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PROBABILISTIC ASSESSMENT OF THE LIFE-CYCLE COSTS OF RENEWABLE AND NON-RENEWABLE POWER PLANTS

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For any modern society to develop, it is needed an energy system ensuring a constant supply. At the heart of this system should be abundant resources, obtained at a reasonable cost and easily transported. These resources must also be of a reasonable quality. Throughout its history, humanity has used two crucial criteria when choosing energy systems: technical availability and economic viability. Fortunately, in the last few decades, environmental and social aspects have been taken into account for this decision. In spite of this, in the real decision-making processes, the economic pillar remains as the most important one, both in the public and private sectors. This paper presents a probabilistic model for assessing the life-cycle costs of renewable and non-renewable power plants. It is based on the MIVES-Monte Carlo method, employing requirement trees, value functions, the analytic hierarchy process and Monte Carlo simulation. The model makes it possible to compare different types of renewable and non renewable power plants according to economic criteria.

Keywords: *power plants; cost; life cycle; MIVES-Monte Carlo, simulation*

EVALUACIÓN PROBABILISTA DE LOS COSTES DEL CICLO DE VIDA DE CENTRALES DE PRODUCCIÓN DE ENERGÍA RENOVABLE Y NO RENOVABLE

El desarrollo de cualquier sociedad moderna necesita un sistema energético que pueda garantizar un suministro regular de energía, basado en unos recursos abundantes, que se puedan obtener a unos costes asequibles, que sean fáciles de transportar y que posean una adecuada calidad energética. La humanidad, a lo largo de su historia, ha seleccionado los sistemas energéticos atendiendo a dos parámetros fundamentales: la disponibilidad técnica y la viabilidad económica. Afortunadamente, en las últimas décadas se están contemplando aspectos ambientales y sociales que condicionan la aceptación o rechazo de los sistemas energéticos. A pesar de ello, en la realidad el pilar económico sigue siendo el más importante en la toma de decisiones, tanto en el sector público como en el privado. En esta comunicación se presenta un modelo probabilista de evaluación de los costes de centrales de producción de energía renovable y no renovable, a lo largo de sus ciclos de vida. El modelo está basado en el método MIVES-Monte Carlo y, por tanto, en el uso de árboles de requerimientos, funciones de valor, el proceso analítico jerárquico y la simulación tipo Monte Carlo. Con él es posible comparar centrales de todo tipo, con diferentes tecnologías, con arreglo a criterios económicos.

Palabras clave: *centrales de producción de energía; costes; ciclo de vida; MIVES-Monte Carlo; simulación*

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1. Introduction

1.1 Background and motivation

The generation mix on the power grid is evolving continuously. Old power plants are retired and new ones are commissioned to ensure generation adequacy, that is, the available generation can cover peak demands. In the last decades, the spread of the renewable energy sources all over the world has considerable increased due to the growing concern for reduction of the environmental emissions from anthropic activities and to the permanent increase of the fossil fuel prices.

Government planners face the challenge of providing the necessary conditions for the development of national society. For any modern society to develop, it is needed an energy system ensuring a constant supply. At the heart of this system, there shall be abundant resources, obtained at a reasonable cost, easily transported and with an adequate energy density for machines and equipment.

It is important to remember that, throughout its history, mankind has used two crucial criteria when assessing and comparing power plants: technical availability and economic viability. The economic aspects remain to be the most important ones in the real decision-making processes. As a result, it is necessary to analyze the cost of renewable power plants to see if they are competitive against their conventional counterparts.

1.2 Literature review

There are different methods for evaluating the economic feasibility of a power plant. One of this metrics is the cost per watt. The frequently considered Net Present Value (NPV), Internal Rate of Return (IRR), Pay Back Period (PBP) and Benefit to Cost Ratio (BCR) indicators are other option.

The Levelised Cost of Electricity (LCOE) is another alternative which is a cost of generating electricity for a specific power plant. The LCOE is an assessment of the economic lifetime energy production and cost. This technique allows alternative technologies to be compared with different scales of investment, operation or operating time. Nevertheless, there are different ways of calculating the LCOE, and the inclusion or exclusion of various factors (levels of contingency, tax, insurance, financial and so on) and the differences in calculation processes can have a significant influence over the LCOE (Hinkley et al., 2013). Therefore, caution needs to be taken when comparing LCOEs from different studies.

Due to the uncertainty of various inputs (capacity factor, construction cost or fuel price, among others) on the LCOE, a sensitivity analysis is frequently performed. Changes in the sensitivity analysis are usually ad hoc without regard to the probability of them happening (Di Lorenzo et al., 2012). Obviously, this is a clear weakness.

In this section, a review of some of the most recent economic studies in the energy sector is presented.

Carapellucci, Giordano and Pierguidi (2015) created a methodology for assessing the technical and economic potential of small hydro on the Abruzzo region in Italy. The economic analysis estimates the cost of the unit of electricity produced as well as the profitability of the initial investment. Said, EL-Shimy and Abdelraheem (2015) presented an improved modelling and analysis of the LCOE related to photovoltaic (PV) power plants. The model considers the effective lifetime rather than the use of the financial lifetime. They performed a sensitivity analysis to show the effect of the uncertainty on the value of LCOE.

Ahmad and Ramana (2014) examined the economics of nuclear power in Saudi Arabia, and compared it to natural gas and solar energy. The costs of electricity generation, water desalination and the opportunity cost associated with forgone oil and gas revenues are calculated. Tola and Pettinau (2014) compared, from the technical and economic points of view, the performance of three coal-fired power generation technologies. Each technology was analyzed with and without CO_2 capture.

Li, Peng and Sun (2014) performed a long-term cost analysis of wind power and compared its competitiveness to non-renewable technologies. They considered important attributes related to wind intermittency that are sometimes ignored in traditional LCOE studies. Hinkley et al. (2013) provided an overview of the costs of concentrating solar power (CSP) deployed internationally. They estimated expected costs in Australia, both for trough and tower technologies. Lüschen and Madlener (2013) studied the economic potential of biomass cofiring in hard coal power plants in Germany. To this end, they identified suitable biomass input fuels, investment and operating costs, and the profitability of cofiring investments.

1.3 Objective: gaps in the current knowledge

The economic aspects of power plants have caught the attention of a great number of authors. Nevertheless, as far as can be known, there is no model providing a global and general vision of the costs for all the more common power plants. Thus, the contribution of this paper is twofold. On the one hand, the aim of this study is to create an assessment model that makes it possible to compare the main energy systems according to economic criteria. On the other hand, this is the first time that the MIVES-Monte Carlo method will be applied for such a purpose in the energy sector. This method makes it possible to consider potential nonlinearities in the assessment, it integrates the Analytic Hierarchy Process (AHP) and it allows to consider uncertainty in the assessment.

2. Materials and methods

2.1 MIVES method

To create the model proposed here, the MIVES method (*Modelo Integrado de Valor para una Evaluación Sostenible,* or Integrated Value Method for Sustainability Assessment) combined with Monte Carlo simulation was used. MIVES is based on requirement trees (Gómez et al., 2012), value functions (Alarcón et al., 2011) and, optionally, the AHP (Saaty, 2006).

MIVES involves several stages. Once the problem to be solved has been defined, a basic diagram of the decision model is created: a requirement tree. It is a hierarchical scheme in which the different characteristics of the product or process to be assessed are defined in an organized way. The tree normally has three levels: requirements, criteria and indicators. The third level defines the concrete aspects that are going to be assessed. The other two levels establish a structure to break down the requirements and facilitate model conception and calculations.

Once this tree has been made, specific mathematical functions, called value functions come into play. Value functions are used to transform the different magnitudes and units for the indicators into a common, dimensionless parameter called value or level of satisfaction. As is the case with the method's foundations, MIVES is based on mathematical elements from the general theory of decision making, specifically Multi-Criteria Decision Making (MCDM). When a design alternative is compared with others, it is possible to consider the existence of a value function $V: P \rightarrow R$, with $P = (P_1, P_2, \ldots, P_N)$, the set of all the indicators considered in the tree. The problem consists of constructing a dimensionless value function $V(P)$ which, integrating all the indicators P_i, reflects the preferences of the decision maker. The solution is a function V, a weighted sum of the N value functions V_i corresponding with the N indicators.

When a problem produces a requirement tree with three levels, V assumes the shape of Equation 1.

$$V(P)=\sum_{i=1}^{i=N}\alpha_i\cdot\beta_i\cdot\gamma_i\cdot V_i(P_i) \tag{1}$$

V(P) measures the performance of the alternative being evaluated, with respect to the set of indicators P; α_i and β_i are the weights of the requirements and criteria to which indicator belongs to, γ_i are the weights for the different indicators; $V_i(P_i)$ are the value functions used to measure the performance of the alternative under study with respect to a given indicator i; and N is the total number of indicators taken into account in the assessment.

Value functions allows to consider potential nonlinearities in the assessment, by means of the function shape. The different geometries make it possible to establish greater or lesser exigency when complying with the requisites for satisfying a given indicator. MIVES uses Equation 2 as a basis for defining each value function V_i.

$$V_i=\frac{1-e^{-m_i\cdot\left(\left|P_i-P_{i,min}\right|/n_i\right)^{-A_i}}}{1-e^{-m_i\cdot\left(\left|P_{i,max}-P_{i,min}\right|/n_i\right)^{-A_i}}} \tag{2}$$

In Equation 2, P_i is the input value of the indicator i for the alternative under assessment. $P_{i,max}$ and $P_{i,min}$ are, respectively, the values of P_i associated with the best and worst performances (here 1 and 0). A_i, n_i and m_i are shape factors used to generate concave, convex, S-shaped or straight line value functions.

The following step in MIVES entails defining the weights or relative importance of each aspect taken into account in the assessment. Experts in the field should stablish the numerical values for the weights α_i, β_i and γ_i. In general, directly allocating weights in branches with up to four elements does not generate problems. With more than four, one often loses the overall view and this can lead to inconsistencies. In such cases, it is a good idea to use a methodological process more rigorous, that is, AHP. Additional information about MIVES can be found in (Gómez et al., 2012) (in Spanish) and in (de la Cruz et al., 2015) (in English).

2.2 MIVES-Monte Carlo method

MIVES has its own limitations when dealing with uncertainty. The approach widely employed involves calculating a best estimate for each indicator (investment cost, operation and maintenance cost, among others) based on the available information and using it in the assessment model. By proceeding this way, it is assumed that it is possible to associate a single value to each indicator and that such values are precise. However, uncertainty can affect specific variables of engineering systems and so, the indicators. Moreover, it could be discrepancies among the experts at the time of establishing value functions and the weights of the tree.

It is necessary to combine MIVES with a technique capable of considering the uncertainty. One option is Monte Carlo simulation (Ripley, 1987).

The MIVES-Monte Carlo method is composed of nine phases. In Phase 1 the probabilistic parameters of the MIVES model will be identified. Indicators, weights and value function parameters could be treated as probabilistic variables. It is recommended that only the variables with the greatest influence over the model and with a high degree of uncertainty are established as probabilistic.

In Phases 2 and 3, the deterministic (Phase 2) and the probabilistic (Phase 3) parameters of the model will be estimated. Phase 2 usually does not cause problems because deterministic variables can be estimated using expert judgement. Besides that, historical databases would be very helpful. In Phase 3, simple and easy to understand probability distributions could be used: open and close triangular ones, uniform distributions, Bernoulli and general discrete functions (de la Cruz et al., 2015).

In Phases 4 to 6 simulation will be performed. According to the previously defined probability distributions, pseudo-random values will be generated for every probabilistic variable (Phase 4). Pseudo-Random Number Generators (PRNGs) and complementary techniques will be used for this purpose; for instance, the inverse transform method and the acceptance-rejection technique can be employed (de la Cruz et al., 2015).

Equations 1 and 2 will be applied in each iteration to obtain a potential value for the final performance of the alternative under study (Phase 5). Phases 4 and 5 will be repeated until convergence has been reached in the results (Phase 6).

In Phase 7 a statistical analysis of the output sample will be performed. This means calculating its essential statistical parameters (maximum, minimum, standard deviation, percentiles, among others). Besides that, the frequency histogram and the curve of cumulative probability can be built. In Phase 8, the users must interpret the statistical analysis. Finally, real, final data must be collected, to be used in future projects (Phase 9). Additional information about the MIVES-Monte Carlo method can be found in (de la Cruz et al., 2015).

2.3 Assessment model

When comparing different alternatives, it is necessary to consider a time period long enough to include all of the predictable circumstances that could happen and the assessable aspects that could arise. Consequently, with the model that is produced, one must be able to carry out the economic assessment throughout the system’s life cycle. The life cycle stages considered are:

- Obtaining the fuel, raw materials or primary energy.
- Treating the fuel or raw materials.
- Transporting the fuel or raw materials.
- Building the plant.
- Running the plant.
- Decommissioning the plant.

The assessment parameter is called the Economic Index (EI). Its formula is found in Equation 3, which is a particular case of Equation 1, adapted to the problem dealt with in this study.

$$EI = \sum_{i=1}^{i=8} \alpha_i \cdot \beta_i \cdot \gamma_i \cdot V_i \qquad (3)$$

Table 1 presents the requirement tree for the model with the corresponding indicators, criteria and requirements, as well as their weights (γ_i, β_i and α_i, respectively).

Table 1: Requirement tree for the model

α_i (%)	Requirements	β_i (%)	Criteria	γ_i (%)	Indicators
100	Economic	16	Cost of obtaining the fuel or raw materials	100	Mining and extraction cost (E1)
		6	Cost of preparing the fuel or raw materials	100	Pre-treatment and enrichment cost (E2)
		6	Cost of transporting the fuel or raw materials	100	Transportation cost (E3)
		29	Investment cost	100	Investment cost (E4)
		39	Operating cost	40	Cost of fuel and CO_2 emissions rights (E5)
				60	Operation and maintenance cost (E6)
		2	Subsidies	100	Subsidies (E7)
		2	Decommissioning cost	100	Decommissioning cost (E8)

Below there is a description of the indicators considered, whose units of measurement are specified in Table 2.

- Mining and extraction cost (E1), including equipment, machinery, accessories and labor needed to extract the raw material or fuel used.
- Pre-treatment and enrichment cost (E2), including the process of washing, milling, drying, refining, distilling, enriching, eliminating impurities and other processes needed to burn the fuel in the plant.
- Transportation cost (E3). Transporting the raw material or fuel from the extraction point to the plant.
- Investment cost (E4) covers designing the plant, as well as acquiring the land, moving earth, excavating and erecting all the buildings and necessary infrastructure. It also includes the process equipment cost. Among this equipment are boilers, alternators, control and monitoring systems, turbines, wind turbines, condensers, nuclear reactors, solar panels, pipe work steam generators and, generally, whatever is deemed necessary for the plant to run well.
- Cost of fuel and CO_2 emissions rights (E5), including cost of buying the fuel and cost of buying CO_2 emissions rights.
- Operation and maintenance cost (E6), including variable and fixed costs.
- Subsidies (E7). State help in the initial investment.
- Decommissioning cost (E8) covers equipment decommissioning, civil works demolition, removing equipment and materials, cleaning and restoring the affected areas and tracking the restoration measures. The residual value is discounted.

As illustrated in Section 2.1, a value function was defined for each indicator. The parameters used for constructing them are shown in Table 2. Value functions were defined according to an expert who has more than 40 years of experience in the energy sector.

Table 2: Parameters for the value functions

Indicator	Parameters					Characteristics
	$P_{i,max}$	$P_{i,min}$	A_i	m_i	n_i	Shape
E1 (€/TJ)	0	7000	7	0.22	5000	S-shaped
E2 (€/TJ)	0	5000	7	0.03	2650	S-shaped
E3 (€/TJ)	0	8000	6	0.43	6000	S-shaped
E4 (€/TJ)	1400	14000	4	0.80	10000	S-shaped
E5 (€/TJ)	0	11000	6	1	8850	S-shaped
E6 (€/TJ)	800	5000	5	0.1	2000	S-shaped
E7 (%)	100	0	0.25	1	40	Convex
E8 (€/TJ)	0	1500	8	1	1350	S-shaped

Defining the weights (Table 1) is not a simple task. As illustrated in Section 2.1, for those branches with up to four elements, weights have been directly allocated. For the remaining cases (criteria) AHP was applied. After doing so, some weights were slightly modified according to the opinions of the previously referred to expert.

2.4 Design alternatives

With the previously created model, a total of fourteen alternatives were assessed.

- Coal-fired power plant (C1).
- Lignite thermal power plant (C2).
- Oil-fired power plant (C3).
- Natural gas-fired plant (C4).
- Nuclear power plant (C5).
- Onshore wind farm (R1).
- Offshore wind farm (R2).
- Photovoltaic solar plant (R3).
- Mini-hydroelectric power plant (R4).
- Biomass plant (R5).
- High temperature solar-thermal plant (R6).
- High temperature solar-thermal plant hybridized with natural gas in a 10% (R7-10).
- High temperature solar-thermal plant hybridized with natural gas in a 15% (R7-15).
- High temperature solar-thermal plant hybridized with natural gas in a 20% (R7-20).

2.5 Economic data

Data regarding each indicator were proposed for every type of power plant. These data were based on an extensive literature review of scientific articles, sectorial reports, real cases with published data and reference to various interviews with the alluded expert. All the indicators were established as probabilistic variables. A triangular probability distribution was defined for each one. At the time of stablishing the minimum (min), mode (mode) and the maximum (max) values for the probability distributions, different aspects have been taken into account such as installed capacity, capacity factor, lifetime, efficiency, calorific values, technologies employed, among others. Table 3 lists the model's input values, estimated for each of the conventional alternatives.

Table 3: Model input values for all the conventional alternatives

Indicators		Alternatives				
		C1	C2	C3	C4	C5
E1	min	1000	1500	200	570	220
	mode	2880	5040	3500	1000	500
	max	5500	11000	8000	1750	1870
E2	min	150	225	490	1260	400
	mode	350	610	1100	2900	610
	max	730	1460	1470	4450	840
E3	min	0	0	100	570	70
	mode	1660	0	800	1860	200
	max	9020	0	1200	3430	640
E4	min	760	760	700	460	1470
	mode	2000	2000	1860	1600	3050
	max	5500	5500	8000	8460	4850
E6	min	1300	1300	610	810	1440
	mode	2700	2700	1300	1700	3350
	max	4800	4800	4000	6000	6230
E7	min	0	0	0	0	0
	mode	0	0	0	0	0
	max	15	15	0	0	0
E8	min	15	15	12	15	50
	mode	50	50	90	70	300
	max	70	70	160	120	3140
Fuel	min	2120	2120	6500	5000	750
	mode	5500	5500	15000	11000	1600
	max	12290	12290	25000	25000	3210
Rights	min	1050	1575	930	400	0
	mode	1700	2975	1520	630	0
	max	2540	5080	2270	2000	0

Table 4 lists the model’s input values for the renewable alternatives.

Table 4: Model input values for all the renewable alternatives

Indicators		Alternatives								
		R1	R2	R3	R4	R5	R6	R7-10	R7-15	R7-20
E1	min	0	0	0	0	5100	0	60	90	120
	mode	0	0	0	0	7100	0	100	160	210
	max	0	0	0	0	16800	0	180	270	360
E2	min	0	0	0	0	2000	0	130	200	270
	mode	0	0	0	0	2330	0	270	410	540
	max	0	0	0	0	3970	0	460	690	930
E3	min	0	0	0	0	1700	0	60	90	120
	mode	0	0	0	0	3000	0	190	300	390
	max	0	0	0	0	7150	0	360	530	710
E4	min	3480	6340	6800	2700	2750	6760	6760	6760	6760
	mode	6330	12500	9360	6000	3470	15000	15000	15000	15000
	max	16890	24890	29390	18820	7940	34980	18640	18640	18640
E6	min	3050	7080	2260	1200	1100	5780	5780	5780	5780
	mode	5000	9000	4500	2990	2590	7400	7400	7400	7400
	max	8940	13960	7490	6250	4500	9430	9430	9430	9430
E7	min	0	0	0	0	0	0	0	0	0
	mode	0	0	0	0	0	0	0	0	0
	max	0	0	0	0	0	0	0	0	0
E8	min	0	150	10	2000	15	30	30	30	30
	mode	40	320	30	3000	50	100	100	100	100
	max	110	1020	50	4300	70	160	160	160	160
Fuel	min	0	0	0	0	8000	0	500	640	860
	mode	0	0	0	0	14500	0	1000	1500	2000
	max	0	0	0	0	26350	0	2500	3750	4990
Rights	min	0	0	0	0	0	0	0	0	0
	mode	0	0	0	0	25	0	0	0	0
	max	0	0	0	0	50	0	0	0	0

For C1 and C2, the input value for the indicator E5 (in each iteration) was calculated according to Equation 4.

$$E5 = Fuel + Rights - E1 - E3 \tag{4}$$

The pseudo-random value generated for E2 was not deducted because the fuel cost values were calculated before entering in the power plant. By way of restriction, the iterations in which the sum of E1 and E3 was higher than the fuel cost were discarded.

For the other alternatives, the input value for the indicator E5 (in each iteration) was calculated according to Equation 5.

$$E5 = Fuel + Rights - E1 - E2 - E3 \tag{5}$$

In a similar way to the previous case, the iterations in which the sum of E1, E2 and E3 was higher than the fuel cost were discarded.

3. Results and discussion

The statistical parameters obtained with the proposed model for the EI of all the alternatives are shown in Table 5; being one and zero the maximum and minimum levels of satisfaction, respectively.

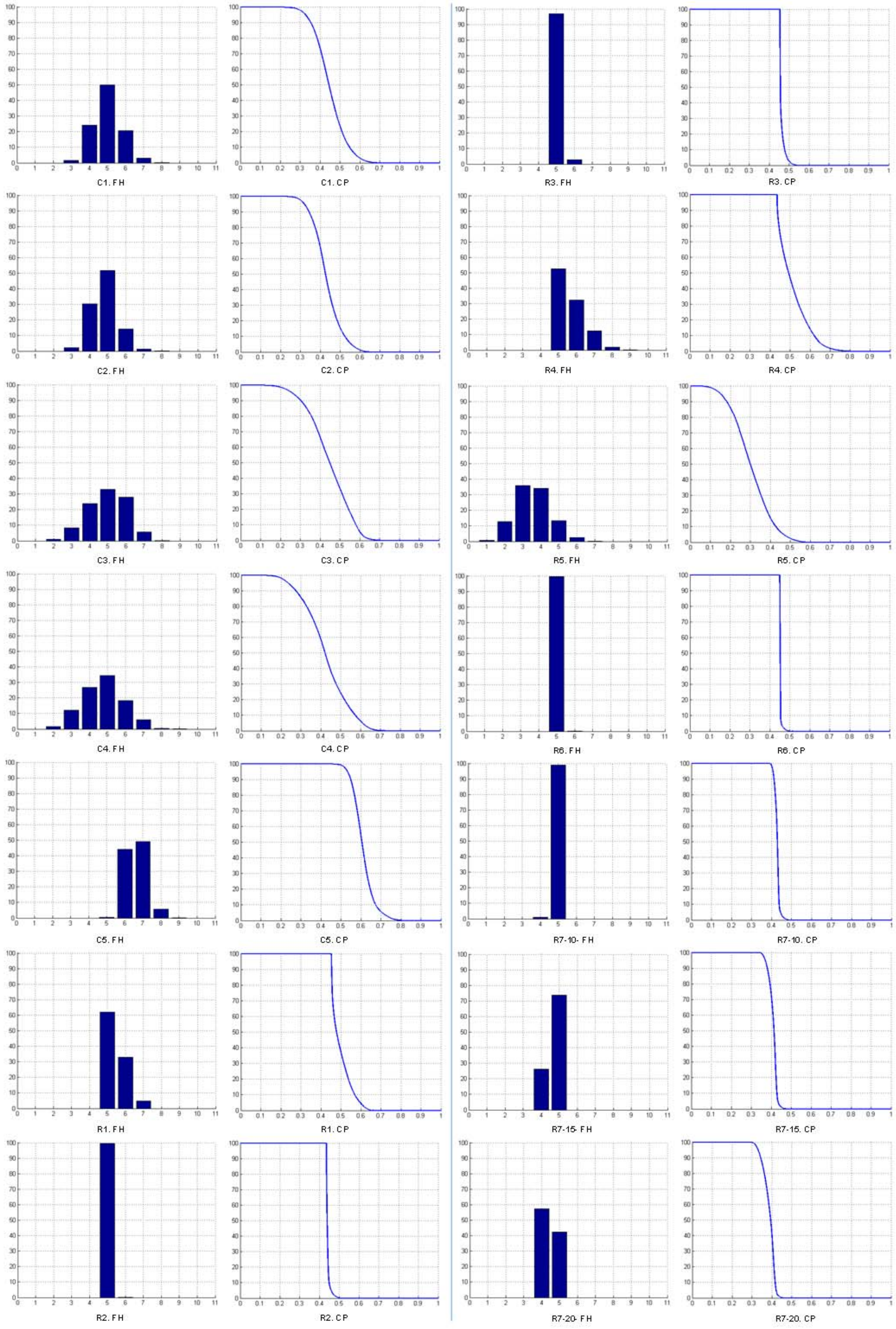
Table 5: Statistical parameters

	Mean	Min	Max	Modal interval (MI)	Frequency of the MI	Variance	Standard deviation	Iterations
C1	0.4493	0.2227	0.7481	[0.4,0.5)	49.9661%	0.0057	0.0755	44300
C2	0.4315	0.2364	0.7018	[0.4,0.5)	51.7457%	0.0048	0.0692	40500
C3	0.4466	0.1211	0.7635	[0.4,0.5)	33.0631%	0.0110	0.1050	52300
C4	0.4243	0.1300	0.8188	[0.4,0.5)	34.4876%	0.0121	0.1100	52500
C5	0.6104	0.4615	0.8484	[0.6,0.7)	49.2996%	0.0027	0.0517	23700
R1	0.4975	0.4520	0.6639	[0.4,0.5)	62.2784%	0.0023	0.0476	27300
R2	0.4424	0.4360	0.5246	[0.4,0.5)	99.7468%	8.54E-5	0.0092	7900
R3	0.4621	0.4544	0.5636	[0.4,0.5)	97.1905%	1.69E-4	0.0130	10500
R4	0.5139	0.4360	0.8618	[0.4,0.5)	52.8598%	0.0055	0.0740	16400
R5	0.3048	0.0635	0.6169	[0.2,0.3)	36.1283%	0.0090	0.0946	26500
R6	0.4536	0.4496	0.5147	[0.4,0.5)	99.8475%	2.57E-5	0.0051	5900
R7-10	0.4289	0.3936	0.4990	[0.4,0.5)	99.0779%	1.40E-4	0.0118	7700
R7-15	0.4099	0.3473	0.4881	[0.4,0.5)	73.8451%	3.82E-4	0.0195	7100
R7-20	0.3877	0.3031	0.4809	[0.3,0.4)	57.4387%	7.99E-4	0.0283	21200

The frequency histograms (FH) and the curves of cumulative probability (CP) for the EI of all the alternatives are shown in Figure 1.

As can be noted, with the exception of C5, R5 and R7-20, all the alternatives have the same more frequent interval ([0.4,0.5)), while the frequency of those intervals varies widely (from 33% to almost 100%), depending on the alternative. That means that a significant part of the power plants present an average economic performance that can be defined as medium.

Figure 1: Frequency histograms and curves of cumulative probability



Nevertheless, the majority of the alternatives present an EI that varies within a wide range. For instance, C1, C2, C3 and C4 can get values close to the minimum level of satisfaction as well as they can get values close to the maximum level of satisfaction. This is a consequence of the variation of some indicators with a great influence over the model such as E4, E5 and E6, among others. With the exception of R4 and R5, this phenomenon is less pronounced in the renewable alternatives because only E4 and E6 experiment important changes in the input values.

As for C5, it is the most attractive option economically. However, this result should be treated with caution. Actually, risks of cost overruns and construction delays are high in that type of power plant, reducing the interest of the investors in it. This study demonstrates that R5, in spite of being a renewable alternative, is not economically interesting. Nevertheless, in a decision-making process, other dimensions, apart from the economic one, should be considered (social, environmental and technical dimensions). The inclusion of other indicators (risk of accidents, employment generation, stability of the power supply chain, among many others) can alter the chosen option.

It is important to point out that there is no a best alternative for all the cases. That is, the alternative with the worst results (R5) can beat the alternative with best results (C5) in a specific case.

4. Conclusions and future developments

In this paper the problem of assessing the life-cycle costs of renewable and conventional power plants is addressed. Furthermore, this study is the first attempt at applying the MIVES-Monte Carlo method to assess the life-cycle costs in the energy sector.

From the results obtained, the general conclusion is that uncertainty can play key role in assessing and comparing power plants from an economic point of view. Furthermore, this study demonstrates that renewable alternatives can economically compete with their conventional counterparts under certain conditions.

Regarding the methodology, the MIVES-Monte Carlo method allows for quantification and analysis of the uncertainty associated with the costs of different power plants and assessing the feasibility of these technologies.

Nonetheless, in the future, the model could be improved. As mentioned in Section 2.2, discrepancies among experts can appear at the time of stablishing value functions and the weights. As a result, probability distributions can be assigned to these variables and not only to the inputs. Thus, the differences between the electricity generation systems could be analyzed in greater detail.

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