BIODIVERSITY INDEXES APPLIED TO THE ANALYSIS OF SUPPLY SECURITY IN POWER SYSTEMS

Fernando Delgado, Alfredo Ortiz, Carlos Renedo, Severiano Pérez, Mario Mañana and Alberto Arroyo

SUMMARY

The evolution of the vulnerability of the Spanish power generation system with respect to the primary energy resources has been assessed by three new indexes developed from biodiversity analysis. The first of these indexes measures, in percentage, the uniformity of the primary energy resources in the system. The second one quantifies the diversity by means of the equivalent number of primary energy resources that are present in similar proportions in the system. The third one allows the calculation of the diversity reduction in the system with the non-evenness of these primary energy resources. They have been applied to the energy results of a stochastic linear model, developed with the software GAMS, in order to demonstrate their usefulness. In this model several generation technologies have been considered (nuclear, clean coal technologies, etc), and also several scenarios of fossil fuel costs. The number of primary energy resources that have to be used depends on the degree of uniformity of the system and on their influence on diversity. In the Spanish case, if nuclear generation is not considered as an energy source, the diversity of the system will diminish significantly in the future, making the system more vulnerable.

Introduction

In the last decade the growth in electricity demand in Spain was ~4.5% annually; capacity and energy demand forecasts estimate that this growth will continue, but at a lower rate (MITC, 2006). Table I shows the power generation mix that has almost entirely covered the demand for electricity in recent years because Spain, in fact, is an 'electric isle'. Moreover, this table shows the capacity of the fixed equipment that has to perform the same function in the future, according to UNESA (2007) and REE (2008), complemented by other investments that have to be decided by the companies. In fact, the developed model allows these new investments to be calculated.

A detailed analysis of Table I leads to several conclusions:

- First, hydroelectric generation (HG), oil/gas turbines (peaking power plants; PPP), thermal power plants, pulverized coal combustion (PCC) and nuclear power (NP), have been the traditional base of the Spanish power generation system. The development of HG and NP has now stagnated, and the other two technologies, PCC and PPP, are in decline.

Regarding the outlook for these technologies, HG is the only one of the four technologies whose development possibility is practically zero due to the almost total exhaustion of the resource. The rest of the technologies could be installed if their restrictions are eliminated or mitigated.

- Second, the natural gas combined cycle (NGCC) and the energies of the special regime (ESR), mainly wind generation (WG), have undergone considerable development. The ESR of the electric sector include the following generation activities: wind, photovoltaic, biomass and mini-hydroelectric, among renewable energies; and cogeneration, urban waste, industrial and agricultural wastes, among non-renewable ones. This type of energy receives incentives to attract private initiatives, since they require heavy investment in technology development and construction, and to bring the power plants into service, while they have long pay-off periods. This development, jointly with the four mentioned technologies above, has allowed to meet the large growth in demand. Also, the commissioning of new power stations of NGCC and WG seems viable *a priori*.

Therefore, the technologies that will form the future Spanish generation mix will be based, mainly, on six primary energy resources: coal, natural gas, uranium, water, wind and sun. In Spain, the current and future situation of the three non-renewable resources is as follows:

- Spain has coal reserves that currently are mainly exploited to supply of power stations. Government subsidies to the coal sector have maintained the national production for several decades, despite the facts of its high operating costs and low quality. However, these aids are decreasing and will only be maintained until 2012. On the other hand, in the last years this resource has been imported in order to replace the national coal. Such imports will continue, and increase, in the future, to ensure the supply (ALGOR, 2009).

- Spain has no natural gas. The supply is procured through two

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ÍNDICES DE BIODIVERSIDAD APLICADOS AL ANÁLISIS DE LA SEGURIDAD DE SUMINISTRO EN SISTEMAS DE POTENCIA

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RESUMEN

La evolución de la vulnerabilidad del sistema de generación de potencia en España, con respecto a los recursos primarios de energía, ha sido evaluada por medio de tres nuevos índices desarrollados a partir del análisis de la biodiversidad. El primero de estos índices mide, en porcentaje, la uniformidad de los recursos primarios en el sistema. El segundo cuantifica la diversidad por medio del número equivalente de recursos primarios que se encuentran en proporciones similares en el sistema. El tercero permite el cálculo de la reducción de la diversidad en el sistema con la desigualdad de esas fuentes primarias de energía. Los índices han sido aplicados a los resultados de un modelo estocástico lineal desarrollado con el logicial GAMS, a fin de demostrar su utilidad. En este modelo se han considerado varias tecnologías de generación (nuclear, tecnologías limpias de carbón, etc.), así como también varios escenarios de costos de combustibles fósiles. El número de recursos energéticos primarios que deben ser utilizados depende del grado de uniformidad del sistema y de sus influencias en la diversidad. En el caso español, si la generación nuclear no es considerada como una fuente de energía, la diversidad del sistema disminuirá significativamente en el futuro, haciendo más vulnerable al sistema.

ÍNDICES DE BIODIVERSIDADE APLICADOS A ANÁLISE DA SEGURANÇA DE SUBMINISTRO EM SISTEMAS DE POTÊNCIA

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RESUMO

A evolução da vulnerabilidade do sistema de geração de potencia na Espanha, em relação aos recursos primários de energia, tem sido avaliada por meio de três novos índices desenvolvidos a partir da análise da biodiversidade. O primeiro destes índices mede, em porcentagem, a uniformidade dos recursos primários no sistema. O segundo quantifica a diversidade por meio do número equivalente de recursos primários que se encontram em proporções similares no sistema. O terceiro permite o cálculo da redução da diversidade no sistema com a desigualdade dessas fontes primárias de energia. Os índices têm sido aplicados aos resultados de um modelo estocástico linear desenvolvido com o modelo logiciel GAMS, com o fim de demonstrar sua utilidade. Neste modelo têm sido consideradas várias tecnologias de geração (nuclear, tecnologias limpas de carvão, etc.), assim como também vários cenários de custos de combustíveis fósseis. O número de recursos energéticos primários que devem ser utilizados depende do grau de uniformidade do sistema e de suas influências na diversidade. No caso espanhol, se a geração nuclear não é considerada como uma fonte de energia, a diversidade do sistema diminuirá significativamente no futuro, fazendo mais vulnerável ao sistema.

TABLE I
STRUCTURE OF ANNUAL CAPACITY (GW) / ENERGY OF SPANISH POWER GENERATION (%)

	HG	NP	PCC	PPP	NGCC	WG	Other ESR	Total
2001	16.6/18	7.8/30	11.5/32	8.2/6	0/0	0.5/0.2	10/13.8	54.6/100
2008	16.6/7	7.7/20	11.4/17	4.4/1	21.7/32	15.9/11	13.2/12	90.9/100
2013	17.7/-	7.7/-	9.3/-	0.5/-	29.2/-	22/-	15.1/-	101.5/-
2020	18.4/-	7.7/-	8.2/-	0/-	29.2/-	29/-	16/-	108.5/-
2030	18.4/-	7.7/-	0.6/-	0/-	29.2/-	35/-	16.9/-	107.8/-

HG: hydroelectric generation, NP: nuclear power, PCC: pulverized coal combustion, PPP: peaking power plants, NGCC: natural gas combined cycle, WG: wind generation, ESR: other energies of the special regime.

pipelines from Algeria and through liquefied natural gas (LNG) shipments from other producer countries (Libya, Egypt, Nigeria, Norway).

- According to statistics supplied by the *Ministerio de Industria, Turismo y Comercio* (MITyC), the level of nuclear fuel self-supply is 100%.

In sum, the degree of dependence on imports may be very high in the future, especially those of coal and natural gas. *A priori*, this may jeopardize the security of the electricity supply. A system can, however, be highly dependent on imports but not vulnerable, if it has a great diversity of resources (WEC, 2008). Among the other aspects of generation expansion planning, it is necessary to analyze the degree of vulnerability of the future power generation system.

This vulnerability is multi-dimensional. It depends on several factors: energy dependence, net energy import bill, price volatility, exchange rates, etc. The individual determination of these factors has been so far the most common strategy of vulnerability evaluation. However, the assessment of the diversity of the system can be used as a simpler and more precise alternative strategy. This task has been carried out in this work by means of three new indices adapted and developed from biodiversity analysis.

The first of these indexes has been derived from the SHE biodiversity analysis, and it measures, in percentage, the uniformity of the primary energy resources in the system (E). The second one has been obtained from the broken stick distribution; it quantifies the equivalent number of primary energy resources that are in similar proportions in the system (S_{eq}). The third one also derives from the SHE analysis and allows calculation of the percentage decrease of the diversity of the system with the non-evenness of the species (D_H).

The aforementioned indexes have been applied to the generation prediction of the different technologies considered for the Spanish power system in the period 2013 to 2032 in order to demonstrate its usefulness. This forecast has been obtained by solving a stochastic linear model of minimum cost for this power system (Delgado *et al*., 2011).

Energy and capacity results have been obtained for each year and each technology in the period 2013 to 2032 from a model that has been developed with GAMS (general algebraic modeling system; www.gams.com). The uncertainties in prices of fossil fuels and of CO_2 emission allowances are considered by analyzing different scenarios in the model. Specifically, three scenarios are considered. In the first of them or 'high priority gas scenario,' the variable cost (fossil fuel cost plus the CO_2 emission allowances cost) of the gas equipment is lower than the variable cost of the coal equipment, with the opposite occurring in the second one, or 'high priority coal scenario.' Finally, the third scenario, or 'intermediate scenario' considers intermediate costs.

Also, the influence of nuclear energy in supply security of the generation system has been taken into account. For that reason, nuclear and non-nuclear cases have been analyzed in these scenarios. In the first case, the current NP plants have to be dismantled when they reach 60 years of life and it is possible to put other NP plants into service. In the second one, it has been considered that the current nuclear moratorium will continue and the existing plants have to be decommissioned when they reach 40 years of operation.

In what follows, the subject is introduced, as well as the indexes that have been developed for the valuations. Afterwards, the model and index results and some brief conclusions about the diversity of the Spanish power generation system are presented. Finally, some conclusions drawn from the results are stated.

TABLE II
CATEGORIES ESTABLISHED FOR FUEL FUNCTION

Category	Fuel
NGCC y GT	Natural Gas
NP	Uranium
PCC, PCC w/CCS and IGCC w/CCS	Coal
WG	Wind
HG	Water
ESR	Water, sun, biomass...

NGCC: natural gas combined cycle, GT: geothermal, NP: nuclear power, PCC: pulverized coal combustion, CCS: CO_2 capture and storage, IGCC: integrated gasification combined cycle, WG: wind generation, ESR: energies of the special regime.

Supply Security and Vulnerability. Diversity Methodology

A way to study the supply security of the electric system (for definitions of supply security and vulnerability see Grubb *et al*., 2006; WEC, 2008; Bhattacharyya, 2009) is to analyze its vulnerability in relation to different factors (energy dependence, import concentration, energy intensity, carbon content of primary energy supply, etc.). Several indexes have been developed to quantify some of the above factors independently. There have in some attempts to synthesize several of them into a single index, with the intention of evaluating the vulnerability with respect to them (Percebois, 2007; WEC, 2008).

However, the vulnerability of the system can be measured in another way, by calculating its diversity regarding the type and source of fuel or technology. The more diverse the system in these last elements, the less vulnerable it will be with regard to them, because it is more flexible. According to Brancart and Antoine (1991), a power system will be flexible in so far as it can rapidly respond to expected or unexpected variations of its main parameters. For the producer, the flexibility means the combination of different fuels in power generation, according to given circumstances (WEC, 2008). Thus, the vulnerability of the system can be determined by calculating its diversity.

There are few papers that use this concept to analyze the supply security of the electric system. For instance, Grubb *et al.* (2006) have attempted to measure the vulnerability of the power system in UK by means of Herfindahl-Hirschman and Shannon-Weiner indexes. In order to apply these indexes in the calculation of the diversity of the UK generation system, the analogies specie/technology grouped by fuel source and habitat/power system have been carried out (Grubb *et al*., 2006). The second one of these indexes is commonly used in the measurement of ecosystems biodiversity.

Henceforth, the analogies specie/technology grouped by fuel type, and habitat/power system are used. The grouping for species considered is shown in Table II. A previous grouping into a single category of several technologies, belonging to the Spanish ESR (photovoltaic, solar-thermal, mini-hydro, cogeneration, etc.), has been performed in spite of not having the same fuel. The probable future marginal individual contribution of these technologies to the power system, and its special treatment in the income-producing set-up, are the two reasons that justify this simplification.

The Shannon-Weiner index (Ec. 1) used in Grubb *et al.* (2006) does not distinguish the contribution from the number of species (species richness, S) of the contribution coming from the proportional distribution of this species in the system (evenness, E) (Hayek and Buzas, 1997).

$$H=-\sum_{i=1}^{I} p_i \times \ln p_i \qquad (1)$$

In 1996, Buzas and colleagues developed a new method based on Shannon's information function to assess the individual contribution of S and E to the diversity of a system, the SHE analysis, (Buzas and Hayek, 1996). This analysis is based on the expression shown in Ec. 2.

$$H= \ln S + \ln E \qquad (2)$$

Here, the value of diversity is obtained as the difference between its maximum possible value, ($H_{max}= \ln S$), minus the quantity of evenness (lnE), since this last term will always be negative or zero. That is, E will vary between 0 and 1, taking the unit value when the abundance of the different species is identical. *Ceteris paribus*, the larger S is, the larger H also is, i.e. greater diversity in the system. Also, the influence of E in the diversity of the system will be lower with a larger S. This is because the latter parameter is usually between 0.2 and 0.7, so that lnE is between -1.6 and -0.36. On the other hand, with S constant, the diversity depends proportionally on the degree of evenness: the diversity of a system will be much larger the greater E is and *vice versa*. In other words, the diversity of a system with a strong dominance of one or a few species will decrease significantly (Hayek and Buzas, 1997).

Other tools that have been widely used by ecologists for decades in the analysis of biodiversity are the abundance distribution models (ADM). These models are statistical tools, mathematical models that show the abundance of all the species ranked in order from most to least abundant. Numerous distribution models have been developed but only four of them are used in practice: geometric series, log series, lognormal and broken stick models. According to Magurran (1988), these models have a sequential order of smaller to greater evenness grade. That is, a few species are abundant but most are very rare in the geometric distribution; in the broken stick distribution, most of the species have similar proportions, and only a few species have a little or a lot of presence; the two remaining distributions are intermediate models of the two previous ones.

The question that immediately arises is which of these four models would better fit the Spanish generation system, both currently and in the future. At present, the different 'species' of the Spanish generating system are working in a fairly uniform way (REE, 2008). Perhaps, in the future, the contribution of one of them to the system can be significantly higher or lower. It is expected, however, that the participation of the majority of them remains fairly balanced, because the Spanish electric system cannot be based on one or two primary energy resources since the autochthonous sources are neither continuous (e.g. wind) nor in the appropriate quantity (e.g. coal). Therefore, from our point of view, the broken stick model is the ADM that can adjust better to the Spanish generating system. According to May (1975), the H_{bs} of this distribution can be estimated approximately as the function of S' with Ec3.

$$H_{bs}= \ln S'-0.40 \qquad (3)$$

By equating the three expressions (Ecs. 1, 2 and 3), it is possible to obtain Ecs. 4, 5 and 6.

$$E=\frac{e^H}{S} \qquad (3)$$

$$D_H(\%)=\left|\frac{\ln S\text{-}H}{\ln S}\right|\times 100=\frac{-\ln E}{\ln S}\times 100 \qquad (4)$$

$$S_{eq}=\frac{S'_{calc}}{e^{0.4}}=e^H \qquad (5)$$

Ec. 4 calculates the value of E of the system as a percentage if the Shannon's index and the number of species are known *a priori*.

With Ec. 5 it is possible to calculate the D_H of the diversity of the system with the non-evenness of the species. Also, if the values of S and E are known it is possible to calculate the number shown in Table III. This table allows fast determination of the D_H considering E and S.

Finally, the numerator (S'_{calc}) of Ec. 6 can be obtained by equating Ecs. 1 and 3 and isolating S'. S'_{calc} is not a value in a real scale; it is necessary to adapt it to the scale where the number of species is real, S_{syst}. This can be done by interpolation, assuming $S'_{calc,max}= S_{syst}$ where $S'_{calc,max}$ is the maximum value of S_{calc}. This maximum value is reached when H is biggest too, ($H= \ln S_{syst}$). This way the expression in Ec. 6 can be obtained. Also, S_{eq} can be estimated directly from H. It is emphasized that this last expression is the numerator of Ec. 4. The final expression allows us to convert H to an equivalent number of species that are in the system in similar proportions, clarifying the meaning of this abstract index.

As stated above, the three aforementioned indexes can be applied in the analysis of the diversity of the future power generation system. To be specific, if S is known *a priori* and H is calculated with the results of energy and capacity obtained from the resolution of a model, it is possible to obtain these three new indexes of diversity.

Model and Index Results

It is important to examine the long-term vulnerability of the Spanish power system and the influence that the costs of fossil fuels (coal and natural gas), and the consideration or not of the nuclear technology as a generation option have on this vulnerability. To this end, a comparative study of this aspect in two cases, nuclear and non-nuclear, for three scenarios of generation variable costs (high priority gas, intermediate and high priority coal) will be carried out with the energy results of the model CCS: CO_2 capture and storage. The results for the analyzed period 2013-2032 have been grouped into five-year periods for a more precise analysis.

TABLE III
PERCENTAGE DECREASE
OF THE DIVERSITY WITH E

S	E				
	0.9	0.8	0.7	0.6	0.5
2	15.2	32.2	51.5	73.7	100.0
3	9.6	20.3	32.5	46.5	63.1
4	7.6	16.1	25.7	36.8	50.0
5	6.5	13.9	22.2	31.7	43.1
6	5.9	12.5	19.9	28.5	38.7
7	5.4	11.5	18.3	26.3	35.6
8	5.1	10.7	17.2	24.6	33.3
9	4.8	10.2	16.2	23.2	31.5
10	4.6	9.7	15.5	22.2	30.1
15	3.9	8.2	13.2	18.9	25.6
20	3.5	7.4	11.9	17.1	23.1
25	3.3	6.9	11.1	15.9	21.5
30	3.1	6.6	10.5	15.0	20.4

TABLE IV
TOTAL CAPACITY (MW) TO BE INSTALLED BY EACH TECHNOLOGY
IN 2013-2032

	Non-nuclear case			Nuclear case		
	High priority gas	Intermediate	High priority coal	High priority gas	Intermediate	High priority coal
NGCC	16,155	16,098	13,115	9,992	9,827	6,189
NP	0	0	0	0	0	0
WG	24,597	24,597	24,597	24,248	24,189	25,032
GT	6,690	6,842	5,358	5,604	5,604	4,335
PCC w/CCS	11,000	11,000	11,000	11,000	11,000	11,000
IGCC w/CCS	4,461	5,235	10,691	3,064	3,246	11,000
Total	62,904	63,771	64,760	53,909	53,867	57,556

NGCC: natural gas combined cycle, NP: nuclear power, WG: wind generation, GT: geothermal, PCC: pulverized coal combustion, CCS: CO_2 capture and storage , IGCC: integrated gasification combined cycle.

So as to give a general idea of the growth in capacity of the system in both cases in the period analyzed, the installed capacity for each technology is presented in Table IV. A brief analysis of this table leads to the following conclusions. First, in both cases NP is the only technology that is not developed, owing to its high investment costs (IC) and the relatively low costs of CO_2 (some estimate this cost in the range of 30-50€/t) in the case of development of the technologies based on the fossil fuels. Second, another obvious conclusion is that a bigger total installed capacity is needed in the non-nuclear case. This is achieved mainly by means of a bigger capacity installation for technologies based on natural gas, NGCC and GT. Third, CCT would make an important contribution in both cases, being the technology based on current PCC the one that would reach their maximum development. Fourth and last, the capacity of WG would be increased by almost 25GW in both cases.

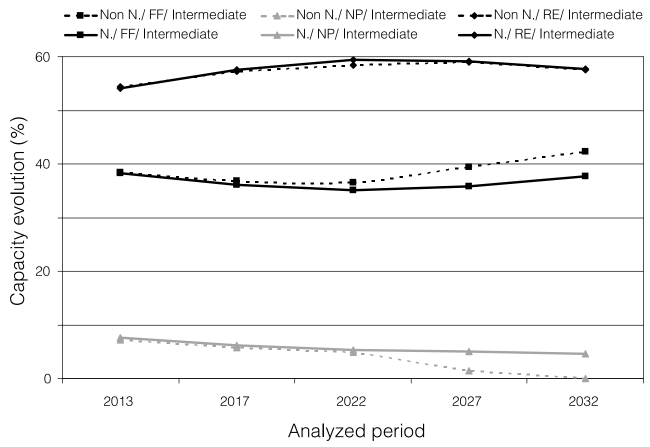

Figure 1. Evolution of the total capacity of the system in both cases and intermediate scenario.

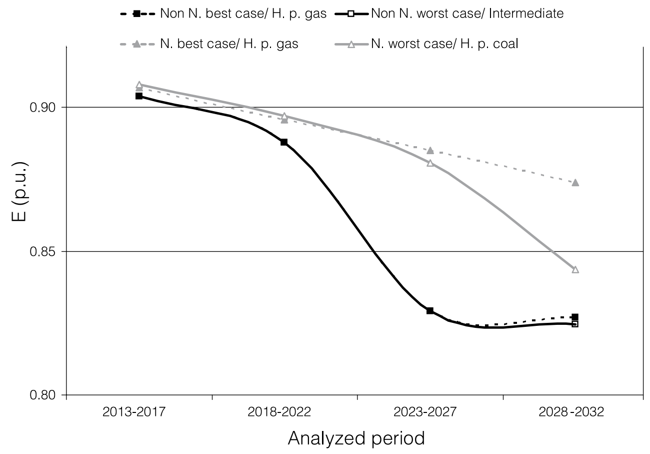

Figure 2. Evolution of E in the best and worst scenarios, in both cases.

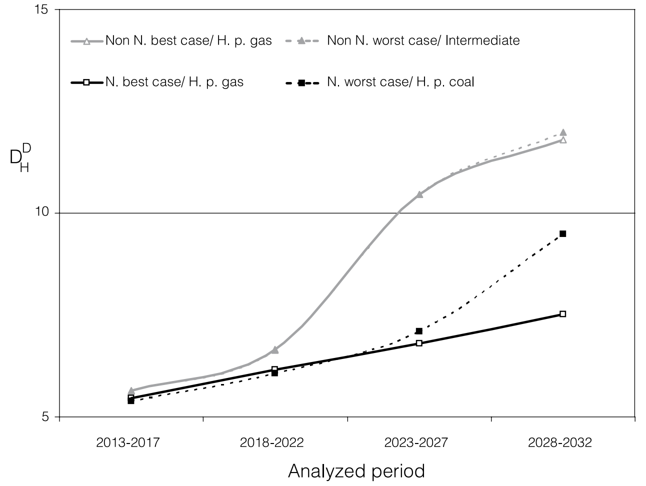

Figure 3. Evolution of D_H with evenness in best and worst scenarios, in both cases.

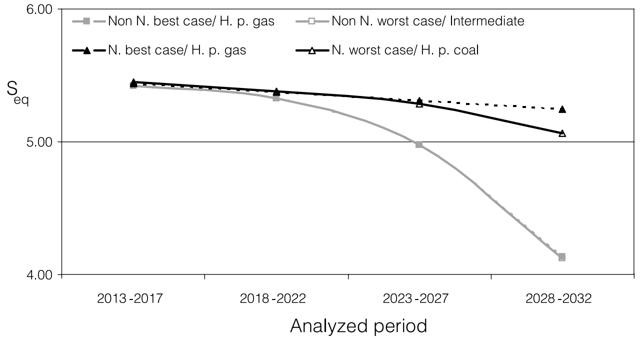

Figure 4. Evolution of S_{eq} in both cases, in the best and worst scenarios.

What is the evolution of the total capacity of the system in the period analyzed? Figure 1 shows the evolution for both cases in the intermediate scenario, since the two remaining scenarios are similar. The different technologies have been grouped by fuel according to the following criteria: fossil fuels (FF), nuclear (NP) and energies belonging to the ESR including WG and HG (renewable energies; RE). Some conclusions are: first, RE holds a total capacity above 50% throughout the studied period in both cases; second, the proportional contribution of FF technologies increases from the third decade of this century, to cover the demand and to substitute for the NP that would be retired totally from the system in the non-nuclear case during this period. In fact, in this case, the last two NP plants must be retired in 2028. Therefore, the number of primary energy resources of the system in the last five-year period of the non-nuclear case is reduced to five. In contrast, the number of 'species' in the nuclear case is six for the whole period.

The operation of the new power system will be different to the way in which the current system works because of the presence of a high percentage of technologies that belongs to the groups of RE and FF. But, how will the vulnerability of the system be affected by this new way of operation? The indexes presented in the second section will be used for this analysis.

The evolution of E is shown in Figure 2. The pronounced fall in uniformity in the first three five-year periods of the non-nuclear case is due to the combined effect of the commissioning of two technologies (NGCC plants and WG farms) and the withdrawal anothter two (current NP plants and some obsolete capacity of PCC). Thus, the energy production would rely increasingly on three primary energy resources: natural gas, coal and wind. The decrease in E would be stabilized in the last five-year period because the number of primary energy sources that is considered in this period is five (previously six primary energy resources were used). Summarizing, in this case the decrease of uniformity in the period is ~8%. However, in the nuclear case, this reduction would be smaller (3.3-6.4%) because the NP plants would continue contributing to the system significantly (in 2032, about 14% of energy would be generated by this technology). But how will the evolution of these uniformities influence the diversity of the system?

Figure 3 shows the evolution of D_H with evenness. As expected, for the non-nuclear case, the increase in D_H is important in the first three five-year periods (~5% increase). The final value would be ~12%. However, for the nuclear case, the increase in D_H would be smaller and the final value would be between 7.5 and 9.5%. But this percentage has been applied to the diversity, and what is the value?

Figure 4 shows the evolution of the diversity by means of S_{eq}. First, one would like to express the diversity using the Shannon index. Its maximum value would be ln6 ≈1.79. In the non nuclear case, this index falls continuously from values of 1.69 to about 1.42. In contrast, in the nuclear case, this index remains practically constant: from values of about 1.70 to final values in the range of 1.62 to 1.66. The conversion of H in S_{eq} clarifies the meaning of the above: in the first case, the diversity falls significantly from 5.4 to about 4.1. That is, 1.3 'species' have been lost. In contrast, in the second case, the loss of diversity is much smaller: from about 5.4 to the range of 5.2 to 5.1. That is, the loss of 'species' is in the range of 0.2 to 0.3.

As a general conclusion for the Spanish case, it could be said that the degree of uniformity decreases slightly during the analyzed period for both cases, from just over 90% to a range of 87 to 82%. Also, D_H increases slightly in both cases, from just over 5.5% to 8-12%. Both indexes indicate that the system looses diversity due to a small reduction in evenness, but this loss is not very meaningful. It is, however, necessary to consider the contribution of the number of species to this diversity. The index S_{eq} shows a significant loss of diversity in the non-nuclear case, being much less important in the nuclear case: between 6.5 and 4.3 times less in the last case with respect to the first one. Therefore, the power system would be more vulnerable if the current NP plants were dismantled.

Conclusions

The total results of energy per primary energy resources in the period 2013-2032 obtained from the model (among other results) have been analyzed by means of several indexes that are deduced from the biodiversity analysis. Some points deserve emphasis:

a) Adapting the results of the model it is possible to analyze the diversity of the power system by considering independently the number of 'species' and their proportion in the system.

b) The application of SHE biodiversity analysis to the power system allows a maximum value to be established for the Shannon index, if the number of species is known. This way, a range where the Shannon index can oscillate is determined, solving the problem mentioned by Grubb *et al.* (2006), "… Since the index (Shannon index) seeks to quantify an inherently nebulous concept, it is difficult to explain the precise implication of different values…"

c) Two of the indexes (E and S_{eq}) analyze the evenness of the system from its number of species and its Shannon's index. Also, S_{eq} allows the Shannon index to be expressed on a clearer scale.

d) The larger the number of primary energy resources of the system, the larger will be its diversity and the smaller its vulnerability. Also, the grade of evenness will have less influence in this diversity. This is nothing new, but what is the ideal number of species for a country that is highly dependent on imports? Table III can help with this determination. According to this table, it is possible to determine S depending on the E and the D_H to be considered.

As an example, if $E= 0.9$ and $D_H= 10\%$, the minimum number of the species would be three, with $H= 0.99$ and $S_{eq}= 2.7$. If, however, an $E=0.8$ and a $D_H= 10\%$ are considered, the solution would be ten, with $H= 2.08$ and $S_{eq}= 8$. Obviously, the latter has twice the diversity of the first case, with almost three times more species with similar proportions in the system.

If the foregoing is applied to the Spanish case, which already has six primary energy sources and evenness near 0.8, the decision seems clear: it is necessary to keep the current species and to introduce four new ones; also, the uniformity of the system has to be maintained or even increased slightly.

Obviously, this task is not easy to achieve for several reasons (technology development, costs, reliability of the system, environmental problems, etc.). This strategy of 'putting the eggs in as many baskets as possible' seems, however, appropriate for countries with high dependence on imports, like Spain, in order to have a less vulnerable system in the future.

Finally, there are other aspects of diversity that should be investigated, like the ideal number of technologies that can be connected to the system or the geographical diversity of the primary energy sources.

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