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A critical analysis on Hybrid Renewable Energy Modelling tools: an emerging opportunity to include social indicators to optimise systems in small communities

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Abstract

The arrival of different renewable and storage technologies with increasingly lower costs is helping small communities to access affordable electricity through energy systems fed from heterogeneous generation sources. With the growing popularity of Hybrid Renewable Energy Systems (HRES), a novel kind of end-user software tools have also emerged to help planners optimize these energy installations. At the same time, there is a growing number of researches which warn about the need of considering not only economical, technical or environmental criteria when designing HRESs, but also social indicators like job creation or social acceptance. Consequently, the optimization of HRESs could also be improved by adding such new social parameters. We present hereby a review which assesses that the vast majority of the popular tools used by the planners to design HRESs do not consider social factors. The inclusion of social parameters within the optimization software is a real opportunity to boost these programs' features, offering additional capabilities to their users, especially to those which design systems are located in small communities. This research provides valuable information for developers of HRES optimization tools, delivering them, on the one hand, with insights about the advantages of the inclusion of social parameters during technology assessment and, on the other hand, contributing with a guide to help decide the best tool select the most pertinent tool, allowing designers to make the most of the sociodemographic structures and local renewable resources.

Keywords: Hybrid renewable energy systems, Optimization, Social indicators, Renewable energy, Software tools

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Nomenclature

API	Application programming interface
$HRES$	Hybrid renewable energy system
KPI	Key performance indicator
$LOEP$	Loss of energy probability
$LOLP$	Loss of load probability
$MCDM$	Multiple criteria decision making
MWh	Megawatt-hour
NPC	Net present cost
PEM	Proton exchange membrane
PV	Photovoltaic
SAM	System advisor model
HDI	Human development index
RES	Renewable energy system

1. Introduction

The democratization of some energy technologies and the reduction of their initial costs are helping some regions catch up with the train of electrification and, therefore, speed up their economic and social development thanks to the linkage between energy consumption and economic growth [1, 2, 3]. There is an increasingly number of generation technologies (both classical and modern) [4], and the concept of Hybrid Renewable Energy Systems (HRESs) [5] refers to those systems that combine several of these technologies with the aim of implementing the best solution available to each new case. The possibilities for hybrid projects are endless [6], tackling issues ranging from the achievement of a higher overall production to the improvement in competitiveness as result of reducing renewable energy intermittence.

The concept of system optimisation emerged as a response to the obstacles arisen from the installation of some energy technologies (see Fig. 1) and the great variety of deployment configurations. The design of suitable energy systems is very important and must take into account issues such as the proper election of the energy sources, the size, and the location of the system itself in order to reduce costs, ensure the energy demand, avoid CO_2 emissions, and satisfy any other relevant factors needed to offer energy of high quality. According to Fathima and Palanisamy [7], the use of optimization methods fully justifies the cost of investment on a HRES microgrid by enabling and economic and reliable use of the resources. Fortunately, the development of computational technologies and new algorithms [8] fostered the creation of a wide range of optimization approaches. Additionally, the recent development of tools focused on end-users with knowledge in energy planning and with scarce skills in software development, managed to help such professionals with the processes of HRESs planning and design, without having to worry about the underlying mathematics [9].

When dealing with the optimization of HRESs, the great majority of the available compu-

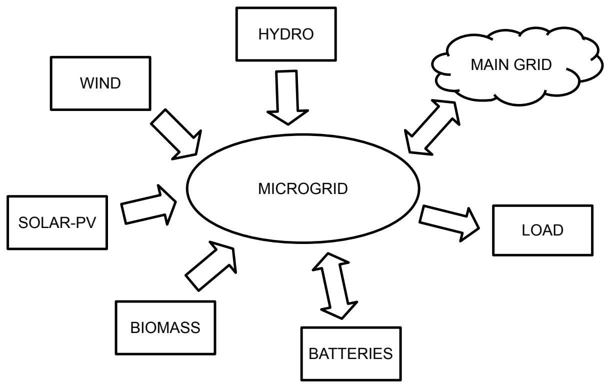

Figure 1: Diagram of a simple HRES.

tational programs analyze indicators related to the technical, economic, and environmental operation of the system, e.g. minimize the initial cost of the HRES, or maximize the share of renewable electricity within the yielded energy. Over the last few years however, several authors advocate for the inclusion of another type of parameters: social indicators. Social indicators, such as job creation or social acceptance, can have a direct impact on the goodness of an energy system. We believe however, that the currently existing end-user software tools focused on HRESs optimization do not take into consideration this kind of indicators. Doing so could be very beneficial when analyzing the operation, deployment and performance of an energy system for each particular case[10], e.g. in Hawai, thousands of people protested against the setting of a new telescope, while in Mexico, the renewable movement has faced substantial opposition from local communities. Thus, HRES tools have to ensure a green future that is just and viable for all, a future that is inclusive and respectful towards nations, cultures, and religions that might view the world, and its progress, differently.

Furthermore, the techniques used to optimize hybrid energy systems in general, and end-user software tools in particular, have traditionally been focused on selecting the best solution based on a specific economic objective function, returning values of economic (capital cost, cost of energy, etc), technical (demand not met, fuel consumption, etc), or environmental indicators (CO_2 emissions, renewable fraction, etc), given a specific configuration, and constrained by fulfilling the technical requirements. For example, HOMER, the world's leading distributed generation and microgrid modeling software, navigates the complexities of building cost effective and reliable microgrids that combine traditionally generated and renewable power, storage, and load management, with cutting edge algorithms for optimizing solar, storage, and more to reduce your overall energy costs. HOMER considers the total net present cost (NPC) as the objective function, an economic criterion which is minimized during each optimization task.

There are some facts which may lead us to think that these economic, technical, or environmental approaches are not enough to find the "optimal design" of the system. We see the possibility of including social criteria, in order to help improve the efficacy of these HRESs in terms of benefiting the communities where they are installed, and in terms of fitting them to the needs of the people consuming the electricity. Wolsink [11] reminds us that smart microgrids have social foundations, since they consist of decentralized socio-technical networks forming a community that exhibits high levels of interaction and integration between the actors. Social perspective, as with any energy source that has potential ubiquitous impact on large communities or nations, should be analysed with respect to its relationship with society for long-term acceptance and support. [12] Therefore, why not considering the social outcome of a microgrid, at the same level of the economic, environmental or technical outcomes?.

We suspect that, taking into account the socio demographic data of the area where the hybrid microgrid is going to be implemented, along with the social features derived from the use of the energy sources (job creation, compatibility with the political situation, etc), the analysis and design of the hybrid systems could be improved. The present study analyzes the way in which the most relevant current software tools are covering the inclusion of social indicators to optimize the HRESs. This approach, not yet covered in academic research, has enormous potential to assist in the design and optimization of a HRES in small communities, helping a big number of energy planners, who may not have enough mathematical or computer skills, to implement the new indicators within such third-party tools or their own ones. In summary, the main contribution of this review is to present a critical analysis about the gaps encountered in the social aspects on a wide range HRES tools, as an improvement opportunity for policy makers, researchers, and software developers. This could lead to more complex but more precisely software tools in the near future.

One of the main motivations to carry out this review paper is to study the social phenomenon behind the thriving of renewable energies, the vast majority of the tools used to plan, design, assess and model the hybrid renewable systems lack of social indicators, up to now seems to be more important than the economical and technical issues, nonetheless, the social indicators are as important as the previously mentioned aspects. Perhaps, this tool does not take into account social issues since the complexity on the measurement of this aspect, like job creation, human development index, etc. Despite the level of complexity, measuring social indicators is a very important research topic given the potential positive and negative effects that large scale actions in the energy system have over society. We are concerned on the social indicators and its relationship with the HRES in the globalised world, might be some countries/enterprises had not take into account the importance of this sort of new systems on the society. It challenges us to make this thoughtful review the existing software for the sizing and planning of HRES in order to assess the degree of social indicators that they cover and the possibility to introduce them.

We are concerned about the social indicators and its relationship with the HRES in the globalised world, might be some countries/enterprises had not take into account the importance of this sort of new systems on the society. It challenges us to make this thoughtful review on more than 100 tools used to HRES planning and assessment.

This review paper is organised as follows: Section 1 introduces the review paper. Section 2 presents the review methodology to find the state-of-the-art of the software tools for HRESs, and their current features, especially focused in the consideration of general and social indicators. Section 2.1 discusses previous works analysing the general techniques to optimise HRESs. Section 2.2 analyses other investigations about the different criteria considered in optimisations in order to produce a list as complete as possible with those indicators, and examines preceding review papers trying to synthesize the different end-user optimisation tools and the way they deal with such indicators. Section 3 shows the results of the survey after assessing the inputs, outputs, constraints, versions, optimisation features, energy technologies covered, and interactivity of the tools analysed. Section 4 is presented an analysis about both the HRES and its social impact. Section 5 this is aimed to portray future scenarios. and Section 6 gives conclusions and related future works.

2. Review methodology

This section is addressed to introduce the overall review methodology implemented to obtain the details, which make us understand minutely the HRES tools analysed thoughtfully here, and also, the research papers which are related to our research query were collected using SCOPUS platform. The entire summary of the tools surveyed can be seen in Appendix. Initially, the objective of this study was to identify HRES tools gaps related to social issues.

The social perspective is maybe the most important aspect in this review, since renewable systems surely will produce impact on Job creation, Health and safety, new infrastructure development, etc. This aspect usually comprises the study of social interactions, social organisation, and behaviour patterns of groups [12]. Nonetheless, very early in the research we realized that a vast majority of HRES tools does not considered the social aspects, and that became a quite interesting challenge. In order to reflect the increasing use of this kind of end-user computing tools by the planners who design and optimize HRESs, we execute the following query on Scopus: TITLE ((”design” OR ”optimisation”)) AND TITLE-ABS-KEY (hybrid AND energy) AND ALL (”homer”). We tried to locate works focused on the design and optimization of hybrid energy systems, which have used the popular HOMER tool.

In an attempt to find the state-of-the-art of software tools for HRESs, and with the aim of analyzing if the most relevant ones are considering the social approach to optimize the systems, we tried to produce a complete up-to-date listing of this kind of software. To produce the inventory, we initially followed the previous collections created by Connolly et al. [8], Sinha and Chandel [13], and Erlwein-Vicua [14]. We considered even the software tools mentioned but not analyzed, just to research whether they have been improved during the last years. The method consisted in trying to access the websites provided in those listings through the provided URLs and by using a web browser, or in using the Google search engine if the original listing did not include the internet address, with the intention of locating the websites. Browsing these sites we tried to collect information about the main characteristics of each one of the tools.

At the same time, we made an effort to extend the already proposed lists of software tools, by locating other applications which either have been created or have got popularity during recent years, like SAM (developed by the National Renewable Energy Laboratory) or

DER-CAM (developed by Berkeley Lab). In the end, we created a list with 106 tools for HRESs, which can be consulted in Table A.10. Our initial aim was to determine if a tool can be considered as an end-user application to design and optimize effortlessly HRESs for small communities, up-to-date, popular among energy planners, and which can be easily accessible by them.

With this purpose in mind and in order to refine the initial 106-element listed, we added in the mentioned Table A.10 several fields of information of each item. Some of these fields were used as a filter to reject those software packages which does not meet the previous definition of desirable tool to analyze deeply, thus limiting the scope of the evaluated software, as shown in Table 1, where shadowed fields are the chosen ones. Once one of the features did not meet the requisites, the other parameters were not filled.

Table 1: Facets of the HRES tools

DIFFERENT FACETS OF THE TOOLS AND THE SELECTED ONES																														
Kind of tool			Energy scope				License						Scale of the projects			Technologies covered (at least)					Purpose		Criteria				Update		Connected	
Pure algorithms	General purpose simulation software	End-use software with technologies included	Electrical systems	Transportation, Electrical Vehicles	Hydrogen	Other energy scopes	Internal use	Only paid version	Both paid and freemium versions	Paid with free demo	Freeware	Open Source	Buildings	Communities/Districts/Islands/Large Plants	Regional/National	Onshore wind	Solar-PV	Batteries storage	Diesel	Other technologies	Simulation	Optimization	Economic	Technical	Environmental	Social	Not updated for the last 2 years	Updated for the last 2 years	Stand-alone (of grid)	Connected to the grid

The name of the organization (or community of developers) which is behind the tool, and a URL to locate and download the software are listed. We contacted by email with the authors of those tools with obsolete information in order to try to locate the way to test the program. If there was no information about how to find the software, it was rejected.

We also included the data of the kind of license of the tool: if the tool is free (even open), paid, or if there is an easy access to the license. If the software has no possibility to be tested in a costless manner, it was rejected. If the tool offers another premium version of the software through a paid license, we selected the version with the most accessible license in order to test it and to include it in the shortlist.

Information about the scale of the software was added as well. Three scales were considered (homes/buildings, communities/districts, and regional/national), rejecting those tools which do not cover the communities/district scale.

The date of the last update was also included, in order to indicate the freshness of the software. Any program which was not updated during the last two years was rejected, since we understand that it does not include the last developments of the HRES technologies. This information is hard to obtain from some of the tools. For instance, the date of the last version of each tool is sometimes shown in the downloads section of the website, on the users manuals, or even is not unveiled. Although our final aim may be to optimize HRESs by using social factors, we included also the tools which only included the option of simulating a specific configuration without the option of optimizing to find the most favorable one.

Finally, we decided to mention all of those tools which allow users to interact with them (e.g. by performing batch calculations through an API), or even give the possibility to freely modify them and improve their features (e.g. open source software packages). In case of future works trying to develop a method to optimize HRESs by using sociodemographic indicators, the possibility of interacting or modifying the initial tool would be a great help, even if it does not include currently the optimization option.

According to researchers [15, 16], open source software is free and easily accessible online, it is attractive for many users including government, home users, schools, or business accounts, and has been advocated by many as a solution for closing the 'digital divide' by assisting developing countries in their efforts to apply information technology. In fact, open source software has been using to implement different technological solutions in several fields of developing countries, such as biotechnology [17] or geographic information systems [18].

In conclusion, following the previous considerations, and in order to analyze if a certain computer program fits our needs, we tried to perform the case-study of a planner who attempts to:

- Use an accessible software tool which does not require to create any generation technology to
- Design a HRES (if possible, to optimize it),
- Which is connected or not the main utility grid,
- Devoted to satisfy the needs of the residents of a community, district or island,
- By meeting their predicted load demand, and
- Using -at least- solar PV, wind, and battery technologies.

The information of the fields for each one of the tools, gathered during the survey process, are shown in Table A.10. The columns of some computer programs were not filled after founding that they did not comply with one of the conditions of the filter.

After applying the previous filters, we obtained a shortlist with the 7 most relevant end-user software tools to design and optimize HRESs for small communities. We installed, reviewed the specifications, and analyzed the tools of this second list, in order to gather the different features of the computer programs and find whether some of them are considering:

- Social outputs (like number of job positions created, or reduction of energy poverty) when simulating a given configuration, or
- Social objective functions when optimizing the system.

HRES tools simulate a certain configuration (to analyze the characteristics of a given design), or a batch of possible ones (so as to find the optimal disposition). Given fixed input values (renewable resource, load to be met, initial costs of the generators, etc), the tools calculate the outputs (capital cost, fuel consumption, CO_2 emissions, etc) following the constraints provided by the user, as seen in Fig. 2. Since the HRES systems can be composed of different types of generators, each calculation is considering different types of technologies (e.g. PV, wind, biomass, etc).

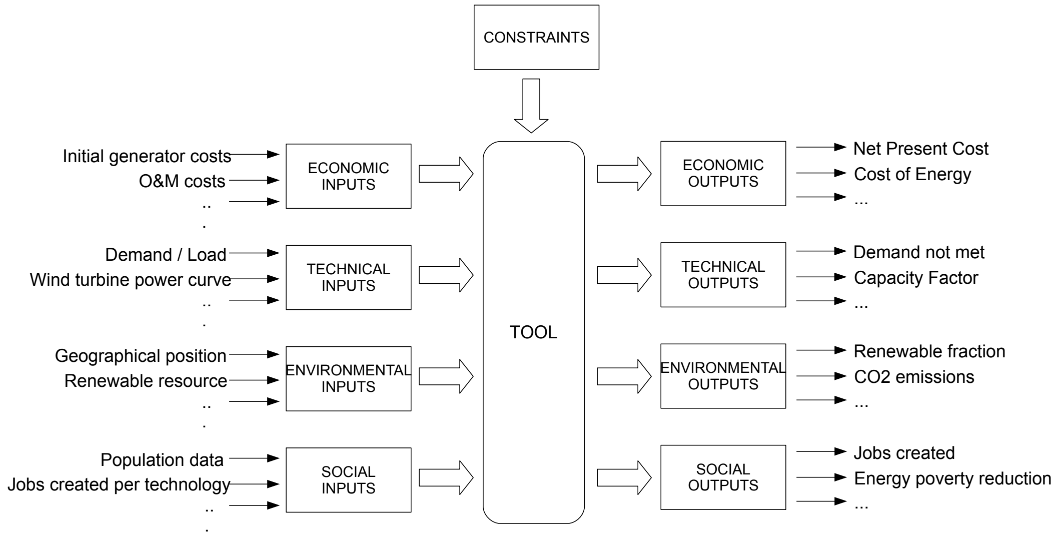

Figure 2: Inputs, outputs and constraints of a HRES tool

After installing, testing, and reviewing inputs, outputs, and other parameters of the software tools, we populated Tables 3 to 9, which include the results of our survey, as detailed in Section 3. It shows the following parameters of each one of the most relevant tools, categorizing the parameters following the main groups seen in Section 2.2 (economic, technical, environmental, and social), and indicating if each one of the programs includes them or not.

Input parameters: information required to simulate or optimize a system, such as the wind turbine power curve or the demand to be met.

Output parameters: the data obtained after the simulation of a given configuration. The fact that one tool includes a kind of output parameter does not imply that the program carries out the optimization of the system following the maximization or minimizing that parameter.

Constraints: when optimizing and finding the optimal configuration of a system, each one of the simulations must fulfill some conditions given by the user, such a minimum renewable fraction. If the calculated system does not satisfy the constraints, the configuration is not considered.

The discovery of the different inputs and outputs has been possible as a result of having obtained the complete list of indicators in Section 2.2, these have been collected in both Tables 3 and 4, in these Tables are portrayed the different inputs and outputs which were considered in the tools analysed in the paper. The election of the parameters and constraints have been done after finding them during the evaluation of the tools. This is, if a parameter was detected in one of the analyzed tools, we tried to locate it in the rest of the items.

Another shown feature is the possibility of doing optimization tasks to find the best configuration of a HRES by maximizing or minimizing one or several parameters, which would become the objective functions. Even some tools, f.i. HOMER, includes the choice of making a sensitivity test, repeating the optimization process for each value of one or even several variables, creating an analysis of how the results are affected by those input variables. Additionally, a bunch of extra features was gathered in order to offer more information about the possibilities of each one of tools:

- Technologies: each one of the energy sources or storage, which are implemented in the tool to help users to include within the simulations and optimizations.
- Interactivity: information about the possibility of access directly to the core of the tool, to perform calculations in an automatic way, or the opportunity of exporting data to a file.
- Versions: data about the specific version used during the survey process, including number and type of license.

All above mentioned in Section 2 were the reasons why we initially gathered a number of features of the original lists in order to filter them, analysing later their features to find any considered social criteria.

2.1. General approaches to optimize HRESs

In this part of the paper, have been analysed the most outstanding research carried out in the field issued here. It must be emphasized that the research work by Connolly et al. [8] covered not only software to design HRES systems, but general-purpose energy tools. Sinha and Chandel [13] included also computer programs used by planners to design HRES systems, but the utilized tools were not necessarily focused in the hybrid renewable field. For instance, OpenModelica [19] is a general-purpose tool for modeling and simulating dynamic systems. If any planner wants to design or optimize a HRES, they have to create programmatically their own components of renewable technologies (solar, wind, etc.). In fact, Migoni et al. [20] developed specifically a new library providing component models such as photovoltaic (PV) cells, proton exchange membrane (PEM) fuel cells, electrolyzers, hydrogen storage tanks, batteries and electronic converters to build different HRES models using the Modelica language. Besides, the H2A tool [21], cited by Connolly et al. [8], is actually focused on hydrogen systems.

Several authors have analyzed the different optimization methods and techniques to find the "best" layout of HRESs. Erdinc and Uzunoglu [5] analyzed the vast literature about optimization and sizing of HRESs, and divided the approaches to find this optimal design into commercial software tools and optimization techniques, like genetic algorithms, particle swarm optimization, simulated annealing, or linear programming. Dawoud et al. [22] described a review of optimization methods for hybrid microgrids containing renewable sources, discussing numerous optimization techniques and organizing them into graphical, probabilistic, deterministic, iterative, artificial intelligence, and finally software tools. Tezer et al. [23] also analyzed the different approaches used for optimization of HRESs, including a wide collection of techniques, and classifying them into a classic optimization approaches, meta-heuristic methods, other approaches, and software tools.

The different techniques detailed by Dawoud et al. [22] and Tezer et al. [23] can be implemented by using different computational languages which try to maximize or minimize an objective function, after having determined it, along with variables and limits of the problem. Such objective functions consider one or several criteria (indicators or KPIs, measured through numerical values), in order to mathematically build the function to be maximized (e.g. the highest energy production) or minimized (e.g. the lowest CO_2 emissions). As can be observed in Fig. 3, each one of the technologies of the system will have different impacts on each one of the indicators considered to build the objective function.

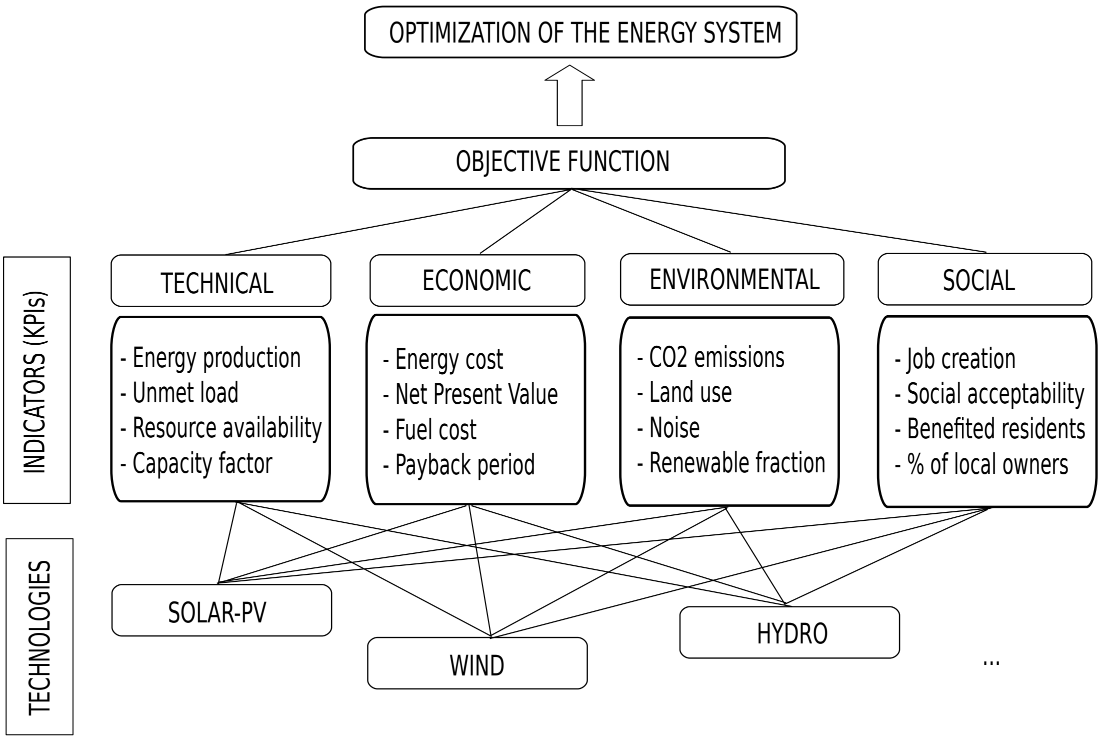

Figure 3: The objective function can consider a wide range of indicators

We found a considerable number of authors analyzing the different categories of the objective functions through different criteria when doing the simple task of planning and designing electricity systems with renewable sources, not specifically the exercise of optimizing a HRES with a software tool. Wang et al. [24] itemized numerous criteria grouped into four classifications when doing multi-criteria decision analysis in sustainable energy decision-making: technical (efficiency, reliability, safety, etc); economic (investment cost, fuel cost, net present value, payback period, etc); environmental (CO_2 emission, land use, noise, etc); and social (social acceptability, job creation, social benefit, etc).

Additionally, most of the authors who had realized the importance of the social factors when designing and optimizing energy systems, and whose text have been reviewed in Section 2.1, found that this intermediate scale of systems was where the examination of social aspects can do their best. Kumar et al. [25] stated that the social factors play a key role for electrification projects in rural developing areas; Rahman et al. [26] found that rural electrification requires effective prioritization and planning, considering socioeconomics; Dufo-López et al. [27] proposed their multi-objective evolutionary algorithm with an example in the optimization of a hybrid system to supply electricity to a small community in Africa; the results by Rojas-Zerpa and Yusta [28] revealed that decentralized power provided by HRESs is the best form of electrification for small rural or remote villages; and Al-falahi et al. [29] concluded that the implementation of HRESs provides a cost-effective and reliable option, given the fuel supply shortage and high cost associated with grid extension for islands and remote rural areas. In Section 2.2 we gathered previous works which reviewed the different KPIs taken into account when designing energy systems in general and HRES in particular.

2.2. HRES indicators

With the aim of finding the longest range of indicators used in the task of optimization, and in order to check such indicators within the software tools we will review later in section 2.2, we evaluated what other authors have been analyzing about the different criteria considered by the energy planners when designing general-purpose electrical systems, not only focused on laying out hybrid ones. Kumar et al. [25] developed an insight into various multiple criteria decision making (MCDM) techniques to find optimal results for renewable energy systems, in complex scenarios including various indicators, and criteria. The authors realized that social factors had always played a very important role in energy planning, and energy projects with sophisticated technologies and promise affordable electricity even tend to fail many times, due to ignorance or less importance of social factors. They finally stated that an energy system design must take into account of social factors by giving it equal importance as other factors.

Strantzali and Aravossis [30] reviewed 183 studies published in the 1983–2014 period in order to investigate the trends in the assessment of RES investments, and analyzing the criteria used to evaluate energy planning projects. The social aspects were considered, and the most utilized criteria was, by far, the job creation (46%), followed by social acceptability (28%), social benefits (15%), visual impact (14%), local development (13%), impacts on health (10%), and income from jobs (8%). Liu [31] elected eleven basic sustainability indicators for renewable energy systems, classifying them into: environmental (CO_2 emission, renewable fraction, etc); economic (costs, return on investment, payback); and social (job creation, benefited residents).

Beccali et al. [32] designated several criteria when doing multi-criteria decision-making in energy planning, grouping them into three categories: technological (reliability, cost of saved primary energy, etc); energy and environmental (land requirement, greenhouse pollutant emissions, etc); social and economic (labor impact, market maturity, compatibility with political situation, etc). Rahman et al. [26] described different criteria to be considered by decision-makers to choose the appropriate option for sustainable rural electrification in developing countries. Those criteria were grouped in five dimensions: technical (capacity factor, annual resource, compatibility with existing infrastructure, etc); economic (capital cost, lifespan of the system, dependence on fossil fuels, etc); social (public and political acceptance, scope for local employment, public awareness and willingness, conflict with other applications); environmental (CO_2 emissions, local impact); and policy/regulation (land requirement, emphasis on the use of local resources, tax incentives, etc).

Upadhya and Sharma [33] gathered several factors and criteria involved while designing a hybrid energy system for a locality. Among them, some socio-political factors were included, like the compatibility with the national energy policy objectives, political acceptance, social acceptance (including the land use, visual impact, electromagnetic interference, acoustic noise, shadow flicker, and ecosystem disturbance), the portfolio risk (the exposure to fuel price instability for carrying out socio-political decisions), or the labor impact.

Štreimikienė et al. [34] went one step further and organized a group of 25 experts to find several qualitative and quantitative criteria which helped to rate several electricity generation technologies (nuclear, gas, biomass, geothermal, hydro, wind) considering their economic, technological, environmental social and political aspects. Among the social aspects, there were the influence on social welfare (jobs, economic security), the influence on sustainable development of society (education, science, culture), and the public acceptance/opinion.

Niu and Wei [35] proposed a simulation an optimization algorithm in a hybrid thermal/wind power system with social-environmental-economic dispatch, where the objective function of the social benefits was obtained by calculating the risk cost caused by the power outages due to the intermittency of wind energy, which can make social losses. Rojas-Zerpa and Yusta [28], proposed a combined methodology to facilitate the selection of the best solution for electrical supply of remote rural locations, involving technical, economic, environmental and social criteria, carrying out the consultation to a group of 16 experts worldwide for weighting the preferences of the criteria, including the social acceptance of power, the creation of jobs, and the human development index (HDI).

Dufo-López et al. [27], based on the work by Rojas-Zerpa and Yusta [28], presented a new methodology, using a multi-objective evolutionary algorithm, for the optimization of off-grid HRESs by minimizing the total net present cost, along with the maximization of HDI and job creation. The work by Dufo-López et al. [27] was one of the works reviewed by Al-falahi et al. [29], who presented a comprehensive review on recent developments in size optimization methodologies, summarizing and explaining various assessment parameters such as economical, reliability, environmental and social parameters, including the 'human development index' indicator, job creation, social cost of carbon, or a socio-demographic factor which describes the energy consumption pattern of a household load in a certain location. However, the use of social parameters was virtually residual, being the economic indicators principally the most considered factors.

In summary, in spite of being a minority, there is an increasing number of design and optimization cases where the social parameters are taken into account to design energy systems in general, and our research will try to find out if the developers of the software tools to optimize HRES systems are including this wider approach.

In order to have a broad overview of all the criteria that can be considered by the energy planners when designing general-purpose electrical systems, we produced the Table 2, with a summary of all the key performance indicators mentioned in the previous papers. As observed, several social parameters can be used as indicators when optimizing a regular electrical system, with job creation and social acceptability as the most popular ones. When checking the software tools, this list will be used to find any of these criteria within them in order to analyze which kind of considerations are they taking into account.

Table 2: List of all the KPIs considered in the analyzed papers.

KPI type	KPI / Criteria	[25]	[30]	[31]	[32]	[26]	[33]	[34]	[35]	[28]	[27]	[29]
Technical	Efficiency	X	X							X		
Technical	Reliability	X	X		X		X			X		
Technical	Resource availability	X	X			X				X		
Technical	Nominal power/Installed capacity (kW)		X					X				
Technical	Maturity	X	X		X							
Technical	Safety	X	X				X	X				
Technical	Energy Production		X									
Technical	Load Demand	X	X									
Technical	Primary Energy Ratio (PER)		X									
Technical	Lifespan	X	X			X		X				
Technical	Continuity		X				X					
Technical	Stability		X									
Technical	Feasibility	X					X					
Technical	Consistence of installation and maintenance requirements with local technical know-how				X	X	X					
Technical	Continuity and predictability of performance				X							
Technical	Target of primary energy saving				X							
Technical	Capacity Factor	X				X						
Technical	Compatibility with future capacity expansion					X						
Technical	Compatibility with existing infrastructure					X						
Technical	Weather and climate condition dependence					X						
Technical	The duration of preparation+implementation phase						X					
Technical	Technology's autonomy (dependence on resource provision)							X				
Technical	Innovativeness							X				
Technical	Energy not supplied, unmet load	X								X		X
Technical	Decomposability	X										
Technical	Non-redundancy	X										
Technical	Hardware component availability	X										
Technical	Power Quality	X										
Technical	Load Management	X										
Technical	Capacity Constraints	X										
Technical	Unpredictability	X										

KPI type	KPI / Criteria	[25]	[30]	[31]	[32]	[26]	[33]	[34]	[35]	[28]	[27]	[29]
Technical	RES Energy not used or stored											X
Economic	Investment Cost	X	X	X		X	X	X				X
Economic	Operation and Maintenance Cost	X	X	X		X				X		
Economic	Energy cost	X	X	X				X				X
Economic	Fuel cost / savings	X										X
Economic	Payback period	X	X	X			X					
Economic	Internal Rate of Return (IRR)	X	X				X					
Economic	Life Cycle Cost (LCC)	X	X									X
Economic	Net Present Value (NPV)		X	X			X					X
Economic	Service life		X							X		
Economic	Equivalent Annual Cost (EAC)		X									
Economic	Return of Investment (ROI)			X								
Economic	Cost of saved primary energy				X							
Economic	Learning rate					X						
Economic	Current market share					X						
Economic	Dependence on fossil fuel	X				X						
Economic	Tax incentives					X						
Economic	Interference with other utilities					X						
Economic	Availability of funds						X					
Economic	Economic efficiency							X				
Economic	Technology's competitiveness							X				
Economic	External costs	X										
Economic	Proportion of cost being utilized in foreign currency	X										
Economic	National economy contributions	X										
Environmental	CO2 emissions	X	X	X		X	X			X		X
Environmental	Land use	X	X		X	X	X			X		
Environmental	Impacts on ecosystems		X									
Environmental	NOx emissions	X	X	X						X		
Environmental	SO2 emissions	X	X	X						X		
Environmental	Emissions (generally)		X									
Environmental	Noise	X	X									
Environmental	Particles emissions		X									
Environmental	Energy Efficiency			X								
Environmental	Renewable Fraction			X				X				
Environmental	Sustainability according to several environmental impacts				X							
Environmental	Local environmental impact	X				X		X				
Environmental	Need of waste disposal						X	X				
Environmental	Effect on climate change and pollution cuts	X						X				
Environmental	Aesthetic	X										
Environmental	Pollution compared to the year 1992	X										
Environmental	Energy Sources conservations (Non-renewables)	X										
Environmental	Obstruction to navigation	X										
Environmental	Impact on marine life	X										
Environmental	Reduced sea usage	X										
Environmental	Embodied Energy											X

KPI type	KPI / Criteria	[25]	[30]	[31]	[32]	[26]	[33]	[34]	[35]	[28]	[27]	[29]
Environmental	Life cycle assessment											X
Social	Job creation	X	X	X	X	X	X	X		X	X	X
Social	Social acceptability	X	X			X	X	X		X		
Social	Social benefits		X									
Social	Visual impact	X	X									
Social	Local development		X									
Social	Impacts on health		X									
Social	Income from jobs		X									
Social	Benefited Residents			X								
Social	Compatibility with political and legislative situation, international obligations				X		X	X				
Social	Public awareness and willingness					X						
Social	Conflict with other applications					X						
Social	Opportunity for private participation					X						
Social	Degree of local ownership					X						
Social	Support of government institutions, political organizations							X				
Social	Economic Security							X				
Social	Influence on sustainable development of society (education, science, culture)							X				
Social	Social losses due to power outage								X			
Social	HDI (Human Development Index)									X	X	X
Social	Social Cost of Carbon											X
Social	Consumption pattern of a household load in a certain location											X

2.3. Software tools and their indicators

As previously commented, the methods and techniques cited in Section 2.1 can be included computer programs which maximize or minimize the objective function. However, the out-of-the-box solutions provided by end-user software tools began to help a big number of planners to design and optimize the hybrid renewable energy systems in an easy way, with limited knowledge of algorithms, exclusively by using a tool with common user interfaces, familiar to users.

In fact, a considerable number of software tools to design and optimize a HRES have been created for the last two decades. Some of them are still being updated, and other ones were discontinued. There are previous works making a list of the tools which evaluate the operation of renewable energy systems, like Connolly et al. [8], who considered 68 tools used to analyze the integration of renewable energy; Sinha and Chandel [13], who detailed 19 applications with their main features; and Erlwein-Vicua [14], who summarized 36 software programs by starting an online survey on the ResearchGate website.

Lyden et al. [36] considered an initial list of 51 tools which model generic energy systems and, after a task of screening, selected and analyzed 15 tools focused on the modelling of community-scale HRESs which include just storage and demand side management. The work gathered a list of design optimization variables and outputs, some of them linked with social indicators, such as HDI and job creation. Pfenninger et al. [37] looked at how energy models face the challenges seen in today's system; resolving time and space, balancing uncertainty and transparency, addressing the growing complexity and integrating human behaviour and social risks and opportunities. As we will show in Section 3, the spectrum of the gathered tools is wide, and some of them only help planners to simulate, while others manage to optimize the system through different algorithms.

Hilpert et al. [38] assess that there exists a serious social responsibility for modellers as model results are widely used to support policy decisions. Therefore, adhering to scientific standards in energy system modelling is an important matter for model development and application. In the end, models need to meet scientific standards and also public acceptance becomes increasingly important.

Wiese et al. [39] analyses that within the transformation process, model-based analyses have become indispensable for advice addressing a diverse set of questions. Among others, this includes grid control and planning, dispatch and unit commitment, expansion planning, and energy market design, as well as environmental and social analysis of highly integrated energy systems.

Ma et al. [40] present a review of 31 computer tools at different scales (national, regional, and building). In this review, they concluded two social indicators as the most important: job creation, and number of benefited residents. The first points out, how many new jobs are to be created owing to the corresponding systems, while the second measures how much residents can be benefited from the HRES system. This work is focused on techno-economic analysis methods.

Mancarella et al. [41] finally, social acceptability, including impact on comfort, represents perhaps the biggest challenge to quantification within a model. In practical terms, the best that might be achievable is to present constraints on the development of particular technologies, e.g. nuclear power.

3. Results and discussion

In order to assess the HRES tools, Section 3 has been arranged to portray all the results obtained through Tables 3 to 9. Table 3 depicts the inputs and Table 4 shows the outputs of the assessed software tools studied in this review. As observed in Table 5, only one of the latest releases (October 2017) of the HRES software programs considers two social KPIs (the HDI and job creation) to design or optimize this kind of energy systems, and even as constraints to find the ideal solution for a hybrid installation. In fact, this new feature is an implementation of the multi-objective evolutionary algorithm for the optimization of HRESs, considering the mentioned two social parameters, developed by Dufo-López et al. [42], and mentioned previously in Section 2. It is remarkable that Dufo-López is the main developer of iHOGA, another HRES tool here surveyed.

The rest of computer tools work out only economical, technical, environmental outputs. Without this social consideration, it is true that planners can use these tools to determine the goodness of a certain configuration of the hybrid system in terms of money savings, in terms of adequacy for meeting the energy demand, or in terms of emitting less CO_2. But these planners will not be able to conclude if a particular disposition of the system, for instance, creates a bigger number of job positions than another one.

HOMER, the most popular HRES tool, not only calculates output parameters for a particular configuration, but also optimizes the system, choosing an optimal combination of elements, given a specific number of technologies selected by the user, and other fixed constraints, like the energy load. However, HOMER considers the capital cost as the only criterion to optimize the configuration of a hybrid system. This is, the tool tries just to find the option which minimizes the objective function of the net present cost, without the possibility of optimizing other parameters, including not existing social ones.

We must underline the differences among the number of technologies considered by the different computer tools. HOMER and RETScreen are the programs with a higher amount, 20 and 16, while others include a lower sum. The diversity of technologies is important to offer users the possibility of choosing the best solution of the optimal configuration of a hybrid installation. The development of new improved renewable generators is increasing, their cost is declining, and some specific renewable technologies could fit better to the needs of a community or to the characteristic renewable resources of a region. For instance, the six technologies considered by iHOGA could be extended to cover more renewable sources, linking them with their respective job creation and improvement of the HDI.

It is also remarkable the increasing number of HRES tools which are delivered under any of the free software licenses, allowing users not only to use the programs free of charge but also to freely modify the code to adapt it to their needs. It could allow planners and researchers to include, in an easy way, social KPIs and their linked technologies. There are some mentioned but not shortlisted tools, like Photurgen, which was firstly released in 2016 trying, according to their creators Watson et al. [43] to address the lack of tools which are free for use, open for collaborations among regional experts and effective for energy planning involving the renewable sources intrinsic to a specific region. Additionally, NREL (a National Laboratory of the U.S. Department of Energy) decided in August 2017 to make the source of System Advisor Model (SAM) available to the public [44] so as to increase transparency, flexibility, and collaboration opportunities.

Table 3: Inputs of the analyzed tools.

KPI Type	Input Parameter	Units	HOMER	Calliope	RETScreen	DER-CAM	Compose	iHOGA	EnergyPRO
Economic	Initial Generator Costs	$; $/kW	X	X	X	X	X	X	X
Economic	O&M Costs	$; $/kw/yr ; $/Mwh	X	X	X	X	X	X	X
Economic	Replacement Generator Costs	$	X	X	-	-	-	-	-
Economic	Fuel Costs	$; $/l	X	X	X	X	X	X	X
Economic	Finantial parameters (Discount rate, Inflation rate, project lifetime)	several	X	-	X	X	X	X	X
Economic	Subsidies / Feed-in Tariff	$/kWh	X	-	-	X	-	-	X
Economic	Electricity prices	$/kWh	X	X	X	X	-	-	X
Technical	Demand / Load	kWh	X	X	X	X	X	X	X
Technical	Grid features (Annual capacity shortage)	-	X	-	-	-	-	-	X
Technical	Technology features (wind curve, efficiency)	-	X	-	X	X	-	X	X
Technical	Grid / Offgrid	-	X	X	X	X	X	X	X
Technical	Strategies (charging, load,)	-	X	-	-	X	-	X	X
Environmental	Renewable Resource	-	X	X	X	X	X	X	X
Environmental	CO2 emissions per fuel	kg/L	X	-	-	X	X	X	X
Social	Number of persons	-	-	-	-	-	-	X	-
Social	Parameters for HDI calculation	Dimensionless	-	-	-	-	-	X	-
Social	Number of jobs created per technology	-	-	-	-	-	-	X	-

Table 4: Outputs of the analyzed tools.

KPI Type	Input Parameter	Units	HOMER	Calliope	RETScreen	DER-CAM	Compose	iHOGA	EnergyPRO
Economic	Capital Cost	$	X	X	X	X	X	X	X
Economic	O&M cost	$	X	X	X	X	X		X
Economic	Net present cost	$	X	-	X	-	X	X	X
Economic	CoE	$/kWh	X	-	X	X	X	X	-
Economic	Levelized cost per technology	$/kWh	-	X	-	-	X	X	-
Economic	Cost of Fuel	$	X	X	X	X	X	X	X
Economic	Present Worth	$	X	-	-	-	-	-	-
Economic	Annual Worth	$/yr	X	-	-	-	-	-	-
Economic	ROI	%	X	-	-	-	-	-	-
Economic	IRR	%	X	-	X	-	-	-	X
Economic	Simple Payback	yr	X	-	X	-	-	-	-
Economic	Discounted Payback	yr	X	-	X	-	-	-	X
Economic	Debt Payments	$	-	-	X	-	-	-	-
Technical	Demand Not Met	% or kWh/yr	X	X	-	X	-	X	X
Technical	Fuel consumption	L ; kWh	X	X	-	X	X	X	X
Technical	Capacity Shortage, curtailments	kWh/yr	X	-	-	X	-	-	-
Technical	Total Energy produced	kWh/yr	X	-	X	X	X	X	X
Technical	Total Energy consumed	kWh/yr	X	-	X	X	X	X	X
Technical	Energy purchased and sold to the grid	kWh	X	-	X	X	-	X	X
Technical	Excess of electricity (dumped becaused it can not be used to serve a load or charge the batteries)	% / kWh/yr	X	-	-	-	-	-	-
Technical	Weight	kg	X	-	-	-	-	X	-
Technical	Capacity Factor per technology	% / Hours / kWh	X	X	-	X	-	-	X
Environmental	Renewable fraction	%	X		-	X	-	X	-
Environmental	MRP (Maximum Renewable Penetration) in a year	%	X	-	-	-	-	-	-
Environmental	Footprint	m2	X	X	-	-	-	-	-
Environmental	CO2 emissions	kg/yr	X	-	X	X	X	X	X
Social	HDI	Dimensionless	-	-	-	-	-	X	-

KPI Type	Input Parameter	Units	HOMER	Calliope	RETScreen	DER-CAM	Compose	iHOGA	EnergyPRO
Social	Jobs created	-	-	-	-	-	-	X	-

Table 5: Constrains of the analyzed tools.

KPI Type	Input Parameter	Units	HOMER	Calliope	RETScreen	DER-CAM	Compose	iHOGA	EnergyPRO
Economical	Levelized cost of energy	\$/Mwh	-	X	-	-	-	X	-
Technical	Demand Not Met or Capacity shortage	% / kWh/yr	X	-	-	-	-	X	-
Technical	Number of days of autonomy	days	-	-	-	-	-	X	-
Technical	Operating reserve	%	X	-	-	-	-	-	-
Technical	Nominal Capacity of Batteries bank	Ah	-	-	-	-	-	X	-
Technical	Minimum part-load operation	0/1	-	-	-	X	-	-	-
Technical	Maximum number of hours per tech	hours/yr	-	-	-	X	-	-	-
Technical	Zero Net Energy	-	-	-	-	X	-	-	-
Environmental	Renewable fraction	%	X	-	-	-	-	X	-

Table 6 summarises the software analyzed (HOMER, Calliope, RETScreen, DER-CAM, Compose, iHOGA, and EnergyPRO) with respect to the capabilities of use. It is noticeable that plenty of them limit the use of their features to a free trial version. Regarding, the optimisation features (see Table 7), it is easy to observe how iHOGA is the most complete tool, since it is not only based on a technical and economic analysis, but also takes into consideration the social impact over the inhabitants benefited from the HRES. Whereas Table 8 shows all of the energy technologies covered in this paper through the analysis of the HRES modelling software, a vast amount of renewable systems are prone to be combined in a hybrid system with any fossil fuels source e.g. diesel generator, natural gas generator, etc. Table 8 shows that HOMER is the software which integrates a wide range of technologies into its structure, this being a bonus for both end-users and the designers. On the other hand, Calliope resulted as the less thorough software because of the lack of energy sources, and the fact that it has been addressed to cover generic systems, leading to a non-realistic usage.

Table 6: Analyzed tools. Evaluated versions.

	HOMER	Calliope	RETScreen	DER-CAM	Compose	iHOGA	EnergyPRO
Version number	3.8.6.0	0.5.4	6.0.7.55	4.4.1.4	3.14.11.105	2.4	4.4.340
Mode	Pro	-	Expert	Full User Level	-	EDU	Unregistered
License	30-days Free Trial	Open Source	Free (Viewer)	n/a	n/a	Free for training	Free

Table 7: Analyzed tools. Optimization features.

	HOMER	Calliope	RETScreen	DER-CAM	Compose	iHOGA	EnergyPRO
Optimization	Lowest Net Present Cost	Lowest Cost of Energy	-	Lowest total energy costs; lowest CO2 emissions. Multi-objective combination of both criteria	-	Lowest Net Present Cost; Lowest CO2 emissions; Lowest unmet load; Highest HDI; Highest job creation. Double or Triple, through Pareto.	-
Sensitivity	X	-	-	-	-	Only PRO version	-

Table 8: Analyzed tools. Energy technologies covered.

	HOMER	Calliope	RETScreen	DER-CAM	Compose	iHOGA	EnergyPRO
Generic System	X	X	-	-	-	-	X
PV	X	-	X	X	X	X	X
High concentration PV	-	-	-	-	-	-	-
Wind	X	-	X	X	X	X	X
Biomass	X	-	-	-	-	-	-
Geothermal	-	-	X	-	X	-	-
CSP	-	-	X	-	-	-	-
Batteries	X	-	X	X	X	X	X
PumpedHydro	X	-	-	-	-	-	-
Flywheel	X	-	-	-	-	-	-
Supercapacitor	X	-	-	-	-	-	-
Combined Heat Power	X	-	-	X	-	-	X
Hydro	X	-	X	-	-	X	-
Hydrogen	X	-	-	-	-	-	-
Reformer	X	-	-	-	-	-	-
Electrolyzer	X	-	-	-	-	-	-
Biogas Generator	X	-	X	-	-	-	-
Diesel Generator	X	-	-	-	X	-	-
AC Generator	-	-	-	-	-	X	-
LP-vapor / LPG	X	-	X	-	-	-	-
Natural Gas Generator	X	-	X	-	-	-	-
Gas turbine Combined Cycle	-	-	X	-	X	-	-
Hydrokinetic	X	-	-	-	-	-	-
Converters	X	-	-	-	-	-	-
Grid	X	-	-	-	-	-	-
Fuel Cell	X	-	X	X	-	X	-
Ocean current	X	-	X	-	-	-	-
Recipocrating engine	-	-	X	-	-	-	-
Steam Turbine	-	-	X	-	-	-	-
Tidal power	X	-	X	-	-	-	-
Wave	X	-	X	-	-	-	-

Table 9 portrays all the software previously analysed with the perspective of the interaction with the core of the tool. In this case, Calliope resulted as complete as HOMER. Nevertheless, Calliope is lightly superior than HOMER because it is completely programmable, whereas HOMER only allows managing control strategies. Additionally, HOMER, Calliope, and RETScreen are able to export data in .CSV format, while DER-CAM, Compose, and IHoga are only able to export data in .XLS format. Finally, EnergyPRO only exports files in .PDF format, which is disadvantageous in many circumstances.

Table 9: Analyzed tools. Interactivity with the core of the tool.

	HOMER	Calliope	RETScreen	DER-CAM	Compose	iHOGA	EnergyPRO
API	Only for control strategies	Completely Programmable (Open Source)	-	-	-	-	-
Export data	Export of data to CSV format	All outputs are in CSV format	To CSV, only in the Professional mode.	Save XLS files	Excel Export	Save XLS files	Only PDF reports

4. Discussion about HRES and its social linkage

This part of the paper is used to establish the existing relationship between HRES softwares and the society, since the first is aimed at developing or planning energy solutions to meet the society needs. Each of the energy generation technologies has its own economic features (e.g. different initial costs) or its own technical features (e.g. different wind turbine power curves). In just the same way, each technology leaves a mark in the surrounding society. Therefore, there are some social indicators which can be linked with each one of the technologies. In this section, we try to enumerate only a few of them in order to show the significance an optimization covering also social KPIs can offer to a HRES planner.

For instance, according to some authors [45], renewable energy sources can create more jobs per unit of currency invested than conventional ones, although it also depends on how many stages of production are carried out in the region. This is noticeable in some regions where the penetration of renewables is rising up. In the United States, solar technologies, both photovoltaic and concentrating, employ almost 374,000 workers, or 43% of the Electric Power Generation workforce in 2016, followed by fossil fuel generation employment, which accounts for 22% of the employment and supports 187,117 workers across coal, oil, and natural gas generation technologies combined [46]. Twice as many solar jobs as fossil-fuel jobs, with nearly twenty times less cumulated installed capacity. This statement was also verified by Wei et al. [47], who found that all non-fossil fuel technologies create more jobs per unit energy than coal and natural gas. This would lead us to consider specific installations over the rest of energy sources, under the same conditions of costs, yielded energy, and other technical, economic, or environmental criteria.

Additionally, some kind of renewable sources create a higher number of jobs and also increase the social value of specific areas rather than in others. For instance, the Portuguese Government tries to create biomass plants at a local level, encouraged by the municipalities, to empower these areas and reduce the forest fire risk [48], and Madrigal et al. [49] claimed that forest biomass collection for energy in the Mediterranean basin reduces fire hazard, but only if both tree and shrub strata are managed at landscape level. Consequently, a proper design of a HRES should consider not only the social impact of the renewable technologies but also the geography where the renewable plants would be located.

Additional improved benefits of an optimal design of a HRES following social criteria could be the enhanced adequacy to the needs of the different social classes. Traditionally, the lack of electrical supply has been solved by optimization models and tools just with the minimization of the objective function of Loss of Load or Loss of Energy, through LOLP and LOEP calculations. However, the factor only lack of MWh and not the harm which this inadequacy could produce to some sectors of the population. Some authors proposed alternatives to measure this damage; Barnes et al. [50] introduced a demand-based approach to define the energy poverty through a threshold point at which households consume a bare minimum level of energy needed to sustain life. And Nussbaumer et al. [51] proposed a new composite index to measure energy poverty, focused on the deprivation of access to modern energy services. The optimization techniques should consider this damage over disadvantaged consumers, without giving up to balance any possible beneficial effect over the system or other consumers.

This approach of considering the different needs to each one of the citizens consuming the electricity is also on the agenda of the lawmakers. In this way, the European Commission is making a big effort to develop the Energy Union Strategy [52], which will try to provide additional measures to protect vulnerable consumers and empower consumers further to participate fully in the market. In fact, the existence of possible incomes for the consumers, themselves could be considered as a social KPI to be analyzed. This new type of agents, the prosumers, both consume and produce energy and can participate in different markets. According to Parag and Sovacool [53], prosuming can enable consumers to save money while also contributing to wider social benefits by diversifying energy supply.

In general, social and environmental indicators are antagonist to technical and economic ones [23]. Hardly ever it could be found a global optimum that maximize all the indicators at the same time so the objective is to build the so called Pareto Frontier of the problem. Namely, the set of solutions where it is not possible to improve any indicator without worsening the rest of them. The theory indicates that all solutions of the Pareto Frontier ar optimal but in realistic scenarios only one can be taken. To solve this problem, there are several methodologies. For example, hardly ever all indicators are given the same importance. So an extremely easy method is just to take the one that maximize this indicator on the Pareto Frontier or a weighted sum of the indicators [54]. Moreover, other more complex solution to this problem exists like qualitative analysis, sensitivity analysis, or post pareto pruning algorithm [55]. For a detailed introduction on the topic, please consult [56]

5. Forecasting future energy scenarios

These lines of the research are aimed to briefly forecast the energy scenarios and their impact on the society. Ram et al. [57] predicted that the higher growth of electricity consumption is going to take place in developing regions where, according to Kaundinya et al. [58], more than 50% of the population resides in rural regions. In these regions, the cost of electricity becomes very expensive and unaffordable to the rural habitants, giving rise to a reduced standard of living and social inequity. For that reason, the interest for HRESs is increasing as a way to provide sustainable energy independence for small communities, as stated by Neves et al. [59]. Additionally, Deshmukh and Deshmukh [60] concluded that HRESs are mainly recognised for remote area power applications.

We can anticipate a global scenario in 2050 where the medium-large installations will be majority within the total installed capacity, since projections of Ram et al. [57] forecasted that the cumulative installed capacity of solar PV at a utility-scale will be 55% of the joined capacity of PV utility scale, PV rooftop, and wind (technology with medium-high generators). Thus, the PV rooftop capacity will be prevailing only in Europe and North America, regions where higher incomes allow prosumers to install their own small generators in buildings, whereas plants with medium-high dimensions are going to help with the energy transition in developing regions, especially in rural areas, during the next decade.

We also considered the number of energy generation technologies included by the tools, and this inclusion must be such that the users do not need to program any additional software. According to the projections of Ram et al. [57] and International Energy Agency ('Sustainable Development' scenario) [61] for installed capacities of power, during the energy transition of the next decade the generation technologies with a higher growth rate are both solar PV and wind, having also the largest installed capacity at the end of the analyzed period.

Ram et al. [57] forecasted that, starting in the 231 GW of solar and 372 GW of wind installed in 2015, in 2030 there will be 6,980 GW of solar and 3,293 GW of wind, and in 2050 there will be 21,959 GW of solar and 3,154 GW of wind. This growth and leadership is constant in all the nine major regions considered in the study. IEA forecasted [61] also an appreciable growth of solar PV and wind technologies, passing from 225 GW and 414 GW in 2015 to 3,246 GW and 2,629 GW in 2040 ('sustainable development' scenario), and to 2,067 GW and 1,664 GW in 2040 ('current policies' scenario), being by far the two fastest growing energy sources.

The cumulative capacity of the installed batteries is going to rise, as stated in the report by Ram et al. [57], from 2 GWh in 2015 to 47,858 GWh in 2050, producing more electricity than the wind plants at the end of the period. The expected level of renewable penetration is going to cause a high variability of the generated energy, which must be mitigated with the introduction of storage technologies which ensure the stability in the electrical system. According to Y. Liu et al. [62], batteries is the storage technology which help with a higher range of power dimensions. Following these figures of projections, along with the features of theses technologies, we could forecast that HRES tools will have to consider, without programming anything additional, the possibility of including -at least- solar PV, wind, and batteries.

6. Conclusions and future works

The arrival of different types of renewable and storage technologies with increasingly lower costs is helping communities to access affordable electricity through the implementation of HREs. Alongside the growth in popularity of the HREs, a novel sort of software tools have emerged to help planners to design and optimize these systems.

As a result, there is a growing number of works taking into account not only economical, technical or environmental indicators, but also considering social criteria when designing and optimizing general renewable energy systems. Consequently, the implementation of HRESs could also be improved by the addition of social parameters, affecting not only the economics, reliability or amount of emissions of CO_2 emissions, but also raising the social impact and social acceptance of the installations.

We found however, that the vast majority of the popular software tools used by the planners to design and optimize HRESs do not include the possibility of considering factors like the job creation or social acceptance. Only the very last version of one of the programs, iHOGA, has recently included the functionality of designing improved system configurations based on the maximization of two social KPIs: HDI and job creation. This computer program has an important limitation for small communities since it is commercial software and full use is limited to paying a license fee.

Therefore, this is a real opportunity for the original developers of these commercial and open source tools to boost their features and offer additional capabilities to their users, especially those which design and optimize HRESs located in small communities. The number of social KPIs included in the commercial programs could be increased, as well as the number of technologies linked with these social parameters, to allow planners of different regions of the world to make the most of the peculiar sociodemographic structures or local specific renewable resources.

Additionally, the improved tools could consider the possibility of interacting programmatically with the results, or even provide open source versions of the tools, in order to help the planners of HRESs to sharpen the calculations by freely modifying the software code so as to adapt it to their own needs. It even presents an inviting space for those researches who want to establish their own methodology which, being supported by the calculation of these computer programs, enhances their possibilities by including social inputs, outputs and constraints.

Future work will investigate cover two directions. On one hand, we will go deeper into the research and assessment of the social impacts of the different generation technologies, following the work started in Section 2.1, even trying to find different KPIs. On the other hand, we will develop new procedures to include social impacts, by using the valuations obtained previously, in the process of optimizing HRESs through the use of any of the shortlisted software tools.

7. Acknowledgements

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Appendix A. Information and features of all the examined tools

Table A.10: List of all the examined tools.

Name	Developer	URL	Licenced	Issues with the facets (kind of tool, energy scope, scale of projects, technologies covered)	Last version	Interactable through computer programming (through API, SDK, etc.)	Considered for the analysis
RETScreen Expert	Government of Canada (Formerly, RETScreen International)	http://www.nrcan.gc.ca/energy/software-tools/7465	Free for Viewer mode. Paid for the rest.	Ok	6.1.0.27 (January 2018)	"Planned (Pilot ""RETScreen Connect"")"	Yes
HOMER Pro	HOMER Energy LLC (formerly, NREL)	http://www.homerenergy.com/	Paid, with a free demo	Ok	3.12.3 (02.10.2018)	HOMER SaaS API allows to create a web interface interacting with the HOMER computation engine hosted in the cloud	No
Homer Quickstart	HOMER Energy LLC (formerly, NREL)	http://quickstart.homerenergy.com/	Free for a limited period	Ok	Online	No	No
HOMER Legacy	HOMER Energy LLC (formerly, NREL)	http://www.homerenergy.com/HOMER˙legacy.html	Free for academics, and non-profits.	Ok	2.68 (July 24, 2009), out of date	-	No
LEAP	Stockholm Environment Institute	http://www.energycommunity.org/LEAP/	Free for students, developing country Govts, and NGOs. Paid for the rest.	Scale of the projects: Regional	-	API which controls LEAP directly, changing data values, calculating results, etc.	No
BCHP Screening Tool	Oak Ridge National Laboratory	http://eber.ed.ornl.gov/bchpsc/	Free	-	2007, out of date	-	No
EnergyPRO	EMD International A/S	http://www.emd.dk/energypro/	Paid, with a free demo	Ok	4.5.358 (September 2018)	No	Yes
H2RES	Faculty Of Mechanical Engineering and Naval Architecture, University of Zagreb	http://h2res.fsb.hr/	Internal use only	Not able to calculate hybrid combined technologies	2009 (v2.8), out of date	-	No
SAM	National Renewable Energy Laboratory (NREL)	https://sam.nrel.gov/	Free (after free registration) and Open Source	Can not simulate hybrid systems (only one technology configurations)	2018.11.11 (November 2018)	SSC SDK and Open Source	No
Hybrid2	University of Massachusetts, Wind Energy Center	https://www.umass.edu/windenergy/research/topics/tools/software/hybrid2	Free, but unsupported	-	2.1.3 (April 2011)	-	No
iHOGA	Dr. Rodolfo Dufo, University of Zaragoza, Electrical Engineering Department	https://ihoga-software.com/	Free limited edition for educational purposes, and paid Pro version.	Ok	2.4 (17.07.2018)	No	Yes
Insel	doppelintegral GmbH	http://www.insel.eu/	Paid	-	8 (August 2014)	-	No
TRNSYS	Thermal Energy System Specialists, LLC	http://www.trnsys.com	Paid, with a free demo	General purpose simulation software	18 (2017)	-	No

Name	Developer	URL	Licenced	Issues with the facets (kind of tool, energy scope, scale of projects, technologies covered)	Last version	Interactable through computer programming (through API, SDK, etc.)	Considered for the analysis
iGRHYSO	University of Zaragoza, Electrical Engineering Department	Existing http://www.unizar.es/rdufo/grhyso.htm was deleted	Paid	-	1.0 (October 2012), out of date	-	No
RAPSIM	Networked and Embedded Systems - Alpen-Adria-Universitt Klagenfurt	https://rapsim.sourceforge.io/	Free and open-source	Technologies covered: Storage not included	0.95 (20.04.2016)	-	No
Modelica / Open Modelica	Open Source Modelica Consortium	https://openmodelica.org	Free and open-source	General purpose simulation software	1.12.0 (26.10.2017)	Open Source	No
EnergyPLAN	Sustainable Energy Planning Research Group at Aalborg University	http://www.energyplan.eu/	Freeware	Scale of the projects: Countries	13.1 (October 2017)	-	No
Invert/EE-Lab	Technische Universitt Wien in Kooperation mit e-think	http://www.invert.at	-	Scale of the projects: Buildings, lighting	-	-	No
Markal/Times	IEA-ETSAP	http://iea-etsap.org/index.php/etsap-tools/model-generators/times	Priced	General purpose simulation software	-	-	No
Message	International Institute for Applied Systems Analysis (IIASA)	http://www.iiasa.ac.at/web/home/research/researchPrograms/Energy/MESSAGE.en.html		Scale of the projects: national or global regions	-	-	No
Generation Economic Modeling and Dispatch (ORCED)	Oak Ridge National Laboratory	No website found	-	-	-	-	No
Wien Automatic System Planning Package (WASP)	International Atomic Energy Agency	http://www-pub.iaea.org/books/IAEABooks/5682/Wien-Automatic-System-Planning-WASP-Package–A-Computer-Code-for-Power-Generating-System-Expansion-Planning-Version-WASP-III-Plus-User-s-Manual-Volume-II-Appendices	Free	-	1999, out of date	-	No
EMCAS	Argonne National Laboratory	http://ceeesa.es.anl.gov/projects/emcas.html	Paid	-	2005, out of date	-	No
EMPS	Sintef	https://www.sintef.no/en/software/emps-multi-area-power-market-simulator/	Commercial Licence or students with very limited use.	-	-	-	No
ENPEP-BALANCE	Argonne National Laboratory	http://ceeesa.es.anl.gov/projects/Enpepwin.html	Free	-	2.2 (February 2008), out of date	-	No
GTMax	Argonne National Laboratory	http://ceeesa.es.anl.gov/projects/Gtmax.html ; http://www.adica.com/software.html	Paid	Scale of the projects: Regional or national generation and transmission systems	6.5 (October 2014), out of date	-	No
Ikarus	Forschungszentrum Jlich	Not found. Neither download link nor webpage with updated information about a tool.	-	-	No version found	-	No
Inforse	International Network for Sustainable Energy (INFORSE)	Not found. Neither download link nor webpage with updated information about a tool.	-	-	No version found	-	No

Name	Developer	URL	Licenced	Issues with the facets (kind of tool, energy scope, scale of projects, technologies covered)	Last version	Interactable through computer programming (through API, SDK, etc.)	Considered for the analysis
Mesap PlaNet	University of Stuttgart, Seven2one Informationssysteme GmbH	Not found. Neither download link nor webpage with updated information about a tool.	-	-	No version found	-	No
NEMS	US Energy Information Administration	http://www.eia.gov/outlooks/aeo/info˙nems˙archive.cfm	Free upon request	Scale of the projects: Regional or national.	2017	Open Source	No
Perseus	Karlsruhe Institute of Technology	Not found. Neither download link nor webpage with updated information about a tool.	-	-	No website found	-	No
ProdRisk	Sintef	https://www.sintef.no/en/software/prodrisk/	Paid	-	-	-	No
RAMSES	Danish Energy Agency	https://ens.dk/en/our-services/projections-and-models/models	Not publicly available	-	7 (15.12.2015)	-	No
SIVAEL	EnergiNet DK	http://www.energinet.dk/DA/El/Udvikling-af-elsystemet/Analysemodeller/Sider/Sivael.aspx	-	-	Not maintaining any longer	-	No
EMINENT	Instituto Superior Tcnico, Technical University of Lisbon	Found papers about the model. Neither download link nor webpage with updated information about a tool.	-	-	No version found	-	No
PRIMES	National Technical University of Athens	http://www.e3mlab.ntua.gr/e3mlab/index.php?option=com˙content&view=category&id=35&Itemid=80&lang=en	Not publicly available	-	-	-	No
BALMOREL	Community	http://www.balmorel.com/	Free and open	Scale of the projects: Regional	3.02 (May 2011), out of date	Open Source	No
E4cast	ABARES, Department of Agriculture and Water Resources of Australia	Not found. Neither download link nor webpage with updated information about a tool.	-	-	No version found	-	No
HYDROGEMS	Institut for Energieteknikk	Not found. Neither download link nor webpage with updated information about a tool. According to archive.org, the website is down since 2009	-	-	No version found	-	No
GCAM (formerly, MiniCAM)	Joint Global Change Research Institute, University of Mariland	http://www.globalchange.umd.edu/gcam/download/ ; http://www.globalchange.umd.edu/gcam/	Free to download. Open Sourced.	Scale of the projects: world and regional scenarios	4.4 (06.11.2017)	Open Source	No
SimREM	Institute for Sustainable Solutions and Innovations (iSUSI)	http://www.isusi.de/index.html	Not for third parties. Only internal use to make studies on demand.	-	-	-	No
STREAM	Ea Energy Analyses, Risoe DTU	http://www.streammodel.org/	Free to download	Scale of the projects: regional	v2	-	No
UniSyD3.0	Unitec New Zealand	"Not found. Neither download link nor webpage with updated information about a tool. Apparentely, the model was in 2009 available ""under negotiated terms"" with a Professor of Unitec."	Available only under negotiated terms	-	-	-	No
WILMAR (Wind Power Integration in Liberalised Electricity Markets) / JMM (Joint Market Model)	Risoe, Universitt Duisburg-Essen	http://www.wilmar.risoe.dk/Results.htm	Not available	Scope of the projects: Electricity markets	No version found	-	No
PowerFactory	DIgSILENT	http://www.digsilent.de/index.php/products-powerfactory.html	Commercial Licence	-	v2018	-	No

Name	Developer	URL	Licenced	Issues with the facets (kind of tool, energy scope, scale of projects, technologies covered)	Last version	Interactable through computer programming (through API, SDK, etc.)	Considered for the analysis
OSeMOSYS	Division of Energy System Analysis. KTH Royal Institute of Technology	http://www.osemosys.org/	Free and open	General purpose simulation software	Model 2016˙08˙01 (01.08.2016)	Open Source	No
DER-CAM	Berkeley Lab	https://building-microgrid.lbl.gov/projects/der-cam	Web services, Acces upon request	Ok	4.4.1.4 (27.04.2016)		Yes
Greenius	Deutsches Zentrum fr Luft- und Raumfahrt e.V.	http://freegreenius.dlr.de/	Free	Technologies covered: it does not offer the possibility of choosing more than one technology	4.3.1 (23.08.2016)	-	No
META	Energy Sector Management Assistance Program (ESMAP, Worl Bank)	http://esmap.org/META	Free to download	Kind of tool: General purpose simulation software	1.4 (August 2012), out of date	-	No
IntiGIS	Ciemat	http://www.ciemat.es/portal.do?IDM=271&NM=2	Free to download	-	2012, out of date	-	No
(TEMOA)”	NC State University	http://temoaproject.org/	Free and open sourced	Kind of tool: General purpose simulation software	December 2016	Open Source	No
Calliope	Individual (Stefan Pfenninger)	https://www.callio.pe/	Free and open sourced	Ok	0.6.3 (03.10.2018)	Open Source	Yes
DIETER	DIW Berlin	http://www.diw.de/de/diw˙01.c.508843.de/forschung˙beratung/nachhaltigkeit/umwelt/verkehr/energie/modelle/dieter/dieter.html	Free and open sourced	Scale of the projects: National Grid	1.2.0 (12/02/2017)	Open Source	No
HYBRIDS	Solaris Homes	No webpage found with information at ’solarishomes.com’	-	-	No version found	-	No
SOMES	Utrecht University	No webpage found with information at ’uu.nl’. Found references of 2005, mentioning licenses upon demand.	-	-	No version found	-	No
SOLSTOR	Sandia National Laboratories	Not found any information at ’sandia.gov’. No longer mantained	-	-	No version found	-	No
Hysim	Sandia National Laboratories	Not found any information at ’sandia.gov’. No longer mantained	-	-	No version found	-	No
HybSim	Sandia National Laboratories	No website found with link to download or obtain a license at ’sandia.gov’.	-	-	No version found	-	No
IPSYS	Risoe DTU	Only old information found at ’dtu.dk’. No link to download or obtain a license.	-	-	No version found	-	No
HYSYS	Ciemat	The only reference to ’Hysis’ found at ’ciemat.es’ is a third party software, called ’Aspen Hysys’, focused on oil and gas producers	-	-	No version found	-	No
ARES	Cardiff school of Engineering	Not found any link to download or obtain a license at ’cardiff.ac.uk’ or ’wales.ac.uk’.	-	-	No version found	-	No
SOLSIM	Fachhochschule Konstanz	No website found with link to download or obtain a license at ’htwg-konstanz.de’	-	-	No version found	-	No
Hybrid Designer	University of Cape Town	No website found with link to download or obtain a license at ’uct.ac.za’	-	-	No version found	-	No
GenOpt	University of California (through Lawrence Berkeley National Laboratory)	http://simulationresearch.lbl.gov/GO/	Free and Open	Kind of tool: General purpose optimization program	3.1.1. (March 2016)	Open Source	No
EnergyPlus	National Renewable Energy Laboratory (NREL)	https://energyplus.net/	Free and Open	Scale of the projects: buildings	9.0.1 (09.10.2018)	Open Source	No

Name	Developer	URL	Licenced	Issues with the facets (kind of tool, energy scope, scale of projects, technologies covered)	Last version	Interactable through computer programming (through API, SDK, etc.)	Considered for the analysis
Dynamic Energy, Emissions, and Cost Optimization (DEECO)	Technical University of Berlin	http://www.iet.tu-berlin.de/deeco/	-	-	2006, out of date. No specific URL with download information found	-	No
Externe	IER, University of Stuttgart	http://www.externe.info/externe˙d7/?q=node/2	-	Energy scope: Emissions and environmental costs	-	-	No
ODESSE (Optimal Design for Smart Energy)	ENEA (Italian Agency for New Technologies and Energy)	http://www.enea.it/it/Ricerca˙sviluppo/ricerca-di-sistema-elettrico/Risparmio-energia-elettrica/tecnologie-per-lefficienza-energetica-nei-servizi/odesse-1	Free to download	Scale of the projects: Buildings	-	-	No
ViPOR (Village Power Optimization Model for Renewables)	NREL	http://analysis.nrel.gov/vipor/	-	-	No version found. No specific URL with download information found	-	No
ETEM	ORDECSYS	http://www.ordecsys.com/en/etem	Free and Open	Kind of tool: General purpose optimization program	Aug 2009, out of date	Open Source	No
EINSTEIN				Energy scope: Thermal sources	-	-	No
OSMOSE	cole Polytechnique Fdrale de Lausanne EPFL	http://leni.epfl.ch/osmose	-	-	No longer available	-	No
Brookhaven Energy System Optimization Model (BESOM)	-	No website found	-	-	-	-	No
CEPEL (MELP and MATRIZ)	Electrobras Cepel	http://www.cepel.br/linhas-de-pesquisa/menu/planejamento-da-expansao-da-geracao.htm	Versions for academics	Scale of the projects: Regions	-	-	No
CHPSizer	eDecisions	http://www.chidwick.ca/?page˙id=69	-	Energy scope: CHP systems	-	-	No
DREAM	Energiekaart	http://energiekaart.net/dream-energy-streams-buildings/	-	Scale of the projects: Buildings	-	-	No
Energy Flow Optimisation Model (EFOM)	Dipartimento di Elettrotecnica ed Elettronica, Politecnico di Bari	https://doi.org/10.1016/S1364-0321(03)00004-2	-	Scale of the projects: Regions	No version found	-	No
Endur	-	No website found	-	-	No version found	-	No
Greenhouse gases, Regulated Emissions, and Energy use in Transportation (GREET)	Argonne National Laboratory	https://greet.es.anl.gov/	-	Energy Scope: Transportation model	-	-	No
HUD CHP Screening Tool	U.S. Departments of Housing and Urban Development and Energy	https://www.hud.gov/program˙offices/comm˙planning/library/energy/software	Free to download	Scope of the projects: Buildings	April 2008, out of date	-	No
HYPRO	U.S. Office of Energy Efficiency & Renewable Energy	No updated website found	-	Energy Scope: Hydrogen	No version found	-	No

Name	Developer	URL	Licenced	Issues with the facets (kind of tool, energy scope, scale of projects, technologies covered)	Last version	Interactable through computer programming (through API, SDK, etc.)	Considered for the analysis
MENSA	Bureau of Agricultural Resource Economics (ABARE)	No updated website found	-	-	No version found	-	No
National Electric Sys-tem Simulation Integrated Evaluator (NESSIE)	Electric Power Research Institute	No updated website found	-	-	No version found	-	No
PSR	-	No website found	-	-	No version found	-	No
Samplan	-	No website found	-	-	No version found	-	No
Phoenix (previously known as SGM)	Joint Global Change Research Institute	http://www.globalchange.umd.edu/archived-models/phoenix/	Not available	-	No version found	-	No
UREM	University of Regina	Not found any website with information, even within uregina.ca domain.	-	-	No version found	-	No
CEEM	-	No website found	-	-	No version found	-	No
CHP capacity optimizer	Oak Ridge National Laboratory	No website found	-	Energy scope: CHP systems	No version found	-	No
DIMES	-	No website found	-	-	No version found	-	No
E3database	LBST	http://www.e3database.com/	Licenced	-	-	-	No
Environmental Defense Fund‘s Electric Utility Financial & Production Cost Model (Elfin)	US Department of Energy	No website found	-	-	No version found	-	No
GmBH	-	No website found	-	-	No version found	-	No
H2A analysis	NREL	https://www.hydrogen.energy.gov/h2a˙analysis.html	-	Energy scope: Hydrogen	-	-	No
HyDIVE	NREL	No website found	-	Energy scope: Vehicles energy	No version found	-	No
HyTrans	Oak Ridge National Laboratory	No website found	-	Energy scope: Vehicles energy	No version found	-	No
MOREHyS (Model for Optimisation of Regional Hydrogen Supply)	French-German Institute for Environmental Research (DFIU/IFARE)	No website found	-	Energy scope: Hydrogen	No version found	-	No
PSAT (Powertrain Analysis Toolkit)	Argonne National Laboratory	No website found	-	Energy scope: Vehicles energy	No version found	-	No
Ready Reckoner	-	No website found	-	-	No version found	-	No
SEDS	NREL	https://seds.nrel.gov/	-	Scale of the projects: U.S. Electric Power System	-	-	No
Time-stepped Energy System Optimization Model (TESOM)	Brookhaven National Laboratory	Old model with no current website with up-to-date information.	-	-	-	-	No
EAM	-	No website found	-	-	No version found	-	No

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