS AND OUTPUTS FOR THE SOFTWARE HOMER, IHOGA, SAM, MATLAB/SIMULINK AND HYBRID2.

Software	Inputs	Outputs
HOMER	- Loads: primary, deferrable and thermal load. - Components: PV, wind turbine, hydro, generator, grid, battery, converter, electrolyzer. - Resources: solar, wind, hydro, biomass, fuel. - Economics: annual real interest rate, project lifetime, cost of unmet load, system fixed capital cost, system fixed operation and maintenance (O&M) cost, carbon tax. - Generator control: dispatch strategy. - Constraints: operating reserve, maximum annual capacity shortage, minimum renewable fraction. Optimization: it contains the values of each optimization variable that are used to build the set of all possible system configurations.	- Simulation: estimates the cost and determines the feasibility of a system design over the 8760 hours in a year. - Optimization: simulates each system configuration and displays list of systems sorted by net present cost (NPC). Sensitivity analysis: optimization for each sensitivity variable.
iHOGA	- Loads data - Resource data - Components data - Constraints - Economic data	- Multi-objective optimization - Life cycle emission - Probability analysis - Buy-sell energy supply analysis
SAM	- Loads data - Resource data - Components data - Financial and economic data - Incentives	- Financial results: levelized cost of energy (LCOE), power purchase price, rate of return, and other financial metrics for utility scale projects. Also, payback period and net present value for residential and commercial projects. - System performance: hourly, monthly, and annual average predictions of the system's performance including net electric output and component efficiencies. - Customizable graphs that show summaries of results from both the performance model and financial model.
MATLAB/ SIMULINK	- Components models, either developed by the user or taken from Simulink library. - Economic and optimization models. - Loads data - Resource data - Components data - Constraints - Economic data	- Numerical results of the simulation/optimization from which the user can elaborate plots, tables, statistics, etc.
HYDRID2	- Loads: primary, deferrable, optional and heating load. - Site/resource: site parameters as well as time series data of wind, insolation and ambient temperature. - Power system: It is based on a three-bus grid that includes an AC, DC, and shaft bus system. Specific types of components are then included in each subsystem that is attached to one of the buses. Components include wind turbine, PV module, diesel, dump load, battery, converter, synchronous condenser and dispatch strategy. - Base case: for comparison purposes, the user can supply the primary and deferrable loads using a diesel-only system. The technical and economic performance of a system with renewable can be compared to those of the diesel-only system. - Economics: costs of the various components as well as economic parameters that are used to evaluate the economic performance of the system.	- Performance summary files of the cumulative energy flows and fuel consumption during the simulation run. - Economics summary file including net present value of total costs, levelized cost of energy, simple payback period, discounted payback period, internal rate of return, yearly cash flows, etc. - Detailed files including values of a number of system variables for each time step (power going to each type of load, the unmet load, the power produced by each generating unit, etc).

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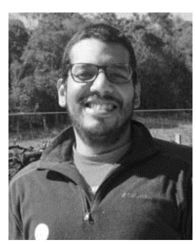

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