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A critical analysis on hybrid renewable energy modeling tools: An emerging opportunity to include social indicators to optimise systems in small communities

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ABSTRACT

The arrival of different renewable energy and storage technologies with lower costs is helping smaller communities to gain access to affordable electricity resources through energy systems fed from heterogeneous generation resources. With the growing popularity of Hybrid Renewable Energy Systems (HRES), a novel kind of end-user software tool has also emerged to help planners optimize such energy installations. At the same time, there is an increase in the number of research articles that warn about the need for considering social indicators such as job creation and social acceptance when designing HRESs in addition to the usual considerations of economical, technical, and environmental criteria. Consequently, the design of HRESs could also be optimized by adding such new social parameters. Mainly, this article presents a complete review of the most popular tools for designing HRESs, and the main conclusion of this survey is that these tools do not consider social factors which is a real opportunity to boost the capabilities of such software packages. Also, this research provides valuable information for the developers of HRES optimization tools, providing them, on the one hand, with insights about the advantages of including social parameters during technology assessment and, on the other hand, with a guide to help them with selecting the most pertinent tool at each case, allowing designers to make the most of the socio-demographic structures and obtain more advantages from local renewable resources.

1. Introduction

The reduction of the initial costs of some energy technologies is helping the poorest regions of the world with catching up with the train of electrification which speeds up their economic and social development [1–3]. Since there is an increasing number of generation technologies (both classical and modern) [4], the concept of Hybrid Renewable Energy Systems (HRESs) [5] was developed, and it refers to systems that combine several such technologies with the aim of implementing the most suitable solution in each case [6]. After all, hybrid designs create multiple possibilities for improvement such as reducing renewable energy intermittency, achieving a higher overall production and attaining higher production rates [7].

The design of suitable energy systems is very important, and it should take into account concepts such as the proper selection of energy sources and the size and location of the system itself in order to reduce costs, fulfill energy demands, minimize CO_2 emissions, and satisfy any other relevant requirements (see Fig. 1). Given the great variety of configurations and the complexity of this matter, the concept of system optimization emerged as a tangible approach [8]. Fortunately, the development of computational technologies and new algorithms [9] has fostered the creation of a wide range of optimization perspectives. Additionally, the recent development of tools, which are designed to be used by energy planners with scarce skills in software development managed to help energy professionals with the processes of HRESs planning and design without having to worry about the underlying mathematics [10].

When dealing with the optimization of HRESs, the great majority of the available computational programs analyze indicators related to the technical, economic, and environmental operation of the system such as the initial cost of the HRES or the share of renewable energy. Nevertheless, there are some facts suggesting that the traditional analysis that is solely based on the technical, economic, and environmental operation is not enough to find the optimal design. For example, thousands of people protested in Hawaii against the setting of a new telescope, while in Mexico, the renewable energy movement faced substantial opposition from local communities [11]. Moreover, Wolsink [12] reminds us that

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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
H2A	Hydrogen analysis
HDI	Human development index
RES	Renewable energy system

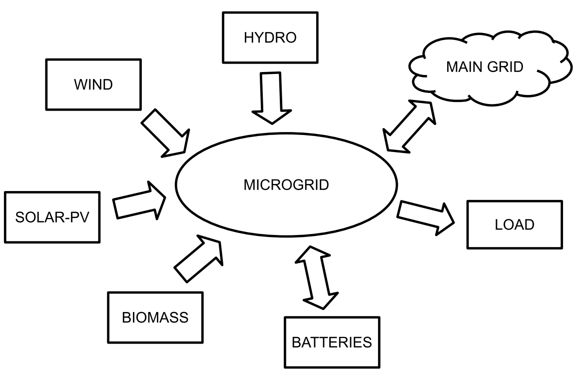

Fig. 1. Diagram of a simple hybrid renewable energy system (HRES).

smart microgrids have social foundations since they consist of decentralized socio-technical networks that form a community with high levels of interactions between the actors. So, social perspective should be analyzed with respect to its relationship with society for long-term acceptance and support [13], as with any energy source that has a clear ubiquitous impact on large communities or nations.

As a result, HRES tools are required to ensure a green future that is fair and sustainable for everybody, a future that is inclusive and respectful towards nations, cultures, and religions that might differently look at the world and its progress. Therefore, why not consider the social outcome of a microgrid, at the same level of the economic, environmental and technical outcomes?

To this end, it is necessary to contemplate an approach that takes into consideration the benefits to local communities and society as a whole. Over the last few years, some authors supported the inclusion of social indicators, such as job creation and social acceptance, and that can measure the impact on the suitability of an energy system to local communities. Nevertheless, the techniques used to optimize hybrid energy systems in general, and end-user software tools in particular, have not traditionally considered such indicators. In fact, they have been focused on selecting the best solution based on a specific economic objective function, considering the values of economic (capital cost, cost of energy, etc.), technical (demand not met, fuel consumption, etc.), and environmental indicators (CO_2 emissions, renewable fraction, etc.) with a specific configuration that is 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 which combine traditional and renewable energy sources, storage, and load management, with cutting edge algorithms to optimize solar storage, and reduce the overall energy costs. HOMER optimizes the Net Present Cost (NPC) as the objective function: an economic criterion that is minimized during each optimization loop of the algorithm.

The present study analyzes the way in which the most relevant current software tools cover the inclusion of social indicators to optimize HRESs. This approach, not yet covered in academic research, has enormous potential to assist in the design and optimization of HRESs in smaller communities, making it easier for energy planners to implement the new indicators within third-party tools or their own tools. In summary, the main purpose of this review is to present a critical analysis of the gaps encountered in social aspects on a wide range of HRES tools as an opportunity to improve the strategies and plans of policymakers, researchers, and software developers.

The remainder of the paper is organized as follows Section 2 presents the review methodology of state-of-the-art software tools for HRESs and their features, especially focusing on the consideration of general and social indicators. Section 2.1 discusses previous work analyzing general techniques to optimize HRESs. Section 2.2 analyzes other research about different criteria considered in HRESs optimization and examines preceding review papers trying to synthesize different end-user optimization tools, and the way, in which such indicators are dealt with. Section 3 shows the results of the thoughtful review carried out. More than 100 tools used for HRES planning have been analyzed to assess the degree of social indicators covered and/or the possibility to introduce such indicators into the models. The inputs, outputs, constraints, versions, optimization features, energy technologies covered, and interactivity of the tools have been taken into account in this analysis. Section 4 presents an analysis of the social impact of HRESs. Section 5 portrays future energy scenarios. Finally, Section 6 draws out, the conclusions and future work.

2. Review methodology

This section introduces a methodological review, allowing to minutely understand the HRES tools analyzed hereby and the papers related to the current research were collected using the SCOPUS platform. Also, the entire summary of the surveyed tools is shown in detail in Appendix Table A.10. Initially, the objective of this study was to identify the HRES tools gaps related to social issues.

The social perspective is maybe the most important aspect of this review since renewable energy systems definitely have an impact on job creation, health and safety, new infrastructure development, etc. This aspect usually comprises the study of social interactions, social organization, and the behavioral patterns of different groups [13]. Nonetheless, it was noticed very early in the research that the majority of HRES tools do not consider social aspects. Thus, in order to reflect the increasing use of this kind of end-user computing tools by the planners who design and optimize HRESs, the following query on SCOPUS was performed: TITLE((design OR optimization)) AND TITLE-ABS-KEY (hybrid AND energy) AND ALL (homer). The localization of available research focused on the design and optimization of hybrid energy systems using the popular HOMER tool.

In an attempt to find the state-of-the-art software tools for HRESs with the aim of analyzing whether they consider the use of social indicators for system optimization, a complete up-to-date listing of these types of software packages was introduced. To this end, the previous collections created by Connolly et al. [9], Sinha and Chandel [14], and Erlwein-Vicuña [15] were initially considered. This review analyzed the software tools mentioned to see if they have been updated during the last few years however, they were not thoroughly analyzed as they were checked by reviewing their websites which permitted the collection of important information about the main characteristics of each of the tools.

At the same time, an effort to extend the already proposed lists of software tools was made by finding other applications, which either have been created or have gained popularity during recent years, like SAM (developed by the National Renewable Energy Laboratory) or DER-CAM (developed by Berkeley Lab). Finally, a list ofermit 106 tools for HRESs, which can be reviewed in Table A.10 was created. The initial aim was to determine if there are easily accessible tools, which can be considered as end-user applications that are up-to-date and popular among energy planners for designing and optimizing HRESs for smaller communities with minimum abilities.

With this purpose in mind and in order to refine the listed 106 elements, more fields of information were added to Table A.10. Some of these fields were used as a filter to reject software packages that did not meet the previous definition of a desirable and popular tool, limiting the scope of the evaluated software tools as shown in Table 1. Once one of the features did not meet the requisites, the other parameters were not filled in. The list considers the following parameters:

- **Name of the organization or community of developers behind the tool**. For those tools with obsolete information, an attempt to contact the authors by e-mail was carried out, and if not answered, the software tool was removed from the list.
- **URL.** From where the software can be downloaded.
- **License type.** Whether the tool is free (even open source), payment tool, or if there is easy access to the license. In case the software had no possibility to be tested in a low-cost manner, it was removed from the list. If the tool offered another premium version of the software through a payment license, the version with the most accessible license was selected.
- **Scale.** Homes/buildings, communities/districts, and regions/nations. The tools that did not cover community/district scales were removed from the list.
- **Date of the last update**. Any tool that was not updated during the last two years was removed, since it might not include the last developments of HRES technologies in some cases. This information is hard to obtain. For instance, the date of the last version of each tool might be shown in the download section of the website, in the user's manual, or might not be mentioned. Although the final aim is to optimize HRESs by using social factors, the tools that only included the option of simulating a specific configuration (without optimization) were also included.
- **Interactions with the users**. Were made by performing batch calculations or through an API, or even by providing the possibility to freely modify the tools to improve their features (in case of open-source software packages). In case of future works that are trying to develop a method for optimizing HRESs by using socio-demographic indicators, the possibility of interacting with or modifying the initial tool will be a great help.

According to researchers [16,17], open source software is free and easily accessible online. It is also attractive to many users including the government, home users, schools, or business accounts, and it has been supported by many authors as a solution for closing the 'digital gap' by assisting developing countries in their efforts to use information technology. In fact, open source software has been used to implement different technological solutions in several fields in developing countries such as biotechnology [18], and geographic information systems [19].

In conclusion, taking into account the previous considerations, and in order to check whether a certain computer program can accomplish all the requirements or not, a case-study concerning the software needs of an HRES planner was developed. The requirements were as follows:

- Uses an accessible software tool that does not require creating any new generation technology.
- Designs an HRES if possible for optimization purposes.
- Specifies whether it is connected or not to the main utility grid.
- Indicates if it satisfies the needs of the residents of a community, district, or island.
- Verifies that it meets the predicted load demand.
- Includes, at least solar PV, wind, and battery technologies.

The details of the fields for each of the tools, which were gathered during the survey process, are shown in Table A.10. The columns of some computer programs were not filled since some of them did not comply with one of the conditions of the above-mentioned filter.

After applying the previous filters, a shortlist with the most relevant seven end-user software tools to design and optimize HRESs for small communities was obtained. Then, the HRESs were installed, reviewed, and analyzed, in order to understand the different features of the computer programs and find out whether some of them consider social outputs (the number of created new jobs and the 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.) while fulfilling the constraints provided by the user, as seen in Fig. 2. Since the HRES system can be composed of different types of generators and

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

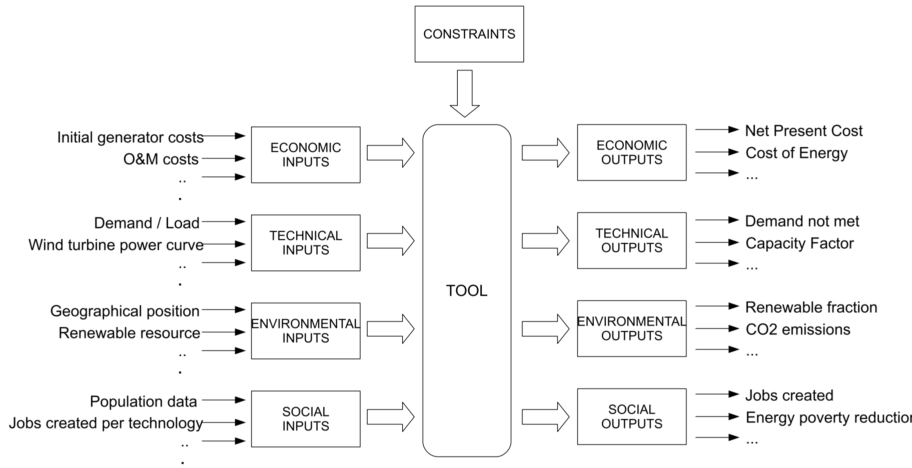

Fig. 2. Inputs, outputs and constraints of an HRES tool.

energy resources, each calculation considers different types of technologies (for example, PV, wind, biomass, etc.)

Tables 3–9 include the results obtained after installing, testing, and reviewing the inputs, outputs, and other parameters of different software tools, categorizing them according to the main groups seen in Section 2.2 (economic, technical, environmental, and social) and indicating whether each software tool contains 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. The fact that one tool includes multiple outputs does not imply that the program is optimized.

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

The definition of different inputs and outputs was possible as a result of obtaining the complete list of indicators in Section 2.2 that were compiled in Tables 3 and 4. These tables show the different inputs and outputs considered when analyzing the tools and the selection of the parameters and constraints was done after coming up with them while evaluating the tools. For example, if any parameter was detected in one of the analyzed tools, we tried to find out whether or not the other tools included it.

Another feature is the possibility of performing optimization tasks to find the best configuration of an HRES by maximizing or minimizing one or several parameters, which would become the objective function. Even some tools, for example, HOMER, include the option of making a sensitivity analysis, by repeating the optimization process for each value. Additionally, a bunch of extra features was gathered to offer more information about the capabilities of each of the tools:

- ***Technologies:*** Each one of the energy sources or storage, technologies that are implemented in the tool to help users include them within simulations and optimizations.
- ***Interactivity:*** Information about the possibility of directly accessing the core of the tool, to automatically perform calculations or the opportunity of exporting data to a file.
- ***Versions:*** Data about the specific versions used during the survey process, including the number, and type of the license.

2.1. General approaches to optimize HRESs

This section analyzes the most outstanding research carried out in terms of HRES optimization tools such as that of Connolly et al. [9], which not only covers the available software tools but also extends the analysis to general-purpose energy tools. Sinha and Chandel [14] present computer programs used by planners to design HRES systems: however, the tools mentioned were not necessarily focused on the hybrid and renewable fields. For instance, OpenModelica [20] is a general-purpose tool for modeling and simulating dynamic systems so if any planner wanted to design or optimize an HRES, they needed to manually create their own renewable technology components (solar, wind, etc.). On the other hand, Migoni et al. used Modelica to develop a specific new library that provides components such as photovoltaic (PV) cells, proton exchange membrane (PEM), fuel cells, electrolyzers, hydrogen storage tanks, batteries, and electronic converters to build different HRESs [21]. Nonetheless, the ‘H2A’ tool [22], cited by Connolly et al. [9], mainly focused on hydrogen systems.

Other authors have analyzed various optimization methods and techniques to find the ”best” layout for HRESs. Erdinc and Uzunoglu [5] analyzed a wide range of research contributions about the optimization and sizing of HRESs, analyzing the approaches to find the ‘optimal design’ and then use it in commercial software tools and optimization techniques, such as genetic algorithms, particle swarm optimization, simulated annealing, or linear programming. Dawoud et al. [23] described a review of optimization methods for hybrid microgrids with renewable sources, discussing numerous optimization techniques and organizing them into graphical, probabilistic, deterministic, iterative, artificial intelligence, and finally, software tools. Tezer et al. [24] also analyzed different approaches used for the optimization of HRESs, including a wide collection of techniques and classifying them into classic optimization approaches, meta-heuristic methods, etc.

The techniques detailed by Dawoud et al. [23] and Tezer et al. [24] can be implemented by using different computational languages to try to maximize or minimize an objective function, after determining it, along with other variables, and limits of the problem. Objective functions consider one or several criteria (indicators or KPIs measured through numerical values) in order to mathematically build the function to be maximized (the highest energy production) or minimized (the lowest CO_2 emissions). As observed in Fig. 3, each of the technologies of the system has different impacts on each of the indicators considered for building the objective function.

A considerable number of authors analyzed different categories of objective functions through different criteria when planning and designing electricity systems with renewable sources without optimizing an HRES with a software tool. Wang et al. [25] used numerous criteria that are grouped within four classifications when doing multi-criteria decision analysis in sustainable energy decision-making: technical (efficiency, reliability, safety, etc.), economical (investment

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										
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										

(*continued on next page*)

Table 2 (*continued*)

KPI type	KPI/Criteria	[25]	[30]	[31]	[32]	[26]	[33]	[34]	[35]	[28]	[27]	[29]
Environmental	Impact on marine life	X										
Environmental	Reduced sea usage	X										
Environmental	Embodied Energy											X
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

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	–

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 realized the importance of considering social factors when designing and optimizing energy systems (Section 2.1.), found that this intermediate scale of systems is where the study of social aspects can provide a solid opportunity for improvement. For example, Kumar et al. [26] stated that social factors play a key role in electrification projects in rural and developing areas and Rahman et al. [27] found that rural electrification requires effective prioritization and planning because of the socioeconomic factors. Also, Dufo-López et al. [28] proposed a multi-objective evolutionary algorithm to optimize a hybrid system that can supply electricity to a small community in Africa. The results by Rojas-Zerpa and Yusta [29] revealed that the decentralized power provided by HRESs is the best form of electrification for small rural and remote villages while Al-falahi et al. [30] concluded that the implementation of HRESs provides a cost-effective and reliable solutions, given the fuel supply shortage and high costs associated with the extension of grids to islands and remote or rural areas. Section 2.2 gathers previous works that review different KPIs that were taken into account when designing energy systems in general, and HRESs in particular.

2.2. *HRESs indicators*

With the aim of finding the longest list of indicators used in the optimization task, and in order to check such indicators within the software tools, the work of other authors on the analysis of different criteria, which were considered by energy planners when designing general-purpose electrical systems, was also evaluated. Kumar et al. [26] developed an insight into various multiple criteria decision making (MCDM) techniques to find the optimal results for renewable energy systems in complex scenarios that include various indicators and criteria. Subsequently, many authors realized that social factors had always played a vital role in energy planning and that energy projects with sophisticated technologies that promise affordable electricity even

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	–
Social	Jobs created	–	–	–	–	–	–	X	–

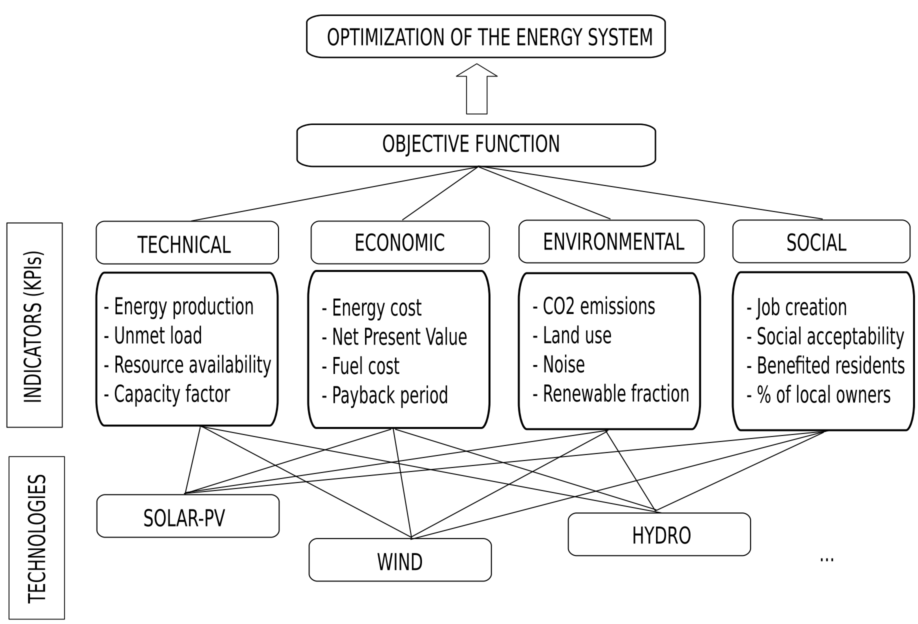

Fig. 3. The objective function can consider a wide range of indicators.

tend to fail due to the negligence of social factors. So an energy system design must take into account social factors by giving them the same importance as any other factor.

Strantzali and Aravossis [31] reviewed 183 studies published between 1983 and 2014 in order to investigate the trends in the assessment of RES investments and analyze 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 [32] selected eleven basic sustainability indicators for renewable energy systems, classifying them into: environmental (CO_2 emissions, renewable fraction, etc), economic (costs, return on investment, payback), and social indicators (job creation, benefited residents).

Beccali et al. [33] designed several criteria when performing 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.), and social and economic (labor impact, market maturity, compatibility with political situation, etc.), Rahman et al. [27] described different criteria to be considered by decision-makers to choose the most appropriate option for sustainable rural electrification in developing countries and these criteria were grouped into five categories: 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 [34] gathered the several factors and criteria involved when designing a hybrid energy system for a certain location and included socio-political factors: the compatibility with the national energy policy objectives, political acceptance, social acceptance (land use, visual impact, electromagnetic interference, acoustic noise, shadow flicker, ecosystem disturbance, etc.), the portfolio risk (the exposure to fuel price instability for carrying out socio-political decisions), and the labor impact.

Štreimikienė et al. [35] went one step further and organized a group of 25 experts to find several qualitative and quantitative criteria that helped with rating several electricity generation technologies (nuclear, gas, biomass, geothermal, hydro, wind, etc.) while considering their economic, technological, environmental social and political aspects. The social aspects included the influence on social welfare (jobs, economic security), the influence on the sustainable development of societies (education, science, culture), and the public acceptance/opinion.

Niu and Wei [36] proposed a simulation of an optimization algorithm in a hybrid thermal/wind power system with a social-environmental-economic dispatch, where the objective function of the social benefits was obtained by calculating the risk cost caused by the power outages resulting from the instability of the generated wind energy, which can result in socio-economic losses. Also, Rojas-Zerpa and Yusta [29] proposed a combined methodology to facilitate the selection of the best solution for the electrification of remote and rural locations, involving technical, economic, environmental, and social criteria, and they consulted a group of 16 experts worldwide about the necessary criteria to be considered, including the social acceptance of power, the creation of jobs, and the human development index (HDI).

Dufo-López et al. [28], based on the work of Rojas-Zerpa and Yusta [29], presented a new methodology by using a multi-objective evolutionary algorithm, which was developed for the optimization of off-grid HRESs by minimizing the total NPC, along with the maximization of HDI and job creation. The work by Dufo-López et al. [28] was one of the works reviewed by Al-falahi et al. [30], who presented a comprehensive review on the recent developments in size optimization methodologies. His review mainly summarized and explained various assessment parameters such as economic, environmental and social parameters, and it also included the 'human development index' indicator, job creation factor, social cost of carbon, and socio-demographic factor, which describes the energy consumption pattern of a household load in a certain location. However, the use of social parameters was not given enough importance, as the economic indicators were the most considered ones.

In summary, there is an increasing number of design and optimization cases where the social parameters were taken into account to develop and design better energy systems and our research will try to find out if the developers of the software tools that aim to optimize HRESs are taking into consideration this wider approach. Table 2 provides a broader overview of all the criteria that can be considered by energy planners when designing general-purpose electrical systems, along with a summary of all previously mentioned key performance indicators. 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 out if any of these criteria were taken into consideration.

2.3. Software tools and their indicators

As previously mentioned, the methods and techniques cited in Section 2.1 can be included in computer programs, that can maximize or minimize an objective function. However, the out-of-the-box solutions provided by end-user software tools began to help many planners with limited knowledge of algorithms in designing and optimizing HRES in an easy way, exclusively by using a tool with common and familiar user interfaces.

In fact, a considerable number of software tools for designing and optimizing HRESs were created over the last two decades. Some of them are still being updated, and other ones were discontinued. There was also previous research that focused on listing the tools that evaluate the operation of renewable energy systems. For example, Connolly et al. [9] considered 68 tools that were used to analyze the integration of renewable energy and Sinha and Chandel [14] detailed 19 applications with their main features. Also, Erlwein-Vicuña [15] summarized 36 software programs by starting an online survey on the ResearchGate website.

Lyden et al. [37] carefully considered an initial list of 51 tools that modeled generic energy systems and then selected and analyzed 15 tools that were focused on the modeling of community-scale HRESs, which only considered storage, and demand-side management. The work gathered a list of design optimization variables and outputs and some of them were linked with social indicators such as HDI and job creation. Pfenninger et al. [38] looked at how energy models face the challenges seen in today's system such as resolving time and space, balancing uncertainty and transparency, addressing the growing complexity, and integrating human behavior, social risks and opportunities. As shown in Section 3, the spectrum of the gathered tools is wide where some of them only help the planners with simulating, while others manage to optimize the system through the use of different algorithms.

Hilpert et al. [39] affirmed that modelers have a serious social responsibility as the result of their models are widely used to support policies and decisions. However, adhering to scientific standards in energy system modeling is important matter for model development. After all, models need to meet the scientific standards but public acceptance is now becoming more important.

Wiese et al. [40] stated that, within the transformation process, model-based analyses have become indispensable for addressing a diverse set of questions including 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. [41] presented a review of 31 computer tools at different scales (national, regional, and single or group of buildings level). This review concluded that two social indicators came out as the most important ones: job creation and the number of benefited residents. The first refers to how many new jobs will exist owing to the corresponding energy systems, while the second estimates how many residents will benefit from the HRES system. This work is focused on techno-economic analysis methods.

Finally, Mancarella et al. [42] stated that social acceptability, including the impact on comfort, perhaps represents the biggest challenge for quantification within a model. In practical terms, the best feasible option is to present constraints on the development of particular technologies, for example, nuclear power.

3. Results and discussion

In order to assess the HRES tools, Section 3 was arranged to portray all the results obtained in Tables 3–9 where 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 social KPIs (the HDI and job creation) to design or optimize energy systems, and it

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
Analyzed tools and 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 and 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 and 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	–	–	–	–

even uses them 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 already mentioned two social parameters, developed by Dufo-López et al. [43] and mentioned previously in Section 2.

The rest of the computer tools work out only economical, technical, and environmental outputs. Thus, without considering social parameters, it is true that planners can use these tools to determine the

Table 9
Analyzed tools and 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

elegibility of a certain configuration of the hybrid systems in terms of money savings, the adequacy for meeting the energy demand, and the environmental impact for fewer CO_2 emissions. However, they will not be able to determine if a particular disposition of the system, for instance, can create more jobs in comparison to another one.

HOMER, the most popular HRES tool, not only calculates output parameters for a particular configuration, but it also optimizes the system by choosing an optimal combination of elements, taking into consideration 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. Thus, it only tries to find the option that minimizes the objective function of the NPC without the possibility of optimizing other parameters, including not-existing social ones.

The differences between the number of technologies considered by different computer tools are quite remarkable. HOMER and RETScreen are the programs with a higher number of technologies: 24 and 16, respectively. In general, the variety of technologies is important as it offers users the possibility of choosing the best solution for the optimal configuration of a hybrid installation. Moreover, the development of new and improved renewable energy generators is growing, their cost are declining, and some specific renewable technologies could better fit the needs of a community or the characteristic renewable resources of a region. For instance, the six technologies considered by iHOGA could be extended to include more sources of renewable energy while considering their job creation factor and HDI.

The increasing number of HRES tools is also remarkable, as they are delivered under free software licenses, allowing users not only to use the programs free of charge but to also freely modify the code to adapt it to their needs. Some of them also 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 and according to its creators Watson et al. [44] it tries to address the lack of tools, which are free to use, open for collaborations among regional experts, and effective for energy planning including 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 the System Advisor Model (SAM) available to the public [45] for more transparency, flexibility, and collaboration opportunities.

Table 6 summarizes the analyzed software (HOMER, Calliope, RETScreen, DER-CAM, Compose, iHOGA, and EnergyPRO) with respect to their capabilities and it can be seen that most of them limit the use of their features to a free trial version. As for the optimization features shown in Table 7, it is easy to observe how iHOGA is the most complete tool since it does not only depend on a technical and economic analyses, but it also takes into consideration the social impact over the inhabitants benefited from HRESs. Whereas Table 8 shows all of the energy technologies covered in this paper through the analyses of the HRESs modeling software, where many renewable energy systems are prone to be combined in hybrid systems with fossil fuel sources (for example, diesel generators, natural gas generators, etc.). Table 8 shows that HOMER is the software that integrates a wide range of technologies into its structure, which is a bonus for both end-users and designers. On the other hand, Calliope tended out to be the most incomplete software because it lacks many energy sources and due to the fact that it is addressed to cover generic systems, but its usage is non-realistic.

Table 9 portrays all the previously analyzed software when it comes to interactions with the core of the tool. In this case, Calliope resulted as complete as HOMER. Nevertheless, Calliope is lightly superior to HOMER since 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.

4. A discussion about HRESs and their social linkage

This section discusses the existing relationship between HRES software tools and society, since HRESs are aimed at developing and planning energy solutions to meet the society needs. Each of the energy generation technologies has its own economic features (for example, different initial costs) or its own technical features (for example, 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, only a few of them have been enumerated in order to show the significance that the use of social KPIs in optimization techniques can offer to an HRES planner.

For instance, according to some authors [46], renewable energy sources can create more jobs per each unit of currency invested compared to conventional ones, although that also depends on how many stages of production are carried out in the region. This can be noticed in some regions where the use of renewable energy sources is growing. For example, in the United States of America, solar technologies, both photovoltaic and concentrating, employed almost 374,000 employees, or 43% of the Electric Power Generation workforce in 2016; however, the employment resulting from fossil fuel power generation accounts for 22% and supports 187,117 employees across coal, oil, and natural gas generation technologies combined [47]. So, there are twice as many solar jobs as fossil-fuel jobs, with nearly twenty times less cumulative installed capacity. This statement was also verified by Wei et al. [48], who found that all non-fossil fuel technologies create more jobs per unit energy compared to coal and natural gas jobs. Thus, we should consider specific installations over the rest of the energy sources, under the same conditions of costs, yielded energy, and other technical, economic, or environmental criteria.

Additionally, some kinds of renewable energy sources create more jobs and also increase the social value of specific areas compared to others. For instance, the Portuguese Government encouraged by municipalities tries to create biomass plants at a local level to empower some areas and reduce the forest fire risk [49], and Madrigal et al. [50] claimed that forest biomass collection for energy in the Mediterranean basin reduces fire hazards, but only if both trees and shrub strata are managed at a landscape level. Consequently, the proper design of an HRES should not only consider the social impact of the renewable energy technologies but also the geography where the renewable plants would be located.

Other improved benefits of an optimal design of an HRES that considers social criteria could include the enhanced adequacy of the needs of different social classes. Traditionally, the lack of electrical supply is usually solved with optimization models and tools or with the minimization of the objective function of Loss of Load or Loss of Energy, through LOLP and LOEP calculations. However, these models only consider the amount of MWh but not the damage that this inadequacy can cause to some sectors of the population. Some authors proposed alternatives to measure this damage; Barnes et al. [51] 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. Also, Nussbaumer et al. [52] proposed a new composite index to measure energy poverty that is focused on the deprivation of access to modern energy services. Optimization techniques should consider these thresholds on disadvantaged consumers, without affecting any possible beneficial effect on the system or other consumers.

The approach of considering the different needs of each one of the citizens who consumes electricity is also on the agenda of the lawmakers. Thus, the European Commission is making a big effort to develop the Energy Union Strategy [53], which will try to provide additional measures to protect vulnerable consumers and empower consumers further so they can participate fully in the energy market. In fact, the existence of possible incomes for consumers can be considered as a social KPI to be analyzed. This new type of citizens, the *prosumers*, both consume and produce energy and can participate in different energy markets. According to Parag and Sovacool [54], prosuming can enable consumers to save money while also contributing to wider social benefits by diversifying energy production.

In general, social and environmental indicators confront with technical and economic ones [24]. It is almost impossible to find a global optimum that maximizes all the indicators at the same time. Therefore, the main 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* are optimal, but one can only be selected in realistic scenarios. There are several methodologies that can help solve this problem. For example, all indicators are hardly ever given the same importance, so an extremely easy method is to choose either the one that maximizes this indicator on the *Pareto Frontier or a weighted sum* of the indicators [55]. Moreover, other more complex solutions to this problem consider the use of qualitative analysis, sensitivity analysis, or a post-Pareto pruning algorithm [56]. For a detailed introduction to the topic, please refer to Ref. [57].

5. Forecasting future energy scenarios

This part of the research is aimed at briefly forecasting energy scenarios and their impact on the societies. Ram et al. [58] predicted that the higher growth of electricity consumption is going to take place in developing regions where, according to Kaundinya et al. [59], more than 50% of the population resides in rural regions. Subsequently, in such regions, the cost of electricity will become very expensive and unaffordable to habitants, leading to a reduced standard of living and social inequity. For that reason, the interest for HRESs is growing as a way to provide sustainable energy independence for smaller communities, as stated by Neves et al. [60]. Additionally, Deshmukh and Deshmukh [61] concluded that HRESs are mainly recognized for remote area power applications.

Ram et al. projected a global scenario in 2050 in which medium to large installations will be the majority within the total installed capacity [58] and the cumulative installed capacity of solar PV at a utility-scale will account for 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, which are the main regions where higher incomes allow prosumers to install their own small generators in buildings, whereas plants with medium to high dimensions are going to help with energy transition in developing regions during the next decade especially in rural regions.

The number of energy generation technologies included by the tools should also be considered, provided that users will not have to program any additional software. According to the projections of Ram et al. [58] and the International Energy Agency ('Sustainable Development' scenario) [62] for installed power capacities, during the energy transition of the next decade the generation technologies with a higher growth rate are going to be solar PV and wind, as they will also have the largest installed capacity at the end of the analyzed period.

Ram et al. [58] forecasted that starting from the 231 GW of solar power and 372 GW of wind power in 2015, in 2030 there will be 6980 GW of solar power and 3293 GW of wind power, and in 2050, there will be 21,959 GW of solar power and 3154 GW of wind power. This growth amount is constant in all the nine major regions considered in the study. IEA also forecasted [62] an appreciable growth of solar PV and wind technologies, passing from 225 GW to 414 GW in 2015 to 3246 GW and 2629 GW in 2040 ('sustainable development' scenario), and to 2067 GW and 1664 GW in 2040 ('current policies' scenario), being by far the two fastest growing energy sources.

As stated in the report by Ram et al. [58], the cumulative capacity of the installed batteries is going to rise, from 2 GWh in 2015 to 47,858 GWh in 2050, producing more electricity than wind plants at the end of the period. Also, the expected level of the use of renewable energy sources is predicted to affect the stability of the generated energy, which must be mitigated with the introduction of storage technologies that ensure the overall stability of the electrical system. According to Y. Liu et al. [63], batteries are the storage technology that helps with a higher range of power dimensions. Following these figures of projections, it is easy to foresee that HRES tools will consider, without the need to program any additional components, the possibility of including at least solar PV, wind, and batteries.

6. Conclusions and future works

The development of different types of renewable energy and storage technologies with increasingly lower costs is helping communities with accessing affordable electricity through the implementation of HRESs. In addition to the growing popularity of HRESs, a novel sort of software tools has emerged to help planners with designing and optimizing such systems.

As a result, there is a growing number of studies that take into account social criteria in addition to the usual economic, technical and environmental indicators 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 CO_2 emissions, but also raising the social impact and social acceptance of the installations.

However, the majority of the popular software tools used by planners to design and optimize HRESs do not include the possibility of considering factors like 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 a commercial software, and its full use is limited to those who pay a license fee.

Therefore, there is a great opportunity for the original developers of commercial and open source tools to boost their features and offer additional options to their users, especially to those who design and optimize HRESs in small communities. The number of social KPIs included in the commercial programs and the number of technologies linked with these social parameters could be increased to allow planners in 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 with sharpening their calculations by freely modifying the software code so as to adapt it to their own needs. This even presents an inviting space for researches who want to establish their own methodology, which can enhance their possibilities and outcomes by including social inputs, outputs and constraints.

Future work will investigate two directions. On one hand, the research requires a deeper assessment of the social impacts of different generation technologies, following the work stated in Section 2.1. On the other hand, new procedures for including social impacts in the process of optimizing HRESs through the use of any of the shortlisted software tools will be assessed and developed on the basis of these conclusions.

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Appendix A. Supplementary data

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