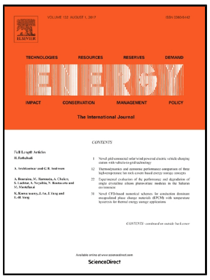

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Comparative analysis of direct employment generated by renewable and non-renewable power plants

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ABSTRACT

A probabilistic and analytical model is presented to assess the direct employment generated by power plants, throughout their lifecycles, from when the fuel is being extracted to the decommissioning stage. To represent the majority of regions and countries around the world, this model provides a global, general and probabilistic vision for all the most common kinds of power plants. Direct job creation is expressed per unit of electricity produced over the plant's lifetime, by means of a normalisation process. Renewables obtained a direct employment generation of around 0.1 to 4 job-years/GWh. On the other hand, the same figure for non-renewable power plants is about 0.1 to 2.4 job-years/GWh. The results reinforce the idea that some renewable -such as photovoltaic, biomass, mini-hydro and high temperature solar thermal power plants- are still the options with the highest direct employment generation. Nevertheless, this study demonstrates that not all renewables present a high direct employment generation. It also shows that non-renewable alternatives can compete with their renewable counterparts under certain conditions.

Keywords:
Direct employment generation
Analytical model
Monte Carlo simulation
Power plants
Renewable energy
Life cycle analysis

1. Introduction and previous work

In general terms, energy is vital not only for industry but also for social development, since it facilitates life through heating, lighting and transport [1]. It is widely accepted that the current global trends in energy supply and consumption are far from reaching integral sustainability [1]. It is already a reality that the majority of renewables can mitigate the most alarming environmental effects [2-10]. Renewable power plants also contribute to reducing energy import dependency, and therefore they boost the reliability of the energy supply [2-5,7,9,11]. Job creation is also one of the benefits associated with promoting renewable energy [4-12]. Nevertheless, this last advantage is still disputed [4,5,7,11,13,14].

In the present world economic crisis, a common problem that affects a great number of countries is a high level of unemployment [15]. Thus, job creation in the energy sector is of paramount importance in this historic period of increasing challenges. As a result, an appropriate policy strategy for the energy sector should also take into account the net impact on the labour market [12], both for renewable and non-renewable power plants.

Taking into account all the aspects mentioned above, it is necessary to analyse the employment generated by renewable power plants to determine if these plants are more labour intensive when set against their non-renewable counterparts.

A great number of authors and organisations have attempted to assess employment generation from energy systems. By using analytical procedures, Moreno and López [16] estimated energy sector employment in Asturias, Northern Spain, for three different scenarios. In Germany, Lehr et al. [12] measured the net impact of different policy strategies on the German labour market by using an Input-Output (IO) vector. The reader can find in Section 2 more information about analytical and IO methods.

In 2008, Williams et al. [17] used an economic IO analysis to estimate the number of jobs associated with building and operating a wind energy project in two counties in Arizona, USA. Also by using the IO methodology, Caldés et al. [18] calculated the employment derived from solar thermal plants in Spain under different scenarios.

The authors in Ref. [19] employed the IO methodology for estimating the direct, indirect and induced employment effects resulting from the development of a lignite and a natural gas fired power plants in Greece. Blanco and Rodrigues [20] calculated the direct employment from wind energy in EU countries. Their study is based on a wide survey, complemented by the analysis of the annual reports from the most important wind energy companies. On the other hand, the number of worldwide jobs in the energy sector is measured in Ref. [21]. The results are shown according to technology and type of job for 2010, 2020 and 2030. They are also broken down into region, including OECD countries, Latin America and transition economies, among others.

In 2010, Llera Sastresa et al. [3] presented an integrated method to assess the creation of jobs derived from establishing renewable energies on a regional scale. Wei et al. [22] used an analytical model for assessing employment generation in the US power sector from 2009 to 2030. Tourkolias and Mirasgedis [23] formulated and implemented an IO approach for estimating the direct, indirect and induced job creation associated with developing renewable energy resources in Greece. In neighbouring Turkey, Çetin and Egrican [1] investigated the direct and indirect employment effects of solar energy. Also based on solar energy, Llera et al. [24] developed an analytical model for the Spanish PV industry in 2013.

In 2013, Oliveira et al. [25] applied a multi-objective IO model to estimate the jobs generated by renewable energy resources in Portugal, under different scenarios. In China, Wang et al. [26] evaluated the direct and indirect job creation at the end of 2011 due to different CDM (Clean Development Mechanism) energy projects. Simas and Pacca [27] assessed the number of jobs created in those wind energy projects expected to begin operating in Brazil before 2017.

In Andalusia, southern Spain, Cansino et al. [28] estimated the number of new jobs generated through increased installed photovoltaic capacity. In Ref. [29], the authors measured rises and falls in direct and indirect employment in the US natural gas, coal, wind and solar industries between 2008 and 2012. In 2015, the International Renewable Energy Agency (IRENA) [30] estimated the direct and indirect number of employees in the renewable energy sector across the world in 2014. In Ref. [4], the authors used an analytical methodology to calculate the direct and indirect employment generation for different renewable technologies. Their results are based on a review of current literature.

Sooriyaarachchi et al. [7] discussed the job creation figures for photovoltaic, wind, concentrated solar power and waste-to-energy technologies in Germany, Spain, the United States and the Middle East. In Ref. [8], the authors relied on an econometric model to estimate employment generation from wind and shale gas in Texas, between 2001 and 2011. In Galicia, northwest Spain, Varela-Vázquez and Sánchez-Carreira [10] analysed, among other aspects, the impact of wind energy in terms of employment generation by using an improved IO approach. In Ref. [11], the authors proposed a novel methodology for calculating the employment generation of renewables. This new method was applied to on- and off-shore wind and photovoltaic technologies among the member states of the European Union for the 2008-2012 period.

On the Iberian Peninsula, this time in Portugal, Henriques et al. [5] assessed the possible impact of renewable energy targets on employment for the years 2008–2020. They used an IO approach. An IO model again came into play in Ref. [31]; the authors analysed potential job creation from offshore wind energy in Spain between 2016 and 2030. Using analytical methods, Dvořák et al. [9] focussed on employment in the renewable energy sector in the Czech Republic for the period 2008-2013.

A great number of authors have delved into assessing how many jobs are generated through power plants. Some of these studies only focus on one type of energy system in a given region or country [10,17,18,24,27,28,31-33].

Other papers go further by studying employment generation for different types of power plants in the same region or country [1,3,5,8,9,12,16,19,22,23,25,26,29]. Still other studies deal with a specific energy system in more than one region or country. Ref. [20] is one example of this last type.

As far as the authors know, very few studies consider employment generation for a range of power plant types in different regions or countries. Ref [4] is one of the few that cover many different countries and several technology options. However, it is limited to renewable energies. The same occurs with Refs. [7,11]. Ref. [21] is uncommon in that it covers employment generation from non-renewable and renewable energies across several regions and countries worldwide. Nevertheless, as it is a deterministic study, uncertainty is not considered in depth. In fact, very few manuscripts adopt a probabilistic approach. The reader can find one in Ref. [17]. Even in this case, Ref. [17] does not examine each of the most common power plants from a general and global perspective.

As for measurement units, very few studies present the results per unit of output. Refs. [19,22,23,34] are some of the examples available in current literature.

One possible conclusion is that no study provides a global, general and probabilistic vision of direct employment generation per unit of electricity produced for all the more common power plants. Therefore, the present study will be representative for the majority of regions and countries around the world. Its original contribution is twofold. On one hand, its aim is to carry out a probabilistic assessment on direct employment generation from renewable and non-renewable power plants. On the other, this is the first time that an analytical model combined with a Monte Carlo simulation will be applied for this purpose in the energy sector.

The model will be used to assess 19 alternatives throughout their life cycles, from the point in which the fuel is obtained to the one in which the plant is decommissioned. Five of these were classified as non-renewable power plants, using coal (C1), lignite (C2), oil (C3), natural gas (C4) and nuclear (C5) power. The rest rely on renewable energies: onshore and offshore-wind (R1 and R2); photovoltaic (R3); mini-hydro (R4); biomass (R5); high temperature solar-thermal (R6); high temperature solar-thermal hybrid using 10%, 15%, 20% and 25% natural gas respectively (R7-10, 15, 20, 25); tidal barrage (R8); tidal stream (R9); wave energy (R10) and large-hydro (R11) power plants. Obtaining reliable input data for all these alternatives is not a simple task [4]. With this in mind, the authors have analysed in detail more than 60 sources, including scientific articles, sector reports and real cases with published data. This was also complemented with various interviews with an expert, who has more than 40 years in the energy sector in the international arena.

In the authors' minds, the study can represent the majority of real case studies. It is hoped that the results obtained with models like the one here will make it easier for public and private decision makers to work with greater objectivity. The model will be described in Section 2.

2. Analytical assessment model

The aim of the model presented in this section is to assess in accurate terms direct employment generation from renewable and non-renewable power plants all over the world. Nevertheless, apart from explaining the model, it is necessary to clarify some essential concepts, as well as to describe both the IO and analytical methodologies. It is also necessary to point out in detail the main reasons that led the authors to use an analytical methodology instead of the IO method.

The employment generation associated with an economic activity is usually divided into three different categories: direct, indirect and induced. In the current literature, authors provide a range of definitions for these types of employment generation. In some cases, this makes it difficult to interpret exactly which stages are considered in each category.

Direct jobs are those in the primary industry sector, usually in construction, manufacturing, installation, fuel supply and the operation and maintenance of the power plant being considered. Some authors also look at consultancies and several minor components not directly related to the sector [27]. These jobs are undertaken at local or national level and contribute directly to overall economic development [23].

Carrying out activities linked to direct jobs entails purchasing goods and services, giving rise to indirect and induced jobs [23]. Indirect jobs generally include employment in secondary industries, which supply the primary industry sector [4,35].

Induced jobs are related to when the salaries earned in the primary and secondary industries are spent. That is to say, people directly or indirectly connected to the power plant will increase their available income for spending [23]. Therefore, additional employment is expected due to a possible increase in consumption related to purchasing goods and services [23].

In short, each study should provide a clear explanation of what is considered a direct, indirect or induced job, so that misleading comparisons can be avoided. In the present study, direct employment refers to the jobs created in building, manufacturing, installing, operating, maintaining and eventually decommissioning the components of the power plant under consideration. It also includes the direct employment generation created in procuring its fuel. In this regard, the jobs created in manufacturing the raw materials used to produce the process equipment are considered indirect jobs. A case in point is manufacturing the steel used to build a wind turbine. Indirect and induced jobs are more difficult to be estimated accurately; they are therefore not included in this manuscript.

Now, it is necessary to explain the various metrics used in assessing employment generation. In this context, differences between temporary and permanent jobs should be addressed in detail, a task that is not often carried out in the existing literature [27]. In fact, there is usually confusion about jobs and job-years [22], the two most common units. One job-year is full time employment for one person, for the duration of one year [22], also known as full-time equivalent job (FTE job). Temporary jobs, such as those generated during the construction, manufacturing, installation and decommissioning stages, are usually measured in job-years. On the other hand, those jobs that have a non-temporary feature, due to the fact they will last throughout the entire service life of the power plant, are usually measured in jobs [27]. Jobs in operation and maintenance are usually included in this latter category.

In terms of ratios, temporary and non-temporary jobs are usually expressed per MW of installed capacity. Nevertheless, according to Ref. [27], it is preferable to use the employment figures expressed per unit of output, that is, per unit of electricity generated. This is due to the great deal of variation in capacity factors between different types of power plants and between power plants with the same type of technology. In this way, biased and non-transparent results will be avoided.

Here, the data extracted from other studies is converted into a common metric. In other words, after a normalisation process, the total direct employment generation associated with each power plant will be expressed in job-years per GWh of electricity produced. Consistent comparisons between different studies will therefore be possible.

There are the two main types of procedures used to calculate employment generation in the energy sector: Input-Output (IO) and analytical methods.

In its most basic form, the IO methodology consists of a linear equation system containing productive coefficients that describe the relationship (flows of goods and services) between the input used by the sector and final product [5,20]. Those flows are registered simultaneously by origin and destination in an IO matrix. The reader can find more information about the mathematical IO model description in Refs. [25] and [36]. An IO model also makes it possible to estimate the employment impacts across the economy by increasing or reducing demand in a specific sector [13]. With IO models, one can calculate the number of direct, indirect and induced jobs [7].

Analytical models, usually based on spreadsheet or database management systems, are the other option for estimating impact of employment on the energy sector. The analytical methodology mostly entails conducting extensive surveys [13] as a way of collecting the data. The data can also be collected from previous studies, as alluded to in Ref. [22].

Currently, there is no unanimity on what the most suitable methodology is for estimating employment generation in the energy sector. Both IO and analytical models have advantages and disadvantages.

The IO tool is intended to model the economy as an interaction of services and goods between industrial sectors and consumers [22]. That is, IO models show how one sector can systematically have an impact on all the others in a particular economy [4,18,20]. Consequently, there is a large data requirement from various scopes [4,26]. This can be an intractable problem for developing countries, where, most of the time, there is a considerable lack of data, not only in the energy sector, but also in other necessary areas. In contrast, the analytical methodology does not intend to model the economy as a whole. The lack-of-data problem is therefore less grave and can be, most often, solved. As this study will provide representative results for the majority of countries around the world, including both developed and developing regions, the IO methodology is found to be inapplicable.

Another disadvantage of IO models is that they make a number of assumptions in order to reach a high level of aggregation [4,37]. In consequence, the effects assessed by an IO model are usually presented as aggregated net impacts. These impacts are the result of an entire suite of energy policies, whose individual impacts are impossible to discern [37]. In other words, IO models, in contrast with analytical ones, are opaque. Furthermore, the renewable energy sector raises new concerns. Therefore, current IO tables are not sufficiently disaggregated to arrive at employment estimates [5].

Since IO models are very labour intensive in terms of collecting data [8], each IO model is usually associated with very few scenarios (from one or two, the most common, to typically no more than three). This makes it difficult, even impossible, to assess the effects of alternative policy scenarios, or the impact of even slight deviations from the baseline scenario [37]. In comparison, analytical models are much more transparent. The assumptions are clear, and it is possible to conduct sensitivity analyses on the results [37]. When compared to their IO counterparts, analytical models have a clear advantage, as the energy sector is continuously changing. In other words, there is a need to review, modify and improve each model in order to include the energy sector's evolution. This is particularly the case if ones takes into consideration that non-renewable resources will be exhausted in the near future.

Introducing changes in an analytical model is quick and easy, while doing so in an IO model can be very difficult, even impossible. Along the same line, if a new emerging sector (type of power plant or technology) needs to be studied, the IO model must be updated [20], considering the interrelationships among this new sector and the old ones [4]. As one can guess, this is no trivial matter. Adding a new power plant or technology is much easier in an analytical model.

In Ref. [22], the authors indicate some drawbacks that are common to both methods. The reader can find in Table 1 of Ref. [26] the main advantages and disadvantages of IO and analytical models.

2.1. Model definition

One problem with the existing studies is that they apply a wide range of different methodologies and assumptions [24]. A detailed explanation of the model is, therefore, unavoidable; the spreadsheet-based analytical model used here is described in this subsection. Through Eq. (1), the model makes it possible to calculate the total direct employment generation (*TDE*) associated with each power plant.

$$TDE = \frac{\left(DE_{CI} + DE_{M} + DE_{D} + DE_{OM} \cdot T\right) \cdot C}{TLEP} + DE_{F} \qquad (1)$$

In Eq. (1), DE_{CI} is the direct employment generation associated with the construction and installation stages of the power plant. DE_M represents the direct jobs created when components are being manufactured for each power plant. Similarly, DE_D is the number of direct jobs generated during the decommissioning of the plant at the end of its lifetime. DE_{CI}, DE_M, and DE_D are measured in job-years/MW. DE_{OM} quantifies the direct employment effects related to operating and maintaining the installation under study. Unlike for the previous variables, DE_{OM} is measured in jobs/MW. *T* is the power plant`s lifetime in years. *C* is the installed capacity of the plant in MW. For calculation purposes, an installed capacity of 1 MW will be assumed. DE_F accounts for the direct employment generated through fuel procurement, in job-years/GWh. Finally, *TLEP* is the total lifetime energy production in GWh. In this paper, Eq. (2) has been used to determine the *TLEP*.

$$TLEP = 8.76 \cdot T \cdot C \cdot CF \qquad (2)$$

In Eq. (2), *CF* is the power plant's capacity factor. The reader should bear in mind that each year has 8,760 hours, hence the factor of 8.76. In accordance with the variables described so far, the *TLEP* is measured in GWh so that *TDE* is expressed in job-years/GWh. In contrast with the majority of existing models, the one considered in this paper is suitably transparent. The functional unit is based on production, rather than installed capacity, due to the reasons referred to above.

It is important to add that Eq. (1) provides a static measurement that looks at a snapshot of possible direct employment generation. The approach commonly used to calculate employment generation involves establishing the best estimate for each input value and using it in the assessment model. By doing so, it is assumed that a single assessment value can be associated with each input, and that this value is precise. Nevertheless, real values can differ considerably from the estimated ones. In other words, uncertainty plays a key role in comparing and assessing the effects on employment of different power plants [4].

Input values may depend on the technology employed, planning and process efficiency and geopolitical situation of each nation, among many other issues. For example, a lower manpower cost in one country is usually associated with a greater number of workers employed to produce each unit of considered output [35]. That is, when labour costs are low, it is generally more cost-efficient to employ a larger work force than to boost mechanised means of production. This is one of the reasons why, for the same activity, developing countries usually need more workers than their developed counterparts.

As a way of addressing the problems mentioned earlier, authors usually perform a sensitivity analysis, changing the value for the most critical parameters. Nevertheless, one of the major drawbacks of sensitivity analysis is that changes do not take into consideration how likely they are to occur. Here, the calculation process for the *TDE* is combined with a Monte Carlo simulation.

At the time of defining the probabilistic variables, historical databases could prove very helpful. Unfortunately, there are no databases for the model's parameters. Only the minimum, modal and maximum values can be estimated. As proposed by Williams [38], easy to understand triangular distributions will be used for continuous numerical variables. They are also straightforward for the user to handle since only the extreme and modal values have to be estimated. These distributions can be configured as asymmetric ones. This is a necessary characteristic here, because the distance between the two extremes and the mode usually varies. If the estimates for the key parameters are reliable, it is preferable to perform a simulation than to depend on deterministic models.

During the simulation, pseudo random values will be generated for every probabilistic variable according to previously defined distribution functions. Each iteration entails calculating a possible value for the *TDE*. Simulation will continue until convergence is achieved, with a maximum of 150,000 iterations set for this study. The real convergence of results during simulation was analysed. For every 100 iterations, some of the statistical estimators for the results obtained up to that point were examined. In particular, the mean and standard deviation, as well as the 99th percentile, were used, although other estimators could have been suitable. The simulation ends when it has been checked that simulating additional iterations does not produce variations in the estimators above certain tolerance values. In this regard, 1% and 99% were fixed as the convergence tolerance and confidence level values, respectively.

Once the simulation has been done, a statistical analysis of the output sample will be performed. Here, the aim is to obtain the distribution function for the model result, along with its main statistical parameters (maximum, minimum, mean and standard deviation, among others). This additional information creates more realistic expectations about direct employment generation from a power plant by allowing the user to understand the range of *TDEs* that are possible.

It is important to remark that there could be correlations between variables in this type of model. Correlation occurs when the samples of two or more input distributions should be related. That is, the value sampled for one distribution should depend on the value sampled for the other. For example, when one input is relatively high, a second input also tends to be so. This is called a direct or positive correlation. The opposite may occur, which is often referred to as an inverse or negative correlation.

In the present study, the correlation of input distributions is based on rank order correlations. The rank order correlation coefficient (also known as Spearman correlation coefficient) was introduced by the English psychologist Charles Edward Spearman in the early 1900s [39-41]. This way of generating correlated samples can be considered a distribution-free approach, since any distribution type can be correlated. Although the samples drawn from two different distributions are correlated, the integrity of the individual distributions is maintained so that the resulting samples for each distribution reflect the input distributions from which they are drawn.

Spearman correlation coefficients fall between the interval [-1, 1]. A value of 0 indicates that there is no linear relationship between the two variables. A value of 1 indicates that the two variables are perfectly linearly related and vary in the same direction. A value of -1 is the same, except that the variables vary in opposite directions. Coefficient values between -1 and 0 and between 0 and 1 specify varying degrees of linear relationship between the two variables. By way of example, a coefficient of 0.8 specifies that, when the value sampled for one input is high, the value sampled for the other one will tend to, but not always, be high.

In this work, correlations between DE_{CI} (construction and installation) and DE_{OM} (operation and maintenance); DE_{CI} (construction and installation) and DE_D (decommissioning) and, finally, DE_{OM} (operation and maintenance) and DE_D (decommissioning) were established. For instance, it is obviously unnecessary to establish a correlation between employment generation during the construction of a power plant and that associated with fuel extraction. The former can take place in a developed country, while the latter one can occur in a developing one and vice versa. In the same vein, equipment can be manufactured in a different country from the one where the power plant is located or where the fuel is extracted.

However, the stages of construction and installation, operation and maintenance and decommissioning should be interrelated, as they usually will take place in the same developed or developing region or country. Thus, if the employment generation associated with construction is typical of a developed country, the ones associated with operation and maintenance and decommissioning should also be typical of a developed country. Nevertheless, in the authors' opinion, there could be cases where those correlations arise to a more limited extent. A case in point can be large countries that have regions with varying degrees of development. This is why two different cases were considered. In the first one, absolutely linear correlations were established. In the second, softer correlations were fixed. The Spearman correlation coefficients are shown in Tables 1 and 2, respectively.

2.2. Employment generation data

Data regarding each variable of the model were proposed for every type of power plant. As mentioned earlier, these data were based on an extensive review of scientific articles, sector reports, real cases with published data and various interviews with an expert. With the article's length in mind, there is no point in including all the references consulted. Nevertheless, Table 3 shows the most representative ones.

As can be noted, Table 3 does not include information for some of the alternatives considered in the present study. This is because it was impossible to find sources that specifically address such alternatives. Nevertheless, this does not mean that it was unfeasible to estimate their input values, as will be explained later.

Table 4 lists the model's input values, estimated for each of the alternatives. The reader should interpret these values from the perspective of orders of magnitude, instead of figures or exact values.

Several points in Table 4 must be clarified. First, the main difference between C1 (coal) and C2 (lignite) is the quality of the fuel used in each. On this basis, it is possible to extrapolate most of the information obtained for a coal power plant to a lignite one. The data for high temperature solar-thermal plants hybridised with natural gas (R7-10, 15, 20, 25) were generated from the data for R6 (high temperature solar-thermal plant without hybridization) and C4 (natural gas). Obviously, the data from C4 (natural gas) were only used for estimating the employment generation from high temperature solar-thermal plants hybridised with natural gas (R7-10, 15, 20, 25) in terms of fuel supply. Furthermore, it was assumed that Dish Stirling technology could not be hybridised. Therefore, this option was included in R6, but absent from the hybridised alternatives (R7-10, 15, 20, 25). This explains the high employment generation during construction and installation of the alternative R6. It has been assumed that the hybridisation percentage hardly affects the input values for certain variables, with the exception of those related to fuel.

As far as the authors know, there is no information related to tidal barrage (R8). Therefore, it has been assumed that, as a first approximation, its employment generation can be of a similar magnitude to the one for large-hydro (R11). Nevertheless, there are reasons to believe that tidal barrage (R8) can achieve a slightly higher direct employment generation than the one for large-hydro (R11). On the one hand, there is greater experience with tidal barrage (R8); Rance Tidal Power Station has been operating since 1967. However, it is more limited in that there are very few installations of this type (five in operation and several more at a proposal stage). On the other hand, turbines in R8 may face a more aggressive environment. In connection with the latter and as far as the authors know, the turbines of the Rance Tidal Power Station have not had salinity problems during their 50 years of operation. Even still, it has been considered better to adopt a conservative approach. This means that tidal barrage (R8) may achieve a higher direct job creation than the one presented in this study, although the opposite is unlikely to happen. Similarly, it has been assumed that employment generation during decommissioning for R8 and R11 is zero. In reality, the decommissioning stage of these alternatives is improbable due to the magnitude of the civil engineering work. In most cases, civil work will provide a new service, such as the water supply for firefighting. On the other hand, the current literature makes no distinction between R9 (tidal stream) and R10 (wave), in terms of job creation. As a result, the same values were set for both alternatives.

As Table 3 shows, data on the decommissioning stage are only available for nuclear energy (C5). As an initial approach, such data were estimated for all the other alternatives from the information concerning the construction and installation stage. In this regard, it was assumed that job creation during decommissioning is similar to that of construction and installation for C1 (coal), C2 (lignite), C4 (natural gas), R3 (photovoltaic), R4 (mini-hydro), R5 (biomass), R6 (high temperature solar-thermal) and R7-10, 15, 20, 25 (high temperature solar-thermal hybridised). For C1 (coal), C2 (lignite), C3 (oil) and R5 (biomass), direct employment generation during the construction and installation stage can be slightly higher than the one for the decommissioning stage, since part of the civil engineering work can be dismantled by blasting. Nevertheless, this is offset by the fact that the cleaning and restoration activities in the area, subsequent to taking apart the equipment and removing the engineering works, create direct jobs that are not included in the construction and installation phase. For R3 (photovoltaic), R6 (high temperature solar-thermal) and R7-10, 15, 20, 25 (high temperature solar-thermal hybridised), the construction and installation phase consists mainly of assembling components. Therefore, in such cases, the decommissioning stage is similar, but reversed. It is true than some types of technologies contained in R6 and R7-10, 15, 20, 25 include minor civil work that can be dismantled by blasting. However, that possible blasting is not representative of the total decommissioning stage. In contrast with large-hydro (R11), the construction of a small-hydro power plant (R4) is painstakingly carried out; the machinery involved is reduced to avoid harming the environment. The same thoroughness has been supposed for the decommissioning stage.

In the case of C3 (oil), slightly higher employment generation from decommissioning was considered. This is due to the possibility of oil contamination. In contrast, slightly lower employment creation during the dismantling stage was established for R1 (onshore wind), R2 (offshore wind), R9 (tidal stream) and R10 (wave). There are several reasons why this might happen. First, the foundations and support structures are not likely to be dismantled. Moreover, blasting techniques can be used for decommissioning the foundations, which hardly generates employment in comparison with construction. Finally, it is not a very labour intensive procedure to decommission floating platforms and equipment. Some of the previous clarifications may lead the reader to think that blasting techniques can also be used in decommissioning other types of power plants such as R4 (mini-hydro). However, it is important to add that the application of this type of technique is limited to those cases where the impact on the environment is reduced.

On the other hand, the reader should bear in mind that the great distance between the extreme values (and also between the extremes and the modal value) in the defined closed triangular distributions is not only motivated by the differences between developing and developed countries. In other words, a developed (or developing) country can have very different input values for the same indicator.

3. Results and discussion

Two cases with different Spearman correlation coefficients were considered. Table 5 summarises the results of the analysis in job-years/GWh. With the information provided in Sections 2.1 and 2.2, the reader can repeat the calculations obtaining similar results to the ones presented in this section. Obviously, the results will not always be exactly the same since the model is probabilistic.

In Section 3.1 the results achieved in Cases 1 and 2 will be compared. In Section 3.2, the results will be analysed and discussed from a general point of view.

3.1. Results for Cases 1 and 2: comparison

With respect to the minimum values, in both cases the alternatives have obtained similar results. The variation in employment generation between cases 1 and 2 ranges from near 0 to 0.0241 job-years/GWh for R8 (tidal barrage) and R7-20 (high temperature solar-thermal with a 20% of hybridisation), respectively. If a list is created for each case so that the alternatives are ranked according to the employment they generate and are, for instance, placed in descending order, the changes seem insignificant. Furthermore, those variations, on most occasions, only mean that two consecutive power plants exchange places.

For maximum values, the variation in the results of both methods is, in general terms, higher than in the previous case. Despite this, the results continue to be similar. In fact, the variation in employment generation is between 0.0016 and 0.2924 job-years/GWh for R8 (tidal barrage) and R4 (mini-hydro), respectively. On the other hand, in the descending order list, all the alternatives occupy the same position, with only one exception: R7-25 (high temperature solar-thermal with a 25% of hybridisation) and R7-15 (high temperature solar-thermal with a 15% of hybridisation), which exchange the eighth and tenth positions.

As for mean values, the differences in direct employment generation between the two cases are near 0 for all the alternatives. Then, obviously, the positions in the ranking remain unchanged. In terms of standard deviation, the differences lie between 0.0006 and 0.0257 job-years/GWh for C4 (natural gas) and R6 (high temperature solar-thermal), respectively. Regarding the two rankings, the comments made for minimum values are applicable to this case.

When modal values are analysed, the variations between cases 1 and 2 range between 0.0036 and 0.0769 job-years/GWh for R7-10 (high temperature solar-thermal with a 10% of hybridisation) and R7-20 (high temperature solar-thermal with a 20% of hybridisation), respectively. These differences can be considered irrelevant. Here, there are several readjustments in the positions that the alternatives occupy in the descending order list, for both cases. However, this is due to the fact that a considerable number of power plants present quite similar modal values. A small variation in the mode between cases 1 and 2 can therefore lead to various movements in the corresponding rankings.

With reference to 5th percentiles, the differences fall between 0.0012 and 0.0223 job-years/GWh for R11 (large-hydro) and R6 (high temperature solar-thermal), respectively. Once again, the results are similar for both cases. In fact, if one analyses the positions of the alternatives between cases 1 and 2, there is only one exchange between R4 (mini-hydro) and R7-15 (high temperature solar-thermal with a 15% of hybridisation). In the first case, R4 occupies the eighth position, while R7-15 is positioned in the ninth slot. However, when the Spearman correlation coefficients take on a value of 0.8, the opposite occurs.

With regard to 95th percentiles, the variations range from 0.0002 to 0.0539 job-years/GWh for C2 (lignite) and R6 (high temperature solar-thermal), respectively. On this occasion, there are more changes in the positions than was the case with 5th percentiles. Nonetheless, this is because there are seven alternatives that have variations between their results below 0.2 job-years/GWh.

Bearing the previous analysis in mind, it can be concluded that the results hardly change between the two considered cases. This is what could be expected, since 0.8 and 1 are Spearman coefficients that are relatively close to each other. Obviously, if one establishes lower Spearman coefficients, the differences in the results between case 1 (absolutely linear) and the new one will increase considerably. Nevertheless, as mentioned in Section 2.1, it is necessary to set linear or close to linear correlations between certain parameters for the model in order to avoid inconsistency. For instance, if a near zero Spearman coefficient is established, in a specific Monte Carlo iteration employment from construction and installation could be characteristic of the USA, while the jobs related to decommissioning could reflect the reality of a developing region. This makes no sense.

3.2. General results discussion

In this section, only the results of Case 1 will be discussed. Similar comments will be applicable for the results of Case 2.

As mentioned previously, there are distinct ways of calculating direct employment generation. Whether various factors are in- or excluded and assumptions are made or not can have a major influence over the results. Furthermore, results for different studies can vary widely due to different methodological approaches [27]. It is therefore difficult to make comparisons across a range of studies. As if this were not enough, the present study estimates direct job creation during the dismantling stage. By the same token, the results are expressed per unit of electricity produced, which is uncommon in current literature. Additionally, results are obtained in different circumstances and conditions in this and other studies. All these factors mean that comparisons are even more difficult to make. Consequently, only biased and specific comparisons will be possible. Nonetheless, if the comparisons are made carefully, it is possible to extract valuable conclusions from them. The results for each alternative are described below.

C1 (coal) has obtained what can be considered middling results in terms of direct employment generation. Its minimum value is close to the alternative with the lowest employment generation (0.08 job-years/GWh) and far from the alternatives with the highest minimum values for job creation (about 0.3 job-years/GWh). Similarly, although less dramatic, the maximum job creation of C1 is far from the options with the highest results (between 3 and 4 job-years/GWh), which achieve more than 2.5 times its employment generation. That may seem rather surprising, since non-renewable power plants require a stage of fuel procurement, in which direct jobs are created. Nevertheless, extractive industries do not employ many people, since growing mechanisation and automatisation translates into fewer jobs [55]. Despite this, underground mines throughout the world (particularly in developing countries) and the full range of mines located in developing nations still generate a considerable number of jobs. There are also great differences in the number of tons extracted per worker in different developed countries (for example the United States, Germany and Poland), and so, in the number of job-years/GWh. This leads to values that can be higher than those for the alternatives with the highest results, under certain conditions. Its mean, mode and 5th percentile occupy the thirteenth position in the descending ranking, again far from the highest results. C1 fares even poorer in terms of the 95th percentile, occupying the fourteenth position in the ranking. This is to say, coal power plants would be unlikely to achieve results equal to or higher than 0.9 job-years/GWh, which, on the contrary, is close to modal values for the alternatives that obtained the highest performances for this statistical parameter (photovoltaic and biomass).

C2 (lignite) has obtained higher results than coal power plants in terms of direct employment generation. This is due to the lower calorific power of lignite in comparison with coal. Excluding extreme cases, between 1.5 and 2 tons of lignite are necessary for obtaining the same energy than with one ton of coal. Consequently, lignite power plants often generate more jobs during the fuel supply stage than coal ones do, which is translated into a higher performance in terms of employment. Its minimum value and its 5th percentile are similar to the ones obtained with coal. This is because it is difficult to delimit in exact terms what coal and lignite are. Lignite with high calorific power is similar to poorer quality coal. Nonetheless, the results for the rest of the statistical parameters are higher-performing. Thus, its maximum and average values, as well as 95th percentile, are acceptable, not too far from the highest values. In terms of mode, C2 is a compromise between the options with the highest and lowest performance, occupying tenth position in the ranking.

C3 (oil) has obtained similar results to the ones for C1. In fact, for some statistical parameters, C3 is one position above C1; while for the rest, the opposite occurs. That is to say, oil-fired power plants are also far from the options with the largest direct job creation. The results for C4 (natural gas) are in the same vein. C4 generates more jobs during the operation and maintenance of the plant, while C3 generates more jobs during the fuel supply stage. For all the statistical parameters, C4 is located in the four last positions of the ranking. According to Tourkolias et al. [19], lignite power plants generate more direct jobs per unit of electricity than their natural gas counterparts in Greece, which is in line with the results obtained in the present study. Henriques et al. [5] also find that coal power plants (C1) are more labour intensive than natural gas power plants (C4). This is the same conclusion that can be extracted from the present study.

For C1, C2, C3 and C4, maximum *TDEs* (from about 1 to about 2.4 job-years/GWh) are also related to low capacity factors. A lower capacity factor implies higher employment generation, since there are jobs that do not depend on production. A case in point is employment generation during construction. These types of power plants, theoretically, can work up to almost 7,500 hours per year. Nevertheless, the reality is that they usually present capacity factors below the theoretical one (85%). In fact, some of them work in intermediate and low peak load, instead of baseload, configurations. The reader can find an oil-fired power plant with a peak load configuration in Ref. [60].

Nuclear energy (C5) is a very labour intensive option during the construction, installation and decommissioning stages. In fact, this is the alternative with the higher input values for those variables. On the other hand, C5 is the least intensive non-renewable option in terms of fuel consumption; it generates fewer jobs than C1, C2, C3 and C4 in the fuel chain production. Furthermore, for technical reasons, nuclear power plants only can work in baseload configurations. The number of jobs generated during those stages, in which there is no relation between job creation and production, are divided by a high number of GWh. Logically, if nuclear power plants could have low capacity factors, their employment generation per GWh would increase considerably. This does not mean that nuclear power plants should reduce their capacity factors in order to obtain a higher direct employment generation per GWh, since, as mentioned previously, the purpose of a power plant, with some exceptions, is to produce as much electricity as possible. For all these reasons, C5 is one of the bottom three alternatives in terms of direct employment generation for all the statistical parameters, with only one exception: the minimum value. C5 has obtained a minimum direct employment generation slightly higher than the remaining non-renewable plants. The overall conclusion is that nuclear plants have only a 5% possibility of achieving more than 0.4 job-years/GWh.

In reference to the results in non-renewable alternatives, something similar happens in Ref. [22], where C1, C4 and C5 have obtained middling performances in terms of direct employment generation (in that case, excluding the decommissioning stage).

R1 (onshore wind) is not only one of the renewable alternatives with the lowest direct job creation, but also one of the options with lowest direct employment generation, in general. In spite of low capacity factors, the job creation per output of electricity is far from the highest-performing alternatives. In fact, for all the statistical parameters, R1 is close to the non-renewable alternatives with the poorest results. This may seem to be the opposite of what is expected; it is a common belief that renewables generate more jobs than non-renewable plants.

Nevertheless, R1 is a sufficiently mature technology. Its efficiency in construction, installation and fabrication processes is considerably high, so that an intensive workforce is not needed. In any case, according to Wei et al. [22], R1 presents a direct employment generation similar to coal (C1), natural gas (C4) and nuclear (C5) power plants, excluding the decommissioning stage. Varela-Vázquez and Sánchez-Carreira [10] also found that wind is a low labour intensity alternative.

Offshore wind (R2) has obtained higher-performing results than the onshore technology option (R1). Construction, installation and decommissioning activities that take place off- rather than on-shore need a higher number of employees. This may be solely as a result of the necessity of using ships, with their corresponding crew. On the other hand, R2 is an alternative capable of reaching the highest and lowest performances. Its minimum *TDE* is the second highest of all alternatives, with a value of about 0.29 job-years/GWh. Similarly, its 5th percentile is also high, occupying the third position in the descending ranking. This implies that R2 is unlikely to achieve a direct employment generation below 0.46 job-years/GWh, which is a strong point. Nevertheless, its maximum possible job creation is far from the highest values. Something similar happens to its 95th percentile. Ultimately, just as R2 is unlikely to achieve bad results, it is also unlikely to achieve a direct employment generation above 1.15 job-years/GWh. In terms of average and modal values, R2 is in a mid-term position between the highest-performing renewable alternatives (photovoltaic (R3) and biomass (R5)) and the non-renewable ones.

Photovoltaic (R3) is the most attractive option in terms of direct employment generation, closely followed by other renewable alternatives, including biomass (R5), mini-hydro (R4) or high temperature solar thermal (R6) plants. R3 is in the first position of the ranking for all the statistical parameters. Its minimum value (0.31 job-years/GWh) is between two and three times higher than the minimum values for non-renewable power plants. Its maximum is considerably far from the other options. In fact, wave energy (R10), that is the option with the second highest direct employment generation, achieves a maximum value of 3.2 job-years/GWh, that is, 0.8 job-years/GWh less than R3. Photovoltaic has obtained the highest results in Refs. [22,23] as well.

Mini-hydro (R4) appears to be an acceptable option. As with R2 (offshore wind), R4 is an alternative capable of reaching the highest and lowest performances. Its minimum is close to the non-renewable alternatives results. Nevertheless, it occupies the third position in terms of maximum possible job creation, with 3 job-years/GWh. Its average and modal values rank in fourth position, which can be deemed relatively high performances.

R5 (biomass) is the second option in terms of the highest mean and mode results. The difference between the *TDEs* obtained by biomass and the ones obtained by non-renewable alternatives is due to the fact that R5 is a more intensive option in terms of fuel consumption. Therefore, it usually needs more workers than non-renewable options for obtaining fuel, as well as running and maintaining the plant. These results are in accordance with those presented in Refs. [22,23].

The results for high temperature solar thermal plant (R6) are founded on the strong need for a labour force during its construction and installation, and during its decommissioning as well. Its minimum value is in an intermediate position within the ranking. Nevertheless, its maximum, its mean and its 95th percentile are in the top four positions of the descending list. R6 can reach top values, even two or more times higher than those enjoyed by most non-renewable energies. R6 generates more jobs than the hybridised alternatives (R7) during the construction, installation and decommissioning stages. This is because Dish Stirling was considered in R6, but not included in R7. As far as the authors know, there are no real cases covering the hybridisation of this type of technology. Dish Stirling is the most labour-intensive concentrated solar power technology. On the other hand, R7 alternatives present a certain level of fuel consumption, which is associated with a certain level of direct employment generation. Due to the assumptions made about R7, a higher percentage of hybridisation involves increased *TDEs.* Nevertheless, the differences in the hybridisation ratio are small; on some occasions, the simulation process can therefore mitigate this effect. All of the above means that, for certain statistical parameters, R7 options have obtained higher-performing results than R6. In other cases, the reverse occurs.

As mentioned in Section 2.2, R8 (tidal barrage) and R11 (large-hydro) present the same employment inputs. Therefore, it is worth analysing both technologies at the same time. The differences in their results are due to distinct capacity factors and lifetimes. In spite of this, the truth is that they seem to be the two lowest-performing options in terms of direct employment generation. Nevertheless, the reader should bear in mind that no decommissioning stage was assumed for either options. Obviously, dismantling the civil engineering works related to R8 and R11 can generate a great number of job posts. Nevertheless, this can be technically challenging. This is the reason why those activities, where possible, are avoided. These options occupy the two last positions in terms of modal results, with a direct employment generation of about 0.2 job-years/GWh. It is necessary to clarify that, from a theoretical point of view, large-hydro power plants (R11) can achieve higher capacity factors than the ones considered in this paper. However, this type of plant is commonly used to cover peaks in electricity demand and to regulate the level of available water. They also serve as baseload plants due to their economy.

The cases of R9 (tidal stream) and R10 (wave) are similar to the previous one in terms of inputs. Both alternatives have the same values for direct employment generation. Consequently, the differences in the results are due to distinct lifetimes and capacity factors. Ocean energies can be considered an emerging sector and hence there is scant information about employment generation for these technologies. In fact, the majority of the estimations are derived from data for offshore wind plants [35]. This lack of maturity means job creation is high, since there is much room for improvement, especially concerning process efficiency. Their direct employment generation is expected to diminish in coming years. At present, both are attractive options, since their employment generation varies between more than 0.2 and more than 2.5 job-years/GWh. For all the statistical parameters, their performance is above non-renewable power plants, with the only exception of C2 (lignite), for certain parameters.

As for renewables, Wei et al. [22] find that photovoltaic energy (R3) has the largest average direct employment generation, followed by mini-hydro (R4), high temperature solar thermal (R6), biomass (R5) and wind (R1) technologies. This ranking is quite similar to the one presented here, with only one exception: R5 (biomass). According to the present study, biomass (R5) has a higher performance. This is because only the theoretical capacity factor is included in Ref. [22], without taking into account that, in practice, biomass power plants can have a lower production level. On the other hand, according to Ref. [23], photovoltaic (R3) is the option with the highest direct employment creation, followed by biomass (R5), wind (R1) and hydro (R11) power plants. These results are in line with the ones presented here. According to Cameron and van der Zwaan [4], which exclude the decommissioning stage, the employment generation of photovoltaic (R3) is significantly higher than that of high temperature solar thermal (R6). In all instances both alternatives ((R3) and (R6)) have a higher employment generation than onshore wind energy (R1) does. In Ref. [4], the results are expressed per unit of installed capacity instead of per unit of electricity produced. Nonetheless, they can be easily converted into the units used here. In relation to these three alternatives, the ranking for direct job creation is the same as the one obtained in this study.

Continuing with renewables, in the Czech Republic, Dvořák et al. [9] ranked some of these according to the highest employment per MWh, for the period 2008-2013 (one ranking for each year). According to this study, biomass (R5) ranks first for 2011, 2012 and 2013, occupying the second position for the remaining years. Photovoltaic (R3) is also well-positioned, occupying the first position three times, the third position two times and second place once. These two alternatives are followed by onshore wind (R1) and mini-hydro (R4) technologies, the latter always falling in the final position. There are some differences between the results presented in Ref. [9] and those obtained in this study. These can be explained. On the one hand, Ref. [9] is specifically related to the Czech Republic; the results are not necessarily representative from a global perspective. Moreover, six years are not enough to extract unbiased results, as some renewables increased their installed capacity, while others remained unchanged. This means that employment generation during the construction stage was not always considered. In Ref. [9] biomass (R5) obtained a higher performance and the explanation for this is twofold. Firstly, biomass (R5) is the most promising renewable energy source in the Czech Republic. Secondly, the biomass industry is an export-oriented sector in that country. In other words, a considerable number of jobs are related to wood chip production. Part of these chips are consumed abroad, so they do not contribute to electricity generation within the Czech Republic. The opposite occurs with mini-hydro (R4) power plants. The main reason they are the weakest performers in Ref. [9] is that, during the period considered, their installation capacity remained unaltered; total job creation was underestimated because the construction, installation and manufacturing stages were not considered. The photovoltaic (R3) sector lost employment between 2008 and 2013. This is due to the end of the Czech solar boom in 2011, when governmental financial incentives were reduced. Nevertheless, photovoltaic (R3) still has a good performance, which is in line with the results presented in Table 5.

It is necessary to make some clarifications about the results. On the one hand, a large number of lower capacity plants are needed to produce the same power that higher capacity power plants generate [22]. In this sense, renewable power plants usually have lower installed capacities than their non-renewable counterparts. Furthermore, a reduced service life means that the installation will need to be replaced sooner. In other words, the employment generation associated with construction, installation and decommissioning activities is distributed over a shorter time period and therefore across a smaller production of electricity. These factors lead to higher values for job-years/GWh and explain why the majority of renewables have obtained higher-performing results.

As stated by Lesser [61], the need for more workers to produce a given amount of electricity is often considered a benefit, which is not entirely true. That is, a higher employment generation per output of electricity can be seen as less efficient. Put in another way, the majority of the renewables are less efficient per worker than their non-renewable counterparts [13]. This point is also related to capacity factors. A low capacity factor produces a higher number of jobs per GWh. Nevertheless, the installation is inoperative over a large part of the year. On the one hand, other installations are more suitable for several reasons. On the other, this kind of plant is unable to operate for longer periods: the case with certain renewables, dependent on phenomena such as wind or solar radiation.

Needless to say, a higher direct employment generation can be, in some occasions, counterproductive. For example, installing a wind farm in a wrong location will generate higher results in terms of employment generation per GWh than installing it in an adequate one, since the amount of electricity produced will be lower while the number of jobs will be the same in both cases. Nevertheless, it is obvious that this does not make sense. In the same line, reducing the capacity factor of a power plant for obtaining higher-performing results in employment generation per unit of output is also nonsense.

This does not mean that there are no real cases in which two or more power plants of the same type and technology, with similar capacity, and installed in different countries, could present very different capacity factors due to various reasons (resource scarcity, political decisions, among many others). This can also happen in different regions of the same country or even for a specific power plant during different periods of its lifetime. The present study takes into account these potential circumstances.

While this study is focused on job numbers, this is only one part of the story. The quality of the jobs is as important as the quantity. There is a wide range of issues such as wages, career prospects, job security, worker rights, working conditions and the level of trade union participation, among others, that should be analysed [55]. A high number of exploitative jobs that condemn workers to live in poverty cannot be considered a positive outcome. It is preferable to generate a smaller number of decent jobs. In this regard, governments, communities and labour unions have a role to play in ensuring sufficiently high quality jobs [55]. It is important to remember that millions of jobs today are characterised by poor practices that compromise the workers' health and living conditions.

Nevertheless, some types of power plants can have special implications for rural communities [24]. For example, certain renewables can be set up in zones far from highly industrialised areas. Energy production is thus decentralised, resulting in equality and development. As mentioned by Lambert and Silva [13], measuring these kinds of qualitative issues is not a simple task.

Finally, this work does not consider the job loss associated with one power plant when it is replaced with other type of technology. The reason for this is that the study's objective is to facilitate the decision-making processes, particularly when determining which type of new power plants should be built to cover growing demand. This work does not promote replacing active installations with new ones.

4. Conclusions and future developments

In this paper, the problem of assessing direct employment generation for power plants is addressed. Recognising the diversity of models used in the current literature for such a purpose, the paper proposed a new analytical model combined with Monte Carlo simulation as a way of considering uncertainty.

The proposed model was used to assess the performance of five non-renewable and fourteen renewable power plants regarding direct employment generation. This is the first time that all the most common power plants were assessed by considering distribution functions for the input values that represent the majority of possible real cases, and not specific values from real cases. Specific values can be non-representative of each type of technology. It is also the first time that direct employment generation was estimated for the decommissioning stage.

From the results obtained, the general conclusion is that uncertainty plays a key role when power plants are being compared and assessed from the employment point of view, as stated in Ref [4]. Many factors can be taken into account: the technology that is used; capacity factor; lifetime; planning and process efficiency and each country's level of development, among others. These are parameters that affect the input values as well as the performance of each alternative. Therefore, there is no better option for all the real cases. Non-renewable power plants (coal, lignite, oil, natural gas and nuclear) have obtained a direct employment generation varying between 0.1 and 2.4 job-years/GWh. Renewable power plants have obtained a direct job creation varying from nearly 0.1 to 4 job-years/GWh.

According to the results, some of the most mature renewables, such as photovoltaic, biomass or mini-hydro, and some of the less mature ones like tidal stream and wave energy are still the technologies with the highest direct employment generation. Nevertheless, wind onshore, in spite of being a renewable option, is close to the non-renewable power plants with the lowest direct job creation. In the same vein, lignite power plants have achieved the highest results amongst non-renewable options.

On the other hand, this study demonstrates that non-renewable alternatives can compete with renewables under certain conditions. It also shows that not all the renewables present high direct employment generation. For instance, the two lowest-performing options (large-hydro and tidal barrage) are renewable technologies. The direct employment generation of the less mature renewables (for example, tidal stream and wave energy) will probably continue to fall in the future [4]. However, it is difficult or even impossible to predict if they will still having a higher performance than the remaining technologies that currently have the lowest results in terms of direct job creation.

Regarding the methodology, this study confirms that an analytical model can be applied not only in regional spheres but also at national and international levels. The key is to use ratios that are representative for different countries all over the world. It is a simple methodology to apply, from which useful information can be extracted. Nevertheless, analytical models have their drawbacks. Consequently, a critical analysis of the results is required, as was done here.

As for future developments, it is necessary to analyse the possibility of estimating indirect and induced employment generation as well including indicators for assessing the quality of each job. Moreover, the model should be reviewed, updated and improved periodically because the energy sector is continually evolving all over the world. Also of key importance is the fact that non-renewable resources will be exhausted in the near future. This, together with the need to reduce environmental impacts, means that non-renewable power plants will gradually switch over to renewables. Taking all these points into account, the current employment scenario may change rapidly; model modifications will probably be required.

On the other hand, the reader must remember that the employment generation is only one of the parameters that should be taken into account in decision-making processes in the energy sector. Therefore, the authors intend to create a probabilistic model for assessing the global sustainability of power plants. Such a model would consider all the sustainability pillars - economic, social, environmental and technical- in depth. The aim would be to generate a model that is as complete as possible. One indicator of that model will be the direct employment generation obtained in this study.

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Tables

Table 1
Correlation matrix with the Spearman correlation coefficients for Case 1.

Variable	Variable				
	DE_{CI}	DE_M	DE_D	DE_{OM}	DE_F
DE_{CI}	1	0	1	1	0
DE_M	0	1	0	0	0
DE_D	1	0	1	1	0
DE_{OM}	1	0	1	1	0
DE_F	0	0	0	0	1

Table 2
Correlation matrix with the Spearman correlation coefficients for Case 2.

Variable	Variable				
	DE_{CI}	DE_M	DE_D	DE_{OM}	DE_F
DE_{CI}	1	0	0.8	0.8	0
DE_M	0	1	0	0	0
DE_D	0.8	0	1	0.8	0
DE_{OM}	0.8	0	0.8	1	0
DE_F	0	0	0	0	1

Table 3
Sources consulted for establishing the input values.

Alternatives	Variable				
	DE_{CI}	DE_M	DE_D	DE_{OM}	DE_F
C1	[21,35,42]	[21,35,42]		[21,22,35,42-44]	[21,22,35,42,43]
C2	[21]	[21]		[19,21,22,44]	[19,22]
C3	[21,35,42]	[21,35,42]		[21,22,35,42,44]	[21,22,35,42]
C4	[21,35,42,45]	[21,35,42,45]		[19,21,22,35,42,44-46]	[21,22,35,42,46]
C5	[35,42]	[35,42]	[35,47]	[21,35,32,42,48-50]	[21,35,42]
R1	[21,27,35,42,45,51-55]	[21,27,35,42,45,51,53-55]		[21-23,27,35,37,42-44,46,51,52,54,56,57]	
R2	[21,35]	[21,35]		[21,22,35]	
R3	[1,21,24,35,42,53,55]	[1,21,24,35,42,53,55]		[21,35,42,43,52,53,37,57-58]	
R4	[21,35]	[21,35]		[21,35,57,59]	
R5	[16,21,35,42]	[21,35,42]		[21,34,35,37,42,43,57]	[21,34,35,37,42,43]
R6	[1,21,35,42]	[1,21,35,42]		[1,21,22,35,42,44,52,57]	
R9	[21,35,42]	[21,35,42]		[21,35,42]	
R10	[21,35,42]	[21,35,42]		[21,35,42]	
R11	[21,35,42,52]	[21,35,42]		[21,23,35,42]	

Table 4
Model input values for all the alternatives.

Alternatives (power plants)	Distribution function	Distribution parameters	Variables						
			DE_{CI} (job-years/MW)	DE_M (job-years/MW)	DE_D (job-years/MW)	DE_{OM} (jobs/MW)	DE_F (job-years/GWh)	T (years)	CF (%)
C1	CT[a]	Min	4.3	3.1	4.3	0.05	0.0291	25	25
		Mode	7	3.5	7	0.1305	0.1476	40	60
		Max	24.6	10	24.6	0.32	0.8160	40	85

		Min	4.3	3.1	4.3	0.05	0.0291	25	25
C2	CT[a]	Mode	7	3.5	7	0.1305	0.2214	40	60
		Max	24.6	10	24.6	0.32	1.6320	40	85
		Min	1.4	1	1.5	0.05	0.06	20	20
C3	CT[a]	Mode	1.9	1	2	0.1375	0.1948	30	60
		Max	7.2	4.3	7.6	0.34	1.052	40	85
		Min	1	1	1	0.08	0.06	20	15
C4	CT[a]	Mode	1.5	1.1	1.5	0.1803	0.1288	30	60
		Max	7.2	4.3	7.2	0.3820	0.5570	40	85
		Min	14	1.3	13.6	0.485	0.0007	40	70
C5	CT[a]	Mode	14.7	1.7	20.2	0.5687	0.001	40	85
		Max	44.8	4.2	54.2	0.9600	0.0066	60	90
		Min	0.4	2.1	0.4	0.056	0	20	20
R1	CT[a]	Mode	2.1	5.1	1.9	0.204	0	25	25
		Max	11.2	13.7	10.1	0.85	0	25	35
		Min	1.9	10.7	1.7	0.2	0	20	25
R2	CT[a]	Mode	5.4	10.9	4.8	0.39	0	25	30
		Max	22.7	24.8	20.4	0.85	0	25	35
		Min	6.1	3.1	6.1	0.12	0	20	10
R3	CT[a]	Mode	9.9	6.7	9.9	0.3762	0	25	20
		Max	24.8	15.5	24.8	0.85	0	25	35
		Min	6	1.7	6	0.22	0	20	20
R4	CT[a]	Mode	12	1.7	12	1.14	0	30	35
		Max	22.5	9.9	22.5	3.25	0	50	50
		Min	3.9	2.9	3.9	0.13	0.13	20	50
R5	CT[a]	Mode	11.6	2.9	11.6	1.356	0.3323	25	65
		Max	31.5	6.5	31.5	3.1	0.8640	25	85
		Min	3	4	3	0.2	0	25	20
R6	CT[a]	Mode	8.6	4.5	8.6	0.5244	0	30	30
		Max	40.2	9	40.2	1.8	0	30	40
		Min	3	4	3	0.2	0.006	25	25
R7-10	CT[a]	Mode	8.6	4.5	8.6	0.5244	0.0129	30	30
		Max	28.5	9	28.5	1.8	0.0557	30	40
		Min	3	4	3	0.2	0.009	25	25
R7-15	CT[a]	Mode	8.6	4.5	8.6	0.5244	0.0193	30	30
		Max	28.5	9	28.5	1.8	0.0836	30	40
		Min	3	4	3	0.2	0.012	25	25
R7-20	CT[a]	Mode	8.6	4.5	8.6	0.5244	0.0258	30	30
		Max	28.5	9	28.5	1.8	0.1114	30	40
		Min	3	4	3	0.2	0.015	25	25
R7-25	CT[a]	Mode	8.6	4.5	8.6	0.5244	0.0322	30	30
		Max	28.5	9	28.5	1.8	0.1393	30	40
		Min	6	1.5	0	0.3	0	120	25
R8	CT[a]	Mode	8.1	1.5	0	0.317	0	120	25
		Max	13.5	9	0	0.675	0	120	25
		Min	1	6.3	5.7	0.32	0	20	10
R9	CT[a]	Mode	1.1	8.6	7.8	0.3466	0	20	25
		Max	2.3	20.3	18.2	0.72	0	25	40
		Min	1	6.3	5.7	0.32	0	15	10
R10	CT[a]	Mode	1.1	8.6	7.8	0.3466	0	15	25
		Max	2.3	20.3	18.2	0.72	0	25	50
		Min	6	1.5	0	0.3	0	30	20
R11	CT[a]	Mode	8.1	1.5	0	0.317	0	50	30
		Max	13.5	9	0	0.675	0	100	50

[a] Closed triangular distribution.

Table 5
Statistical parameters for the two cases.

Plants	Cases													
	Case 1							Case 2						
	Parameters													
	Min	Max	Mean	S. Dev.[a]	Mode	5th P.[b]	95th P.[c]	Min	Max	Mean	S. Dev.	Mode	5th P.	95th P.
C1	0.1065	1.4246	0.5502	0.1969	0.4153	0.2691	0.9028	0.1124	1.4827	0.5502	0.1949	0.4262	0.2713	0.8991
C2	0.1196	2.4281	0.8468	0.3692	0.5803	0.3398	1.5276	0.1162	2.2488	0.8468	0.3684	0.6083	0.3432	1.5278
C3	0.1076	1.3322	0.5466	0.2255	0.3614	0.2381	0.9636	0.1065	1.3891	0.5466	0.2247	0.3337	0.2397	0.9625
C4	0.0992	1.1403	0.3691	0.1256	0.2818	0.1925	0.5944	0.1055	1.0392	0.3691	0.1251	0.2954	0.1942	0.5941
C5	0.1361	0.5572	0.2693	0.0678	0.2146	0.1783	0.3955	0.1369	0.5325	0.2693	0.0635	0.2295	0.1822	0.3870
R1	0.0801	1.2141	0.4595	0.1775	0.3367	0.2154	0.7882	0.0863	1.2460	0.4595	0.1671	0.3720	0.2246	0.7674
R2	0.2869	1.7069	0.7625	0.2148	0.5990	0.4594	1.1539	0.2915	1.6734	0.7625	0.2018	0.6373	0.4729	1.1288
R3	0.3093	4.0113	1.1277	0.4195	0.9729	0.5882	1.9283	0.3073	3.7504	1.1277	0.4049	0.9173	0.6035	1.8983
R4	0.1576	3.0377	0.8525	0.3399	0.6685	0.3852	1.4817	0.1470	2.7454	0.8523	0.3288	0.7070	0.3994	1.4599
R5	0.2663	2.0856	0.9768	0.2563	0.9584	0.5825	1.4245	0.2496	2.0526	0.9770	0.2471	0.9411	0.5944	1.4055
R6	0.1810	2.6998	0.8908	0.3891	0.6146	0.3770	1.6197	0.1925	2.6452	0.8905	0.3634	0.6557	0.3993	1.5658
R7-10	0.2069	1.8523	0.7582	0.2809	0.5601	0.3708	1.2794	0.2081	1.8237	0.7583	0.2633	0.5565	0.3901	1.2426
R7-15	0.1974	1.9733	0.7708	0.2816	0.5929	0.3832	1.2936	0.2189	1.8382	0.7707	0.2633	0.6032	0.4020	1.2557
R7-20	0.1967	1.9160	0.7829	0.2810	0.5583	0.3954	1.3036	0.2209	1.8695	0.7831	0.2636	0.6352	0.4139	1.2691
R7-25	0.2264	1.8619	0.7956	0.2824	0.6388	0.4068	1.3171	0.2119	1.8905	0.7955	0.2642	0.6600	0.4246	1.2806
R8	0.1665	0.3860	0.2469	0.0460	0.1983	0.1850	0.3325	0.1665	0.3875	0.2469	0.0449	0.2061	0.1863	0.3302
R9	0.2848	2.6803	0.7758	0.2637	0.6854	0.4534	1.2881	0.2904	2.5705	0.7757	0.2602	0.6293	0.4569	1.2812
R10	0.2277	3.2049	0.8011	0.3139	0.6168	0.4217	1.4087	0.2417	3.1767	0.8036	0.3116	0.6257	0.4265	1.4121
R11	0.0947	0.6131	0.2365	0.0657	0.1999	0.1459	0.3589	0.0915	0.6008	0.2365	0.0647	0.2081	0.1471	0.3564

[a] Standard deviation.

[b] 5th percentile.

[c] 95th percentile.

Highlights:

A model is presented to assess the direct employment generated by power plants.
Some renewables are still the options with the highest direct employment generation.
Non-renewable energies can compete with the renewables under certain conditions.
The model aids the decision making process in the energy policy field.
Complete sustainability assessment models should include the parameter here proposed.