Use of the multicriteria analysis methods to optimize sustainable energy systems based on renewable sources

Uso de herramientas de análisis multicriterio para la optimización de sistemas energéticos sustentables a partir de fuentes renovables

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Abstract

Sustainable The sustainable energy development implies to look for balanced technological alternatives, economically, socially, and environmentally. Therefore, it is a complex process which solution is commonly supported on mathematic tools, whether multi-objective optimization (MODM) or multicriteria analysis (MCDM). In this work, an analysis of these tools in the field of the renewable energy is carried out, with the purpose of identify the hybrid renewable energy systems design under a sustainable view perspective, which implies the use of MCDM or MODM tools. The methodology used consists of identifying the references related to the design of hybrid renewable energy systems and the sustainability term, using the WOS (Web of Science) search engine, which were analyzed in chronological order to identify the basic forms of the methods, the application foundations, and finally, the perspectives, reflected in the most recent publications. MCDM tools were identified as the most used with the 71% of the analyzed references, above the multiobjective methodologies; being the most popular the Hierarchical Analytical Process (AHP) and the Order of Preference for Similarity with the Ideal solution (TOPSIS). It is important that the decision makers use such kind of tools, both to design and to plan sustainable energy systems.

Sustainable development, Renewable energy, Decision-making, Multicriteria analysis, Multiobjective analysis

Resumen

El desarrollo energético sustentable implica buscar alternativas tecnológicas equilibradas, en lo económico, lo social y lo ambiental. Por ello, es un proceso complejo cuya solución suele apoyarse en herramientas matemáticas, ya sea de optimización multi-objetivo (MODM) o de análisis multicriterio (MCDM). En este trabajo se realiza un análisis de dichas herramientas en el campo de las energías renovables con el fin de identificar las perspectivas en el diseño de sistemas híbridos renovables, bajo un enfoque de sustentabilidad, empleando herramientas MCDM o MODM. La metodología empleada consiste en la identificación de las referencias relacionadas con el diseño de sistemas híbridos renovables y el término sustentabilidad, empleando el motor de búsqueda WOS (Web of Science), las cuales fueron analizadas en orden cronológico para identificar los métodos en sus formas básicas, los fundamentos para su aplicación, y finalmente las perspectivas reflejadas en las publicaciones más recientes. Se identificó que las MCDM son empleadas en el 71% de los casos analizados; siendo las más populares la de Proceso Analítico Jerárquico (AHP) y la de Orden de Preferencia por Similitud con la Solución Ideal (TOPSIS). Es importante que los tomadores de decisiones usen tales herramientas, tanto para diseñar como para planear sistemas energéticos sustentables.

Desarrollo sustentable, Energías renovables, Toma de decisiones, Análisis multicriterio, Optimización multiobjetivo

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Introduction

Sustainable energy systems are a set of equipment and devices that transform the energy available in a given place, into useful energy, either electrical or kinetic energy for use at the moment or for storage and subsequent use. The nuance of sustainability implies that these energy transformation systems are economically favorable, technologically reliable and viable, and mainly environmentally friendly. Other dimensions of sustainability have been added in recent years, the social and institutional dimensions; that have been fundamental pieces in the implementation and fulfillment of the project period, being cases of success.

It is there where the application of multi-criteria analysis tools (MCDM) or multi-objective methodologies (MODC) is required for decision making; since they allow solving situations that depend on multiple actors, criteria and objectives, especially when some objectives are opposed to others. They comprise five elements: the goal, stakeholder preferences, alternatives, criteria, and outcomes.

Traditionally, commercial software programs and methods for the design of renewable energy systems (HOMER, RETSCReen, TRNSYS, HYDROGEMS, HYBRID2, among others), contemplate a single objective that is generally economic or technical. Using these programs, a list of alternatives or configurations of renewable systems can be generated with the different combinations between the devices for the use of available resources (photovoltaic modules, wind turbines, mini-hydraulic turbines, pumps, heat biodigesters, gasifiers, among others.) energy storage devices (battery banks, hydrogen storage, water pumping, flywheels, among others), backup systems (gasoline or diesel generators, electricity supply network) and adaptation devices and energy supply (inverters, charge controllers, converters, maximum power point trackers, among others); to cover a type of demand (residential, industrial, school, among others) determined by an annual profile and an average value of energy consumption.

The importance of identifying the perspectives on this issue is to establish the most used tools for the development and planning of renewable hybrid systems since the alternatives or configurations obtained allow to supply the energy demand given in a given site, some with higher investment costs, others with higher emissions, some that could cause discomfort to the inhabitants around the site, etc. It is there where the different aspects that favor or harm the sustainability of these systems intervene. Through the criteria or sustainability objectives, the alternatives are compared, and, according to the preferences of the users, an importance value is assigned to some over others to obtain the most convenient system, through the weighting of applicable weights. in the MCDM.

Currently there is a great variety of MCDM and MODM, applied in their basic forms, combined or with variations that imply a greater difficulty in the implementation to improve their precision. Hence the added value of identifying the most popular and most easily implemented tools for their application by users with different levels of preparation.

Around the world, hybrid power generation systems have been implemented (that take advantage of two or more renewable sources), with several success stories through the years for which it was conceived, and in some cases transcending that value. In the particular case of Mexico (Agredano, 2000), these systems have been, for the most part, dismantled long before reaching their lifetime, due to several problems identified: under or oversizing, deterioration of equipment due to environmental factors, increased energy demand, no refurbishment, no after-sales technical service, insufficient maintenance fees, disorganization in communities, lack of technology transfer. It is important to continue promoting this type of system, mainly in remote areas where there are still more than half a million Mexican homes that lack this basic service. By applying the most popular MCDM or MODM, the optimal sustainable energy system can be obtained, such that it supplies the required demand, during the entire useful life for which it was projected.

In the introductory section, the reader was contextualized in the topic to be developed, setting out basic guidelines to facilitate the understanding of the subsequent sections.

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In the methodology section, the steps followed for the bibliographic review of the references found are presented, in chronological order to facilitate understanding of the topic. The results present a classification of references in antecedents, fundamentals and trends, for the identification, understanding of MCDM and MODM, and trends. Subsequently, a discussion section is developed in order to visualize and analyze the different characteristics found in the review, to finally present the conclusions.

Methodology

For the information search, the tree of science platform (TOS-Core of science) is used, which provides a classification in the form of a tree, resulting from the interaction between the citations and the references obtained when entering the search keywords. related information.

Tree of Science - TOS

It is a platform developed by a research group from the National University of Colombia (Robledo-Giraldo et al., 2014) that arose from the need to establish the theoretical bases of a topic "X". A regular search for X generated 214 articles as a result; Following the established procedure, 1476 articles and 4212 citations were found. At the bottom of fig. 1 the tree can be seen. The root files in yellow represent the background, the trunk in brown represents the fundamentals, and the leaves in green represent the trends. From this breadbasket they were able to identify X's perspectives and how to develop the TOS platform.

Figure 1 presents a simplified guide to using TOS in bibliographic searches, which will open a broad overview of a topic of interest.
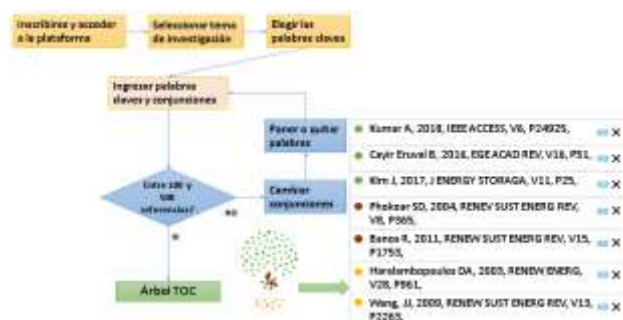
Figure 1 Block diagram for TOS users
Source: Own Elaboration

a. Verify the subscription to the WOS (Web of science) search page and enter the selected topic (for this example it was "Hybrid renewable energy systems multicriteria optimization"). Only 11 references were found, insufficient to plant a tree. To obtain more references, the word "Hybrid" was eliminated and in this way 113 references were generated (the range is between 100 and 500 to plant a tree).
b. Export the bibliographic references and citations file to a txt file.
c. Enter the page tos.coreofscience.com and paste the previously generated txt file (the platform calls it a seed file).
d. Review the entries and click CONTINUE so that the tree is generated.
e. It is recommended to read the references selected by the platform in order of roots, trunk and finally leaves for a better understanding of the subject.

From the information analyzed, different comparisons, contrasts and classifications are made, represented in tables and graphs constructed by the authors, specific information that is presented more during the development of this writing.

Results

Background (Roots)

The first document suggested by TOS is the book "The analytic Hierarchy Process: Planning, priority setting, resource allocation" by the renowned professor Thomas L. Saaty in 1980, which is not found on the web, but refers to it in later publications (Dong, Q., Saaty, TL, 2014), in which the bases of the AHP (Analytic Hierarchy Process) multi-criteria tool are outlined. This methodology proposes a pairwise comparison of each of the criteria, giving a value taken from the Saaty nine-point scale. Subsequently, the normalization of each of the rows of the pairwise comparison matrix is carried out to obtain the value or weighted weight of each criterion. The classification of the alternatives is obtained by multiplying each criterion by its weight (taking into account the positive sign if the criterion is beneficial, and the negative if it is not) and performing the summation for each of the alternatives, in the matrix of decisions.

Higher values will be the best, and the best rated alternative will be optimal. They establish the consistency index of the assigned values and the importance of evaluating it.

Georgopoulou et al. (1998) propose a procedure using PROMETHEE II (Preference Ranking Organization Method for Enrichment Evaluations) for the evaluation of various alternatives for the participation of renewable energy systems (RES). They compared the results obtained with AHP, MAUT (or MAVT, Multi Attribute / Value Utility Theory) and the previous version PROMETHEE.

Haralambopoulos & Polatidis (2003) also used PROMETHEE II for the development of RES projects, a particular case of the geothermal resource. By 2006, Zhou et al. Published an update on energy and environmental decision models compared to a previous publication by Huang et al., In 1995. They found that the number of related publications had tripled.

Loken in 2007, established that most group decision-making methodologies (TDG) require several opposing considerations, and classified them into: measured value models (AHP, MAUT), objective, goal and level of achievement models. reference (GP (Goal programming), TOPSIS (Technique for Order of Preference by Similarity to Ideal Solution)), and improvement models (PROMETHEE II, ELECTRE III (Elimination and Choice Expressing Reality)). He applied the three types of methodologies for energy planning problems (EP), concluding that a single model is not applicable in all cases, that two or more must be used (in combination or in parallel) to take advantage of the strengths and minimize the weaknesses .

Tsoutsos et al. (2009) mention that traditional evaluation methods, such as cost / benefit analysis and macroeconomic indicators are not rigorous enough; and that the MCDM allow to interrelate a wide range of variables being a valid support for decision making. Wang et al. (2009) highlighted the increase in the popularity of MCDM in energy sustainability due to the multidimensionality of the objectives. They analyzed the different stages of the methods for (TDG) in RES projects such as the selection of the criteria, the weighting, the evaluation and the final aggregation.

They found that the weight-weighted method (WWM), equal weights, and the MCDM AHP, remained the most popular.

For their part, Connolly et al. (2010) reviewed the different existing computational tools for integrating RES to conventional systems. They included 37 out of 68 existing ones. They conclude that there is no single tool to address all options related to energy integration (EI) but they establish a useful guide to choose one of the tools, as appropriate. In another of the research roots references (Kaya & Kahraman, 2010) they used VIKOR (Vlse Kriterijumska Optimizacija I Kompromisno Resenje (Serbian) / Multicriteria Optimization and Compromise Solution) and AHP to determine the best RES alternative for Istanbul, wind energy . Finally, Sengül et al. (2015) developed a proposal using the SEIM WWM (Shannon entropy interval) to prioritize energy supply sources in Turkey (first, hydroelectric).

The MCDM methodologies for TDG began to gain relevance towards the end of the 90s, according to the analyzed antecedents. The main renewable sources studied in the world until then were wind, solar, geothermal and biomass. Table 1 presents a summary of the antecedents or roots (ROOTS) of this TOS.

Author	Methodology	Energy sources	country
Saaty, 1980	AHP	General energies	USES
Georgopoulou, 1998	PROMETHEE II	W / SHy / PV /	Greece
Haralambopoulos, 2003	PROMETHEE II	ST / BM / GT	Greece
Zhou, 2006	Review	GT	Singapore
Loken, 2007	Review	General energies	Norway
Wang, 2009	Review	General energies	China
Tsoustos, 2009	PROMETHEE I and II	General energies	Greece
Connolly, 2010	software	W / SHy / Hy / PV / ST / BM	Denmark
Kaya, 2010	VIKOR-AHP	General energies	Turkey
Sengul, 2015	TOPSIS / FL	W / Hy / SHy / PV / ST / BM	Turkey

Table 1 Background summary (Roots of TOS)
Source: Own Elaboration

Fundamentals (Trunk)

The fundamentals developed in this section include the classification of MCDM tools addressed by Pohekar & Ramachandran (2015) and by Baños et al. (2011). In the first work, the authors analyzed the methodologies identified in 90 publications, finding AHP as the most popular, followed by PROMETHEE and ELECTRE. They also analyzed interactive and fuzzy logic (FL) methods to reduce data uncertainty. In the second work, they analyzed the MODM based on the vital importance of energy for the integral development of emerging nations. Among the most used MODMs were MILP (mixed integer linear programming), MIQP (Lagrangian relaxation, quadratic programming) and Simplex; as well as heuristic techniques such as GA (genetic algorithms) and PSO (Particle Swarm Optimization).

In a bibliography focused on the bioenergy sector (Scott et al. 2012), they found that the most popular methods were those that gave a choice between few discrete alternatives, followed by the methods for choosing between several continuous and step-by-step alternatives. For his part, Bhattacharyya (2012) argued that electrification outside the grid is gaining importance in developing countries, for which he focused a bibliographic review on isolated systems (not connected to the grid), where he presented the strengths and weaknesses of the methodologies found, and recommended using a hybrid structure that combines two or more options to take advantage of strengths and mitigate weaknesses.

Perera et al. (2013) proposed a combination of MCDM and MODM to design a hybrid system W / PV (wind / photovoltaic), where they obtain the Pareto front (Obtained through MODM) and subsequently select the optimal RES using four criteria and applying a MCDM. On the other hand, Ribeiro et al. (2013) presented a proposal in Excel (MILP), to evaluate different energy production scenarios, for which they used 12 criteria, finding that the most expensive scenario was the one with the maximum renewable fraction and the most economical the one with the renewable fraction 0%. Although the different alternatives with renewable fractions greater than zero, are more expensive, they substantially reduce emissions and energy dependence.

Coming to 2016, Çelikbilek & Tüysüz, establish that RES alternatives should be considered in the energy portfolios of all countries that seek the most adequate energy resources to sustain their social and economic development. They presented a gray model similar to FL, integrating three methods: (i) DEMANTEL (Decision Making Trial and Evaluation Decision Making Evaluation Laboratory) to find interrelationships between the criteria; (ii) ANP (network analytical process) as WWM; and (iii) VIKOR for the evaluation and classification of the alternatives. Meanwhile, Kumar et al. (2017) stated that energy planning has become complex, due to the influence of multiple economic, technical, environmental and social points of view; these and more constraints must be faced by developers when optimizing energy alternatives for rural communities.

According to Arce et al. (2015), European energy systems are characterized by high dependence on fossil fuels and energy imports. An analysis of the energy system is required involving MCDM tools. Similar studies mainly evaluate technical and environmental parameters, using AHP as MWW. In the same year, Tahri et al., Established that environmental regulations are currently dedicated to promoting the development of RES in Morocco. The authors combined GIS (Geographical Information System) with MCDM tools the sustainability of the sites to implement RES. They found that weather conditions are the most important criterion, because they define the potential of energy resources, followed by orography. Table 2 presents a summary of the research reviewed during the analysis of the fundamentals (TRUNK), the trunk of the TOS.

Author	Methodology	Energy sources	country
Pohekar, 2004	Revisión	Energy in general	India
Baños, 2011	Revisión	W/ST/Hy/SHy/H$_2$-T/BM/GT	España
Bhattacharyya, 2012	Revisión	PV/Madera aislados	Inglaterra
Scott, 2012	Revisión	Energy in general	Inglaterra
Perera, 2013	Revisión	W/PV/Batt	Sri Lanka
Ribeiro, 2013	GIS-AHP	W/Coal	Portugal
Arce, 2015	FL TOPSIS	W/PV/ST/H$_2$-T/BM/GT	España
Tahri, 2015	Review	PV	Marruecos
Celikbilek, 2016	ANP, DEMATEL, VIKOR	W/PV/ST/Hy/BM/GT	Turquía
Kumar, 2017	MILP/GAMS	W/Hy/SHy/PV/ST/BM	India

Table 2 Summary of fundamentals (Tronco del TOS)
Source: Own Elaboration

Trends (Leaves)

The MCDM tools have been applied to the design of RES to promote renewable energies in sustainable use, in isolated systems (Strantzali et al., 2017; Ray et al., 2018; Hernández et al., 2014; Alsayed et al., 2014), to mitigate inherent variability in sources. While, in interconnected systems (Ray et al., 2018; Hernández et al., 2014; Alsayed, et al., 2014; Theodosious et al., 2015) it has been carried out to promote the diversification of energy sources, to reduce greenhouse gas (GHG) emissions and dependence on fossil fuels.

For example, the PROMETHEE II tool was implemented by Alsayed et al. (2014), for a RES W / PV interconnected to a PGS (power generation system). Subsequently, Strantzali et al. (2017) applied the same tool to an isolated W / NLG (Natural liquified gas) system with a fuel generator as a backup system. In a more recent publication (Ray et al., 2018), CSA (Cuckoo search algorithm) was applied for the design of a W / PV system with a combined cycle gasifier digester.

Hernández et al. (2014), applied VIKOR, for the optimal selection of two RES; one of these W / PV interconnected to the network to supply the demand of the laboratories of a university on the isthmus of Tehuantepec. And another system, also W / PV, but isolated, for the electrification of a rural area in Cuba. In other studies of W / PV systems, TOPSIS has been applied in its basic form (Perera et al., 2015), or with FL defining the fuzzy TOPSIS tool (Theodosiou et al., 2015). For their part, Ifaei et al. (2018), applied the same tool to simulate a RES composed of PV / W / BG / HY / BM, as a pilot unit to evaluate the energy potential of Iran.

Bakhtiari & Naghizadeh (2016), propose the SFLA / ε-constrain (Shuffled Frog Leaping Algorithm / Restrictions Ipsilon) tool, for the design of a RES W / PV / FC / Elec / H2 / Batt, with an intermittent demand profile. For a case study in England, (Malekpoor et al., 2017), they suggested the implementation of technologies with low CO2 emissions, reducing the use of coal and gasoline. They used the GRA-MOGLP Gray Relational Analysis- Multi-objective Gray Linear Programming MODM; being an effective tool for the evaluation, optimization and planning of sustainable electricity generation.

Subsequently, an adaptable, affordable and sustainable wastewater treatment system powered by a W / PV system, based on theory and technology, was proposed (Soni et al., 2017). Similarly, MacKenna et al. (2018), presented the MILP (RE3ASON) / MAVT proposal for energy planning, using renewable sources such as W / PV / BM.

Trutnevyte (2018), developed the EXPANSE (EXploration of Patterns in Near-optimal energy ScEnarios) methodology for the design of RES and their interaction with sources for the evaluation of the economic potential of RES from a hybrid perspective (energy mix), with in order to address two limitations of the evaluations of the economic potential of RES: (1) they do not capture that this economic potential depends on the participation of each energy within the mix, or they do not provide an optimal individual cost within the mix, and (2) do not allow for consensus building among relevant stakeholders.

In 2015, Theodosius et al., Used LCA (Life Cycle Analysis) and MDCM for the design of RES with renewable and conventional sources. Finally, Kim et al., In 2017, used AHP, MAUT, PROMETHEE and ELECTRE in order to compare the results obtained, emphasizing the storage system.

In other references, MCDM tools were applied to guide the decision-making process in different areas of renewable energy, such as energy planning (EP), development of distributed energy systems (DEP), and selection of sustainability indicators (SI).

Table 3 summarizes the fundamental aspects in these studies, as well as those mentioned above, in the field of RES. All of these constitute the trends and are located in the TOS (leaves).

Table 3

Year: Authors	Methodology	Energy sources	country
2011: Golic; Manfren	VIKOR; Software optimization	ST; General energy	Serbia; Italy
2012: Tegou	AHP	W / GT / fuel	Greece
2013: Trutnevyte; Yilmaz	EXPAND; MCDM-MODM	Hy / GT / ST / Firewood; Isolated BM	Switzerland; Turkey
2014: Cannemi; Hernández; Mallikarjun	ANP; VIKOR; DEA / GP	BM; W / PV; General energy	Italy; Mexico / Cuba; USES
2015: Jin; Perera; Theodosious; Kilkis	WS / GA; FL TOPSIS; LCA; REMM (ATMCI)	W / PV; W / ST / Hy / H2-T / BM / GT; GT / BM / W	USES; Sri Lanka; Greece; Turkey
2016: Pankovits; Xu; Diemuodeke; Cayir; Kolios; Sun; Zhang; Zhao	FL, GA; PROMETHEE II; TOPSIS; Review; TOPSIS, PROMETHEE, WSM, WPM, AHP, ELECTRE; TOPSIS; Monte Carlo; GRA-VIKOR	Energy in general; W / PV; W / PV / Diesel; Energy in general; W; W / PV / B / Hy / SHy / GT / TE / WE / OTE; W / PV; Electric vehicles	France; England; Nigeria; Turkey; England; China; Hong Kong; China
2017: Strantzali; Kim; Soni; Naz; Cajot; Ioannou; Chen; Perera; Malkawi; Dziugaite-Tumeniene; Yousefi; Ali; Eichhorn; Kazak; Suuronen; Gentils; Sagbansua; Sahabmanesh	PROMETHEE II; AHP / MAUT / PROMETHEE / ELECTRE; WSM / MILP / NSGA / FL / GA; Review; Review; MIQP mix; FL TOPSIS; AHP; ESSINTEGRA; AHP / GA; AHP / FTN; GIS / DANP / MABAC; GIS / SDSS; AHP / OWA / GIS; FEA / GA; AHP / TOPSIS; AHP	W / LNG / fuel; Energy in general; W / PV; PV / W / B; Energy in general; W / PV / Hy / H2-T; W / TG; PV / W / Batt / ICG; B / W / PV / ST; B / Firewood / PV / ST; PV / ST / GN / ICG; W; W; W; PV; W offshore; W; General energy	Greece; USES; India; Pakistan; Germany; England; USES; SriLanka; Jordan; Lithuania; Iran; South Korea; Germany; Poland; Chile; England; Turkey; Iran
2018: Celli; Li; Medina-Gonzalez; Bakhtiari; Ifaei; Malekpoor; Ray; McKenna; Giaouris; Kumar; Pamucar; Hajibandeh; Atabaki; Sehatpour; Vishnupriyan; Chen; Harkouss; Lotfi; Davtalab; Xu; Liu	AHP / TOPSIS; TOPSIS / DEA / COPRAS; ELECTRE IV / MILP; SFLA / ε-constrain; FA / TOPSIS; GRA / MOGLP; CSA; MILP (RE3ASON) / MAVT; EMS, MILP; TOPSIS AHP; LNN PW-CODAS; MM; AHP / MILP; FL GP / SIR; AHP; NSGA II / MOEA / DA; ELECTRE III; TOPSIS FL; GIS / ANP FL / OWA; TOPSIS / IT2 FNs FLs; AHP FL	Storage; W / PV / Diesel; BM; W / PV / batt / H2 / T; PV / WT / BG / Hy / SHy / BM; W / PVT / BM / Hy / H2-Coal / Oil / Gas / Nuc; W / PV / gasificator / CC / digester; W / PV / B; PV / W / diesel / PEMFC; PV / W / Diesel / BB; W / PV / ST / GT; W; General energy; Fuel / diesel / CNG / LPG / Biodiesel; PV; W / H2-T PEMFC; PV / ST Arq; W; BM; Electric vehicles; W / PV / B	Italy; China; Spain; Iran; Iran; England; India; Germany; Greece; India; Libya; Portugal; Iran; Iran; India; China; France; Iran; Iran; China; China

**Table 3** Trend summary (TOS sheets)
Source: Own Elaboration

According to the number of MODM and MCDM publications found in the trends (Table 4), it is observed that 71.2% of the studies used the MCDM tools, and the most popular were AHP, VIKOR and TOPSIS, due to their easy implementation, and their great flexibility, allowing the inclusion of a large number of criteria for analysis and selection of the closest alternative to the ideal optimal solution.

MCDM	NP	MODM	NP
AHP	13	DEA	1
ANP	2	GA	3
VIKOR	3	MILP	2
GP	1	COPRAS	1
PROMETHEE	2	SFLA	1
ELECTRE	2	MOGLP	1
TOPSIS	8	CSA	1
MAUT	1	NSGA	2
CODAS	1	MIQP	1
DEMANTEL	1	MOEA	1
MABAC	1	REMM	1
SIR	1		
SDSS	1		

Table 4 Number of publications (NP) by MCDM and MODM found in the trends (leaves)
Source: Own Elaboration

Furthermore, in graph 1, it can be seen that the MCDM tools in RES have been more frequently used for their design (23%) and for the DEP (17%). The design of RES is projected as one of the most extensive areas for the application of MCDM tools in the TDG.
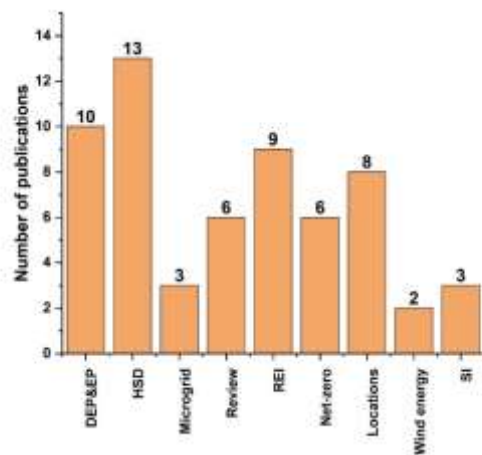
Graphic 1 MCDM in the trends of the THREE
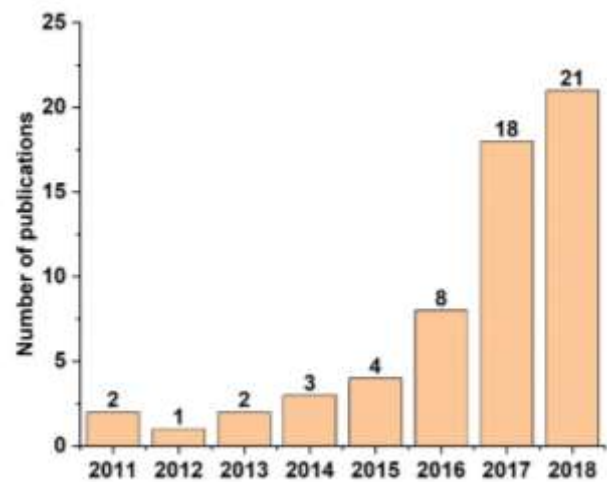*Source: Own Elaboration*

Discussion

From the trends section (Leaves) it is notable that, for example, 77% of the publications considered W and PV energies as a synergistic and significant group within renewable sources.

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It can also be observed that such investigations include different types of MCDM tools (TOPSIS, AHP, PROMETHEE II and VIKOR), and MODM methodologies (CSA, MOGLP, SFLA). 56% applied MCDM tools, being TOPSIS the most common; which coincides with the results of Table 4 due to the frequency of its application to the RES design. Each tool has its own advantages and disadvantages, summarized in Table 5, in which some MCDMs are suggested for the dimensioning or design of RES.

MCDM	Advantage	Disadvantages	Chosen because:
PROMETHEE II (Alsayed, 2014)	Involves all levels of decision making	Doesn't structure the goal properly	Take into account the preferences of decision-makers
	Can take into account qualitative and quantitative indicators	It is complex, users must be experts	Define the best solution among the alternatives
	Incorporates information on uncertainty and diffusivity	The weighting of the weights depends on the decision makers	
VIKOR (Hernández, 2014)	It is an improved version of TOPSIS	Difficulties arise in conflict situations	Take into account the preferences of the main decision-makers
	Calculate the ratio of positive and negative responses, reducing bias.	Requires modifications when data is similar, presents difficulties for real-time modeling	
TOPSIS (Ifaei, 2018)	Establish the fundamental order	Principles of Euclidean distances that do not differentiate between positive and negative values	Allows the implementation of 13 sustainability criteria
	Use all available information	Attribute values can be monotonically increasing or decreasing	Allows the construction of large matrices
	The information required is not independent		
AHP (Kim, 2017)	Adaptable	Independence between outcomes and alternatives can lead to risky outcomes	It is the most popular tool in the field of renewable energy
	Does not require complex math	When many actors are involved, weighting the weights is a complex process	It is the most popular model in the administration of scientific research and its applications
	Hierarchical structure where the criteria are well focused and managed in a transparent way	Requires data collection based on experience	

Table 5 Most Popular MCDMs in Hybrid System Design - Advantages and Disadvantages
Source: Own Elaboration

The methodologies previously analyzed were applied in their basic form or original structure, because they are still in force, as can be seen by the year of publication. The complex implementation of the MCDM is a negative factor, since there are other less difficult options with which similar results can be obtained, easy to implement, with lower requirements and shorter calculation times. Additionally, as suggested by some authors (Connolly et al., 2010; Loken, 2007), the results obtained by a tool must be corroborated using another that agrees, and in the opposite case, a third option that to support two out of three coincidences.

It should be noted that the number of publications that define trends in the use of MCDM tools in RES has increased considerably (Graphic 2) This fact is related to global concern about the problems associated with the use of fossil fuels and their impact on the changes that the Earth is undergoing. Increasingly, academic and scientific institutions, as well as government and society, are involved in the need to carry out energy development in a sustainable way. But, to achieve these goals, it is necessary to take actions that incorporate MCDM tools, to take into account the three pillars of sustainable development and the institutional sphere..


Graphic 2 Publications per year (TOS sheets)
Source: Own Elaboration

However, international efforts in this direction have different dimensions between some countries and others; This is evident when analyzing the distribution by country of the publications suggested by TOS, which defined the trends (Graphic 3).

For example, there is a very low number of publications from Latin American countries. Only Chile, Cuba and Mexico appear, each with a single published case study.
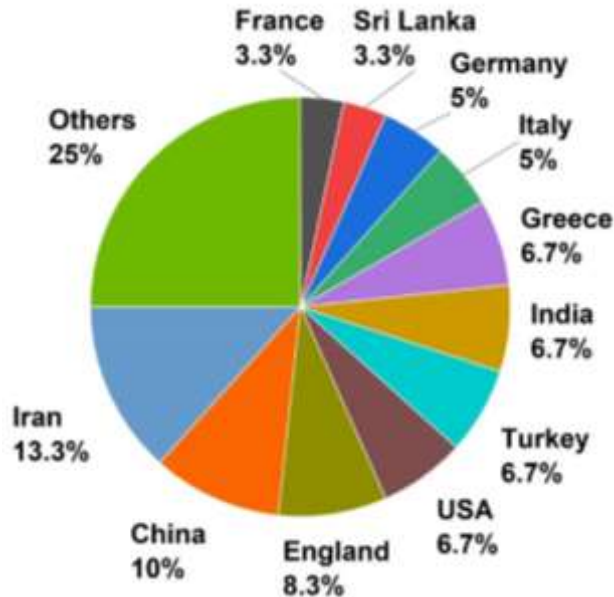
Graphic 3 Publications by country in trends. Others include: Chile, Jordan, Libya, Lithuania, Mexico, Cuba, Nigeria, Pakistan, Poland, Portugal, South Korea, Sri Lanka, Switzerland
Source: Own Elaboration

The MCDM tools are expected to be used more frequently in the renewable energy field and by a larger number of nations, as they can help resolve disagreements among stakeholders during the complex transition from conventional to renewables.

This is where the importance of using the basic structures of the MCDM tools falls, to motivate communities to use them to have support during decision-making processes, which allows support and active participation in energy generation projects based on in one or more renewable sources. Which would ensure its correct operation and functioning throughout the life cycle of the designed project, through stakeholders and involving users.

Annexes

Nomenclature

Batt	Batteries
BG	Biogas
BM	Biomass
CCHP	Combined Cooling, Heating and Power
CODAS	Combinative Distance-based Assessment
COPRAS	Complex Proportional Assessment
DA	Diferential Algorithm
DANP	DEMANTEL ANP
DEA	Data Envelopment Analysis
DEP	Distributed Energy Planning
E	Electrolyzer
EP	Energy planning
EXPANSE	Exploration of Paterns in Near-Optimal Energy Scenarios
FA	Factor Analysis
FC	Fuel Cell
FEA	Finite Element Analysis
GAUF	Geometric Average Utility Function
GE	Gas Engine
GRA	Gray relational análisis
H_2-T	Hydrogen Tank
HP	Heat Pumps
HSD	Hybrid system design
Hy	Hydraulics
ICG	Internal Combustion Generator
LNG	Liquefied Natural Gas
MABAC	Multi-Attributive Border Approximation Area Comparison
MOEA	Multi-Objective Evolutionary Algorithm
NSGA	Non-Sorting GA
PEMFC	Proton Excechance Membrane Fuel Cell
PV	Photovoltaics
REI	Renewable Energy Integration
SHy	Small Hydraulic
SI	Sustainability Indicators
ST	Solar Thermical
TG	Thermal Generators
TH	Thermal
W	Wind
WA	Waves
H_2-T	Hydrogen Tank
HP	Heat Pumps
GT	Geothermical

Acknowledgments

Conclusions

A bibliographic analysis is presented on the optimization of renewable energy systems using multi-criteria analysis methodologies, according to the references suggested by the tree of science platform (TOS), whose classification into roots, trunk and leaves, facilitated the understanding of the subject.

It was observed that multi-criteria analysis tools (MCDM) for group decision-making (TDG) have been applied successfully to renewable energy systems (RES), mainly because they allow reaching a consensus among stakeholders. These tools also take into account multiple qualitative and quantitative criteria for the evaluation and selection of the best real system. The evolution of methodologies, as well as their application to renewable energy projects began in the early 80s.

Several studies concluded that decision makers and researchers saw the need to address the flaws of basic methodologies over the years and in different case studies, where they implemented the simulation of uncertainty with methods such as fuzzy logic (FL), approximate numbers (RN) and gray calculations. The methodologies were expanded to other regions where the parameters and inputs differed, as well as the variations in the applied proposal.

It is evident that some methods were not effective in certain cases, because the results depended on the initial values, as well as on the literature analyzed; Therefore, the recommendation of the authors and the experts is to use two or more methodologies in series or in parallel, to reduce the deficiencies and enhance the advantages of each one.

It should be noted that highly complex calculation methods have shown good results, but their implementation is inconvenient. However, some similar methodologies could yield similar results with less complexity and low setup and calculation times.

Finally, it can be said that the area of renewable energies in which the MCDM tools are having greater applicability is the design of renewable hybrid systems under a sustainability approach, therefore, it is highly recommended to work in this direction.

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