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Study of energy poverty in the European Union: the effect of distributed generation

Abstract

The objective of this work is to measure the energy poverty in the European Union through the construction of an Energy Poverty Index by means of the multivariant technique of factorial analysis.

The index is calculated for the 28 member countries of the European Union in the years 2008 and 2017. Moreover, the effect of distributed generation renewable resources (such as photovoltaic, small hydro or micro wind) on energy poverty is studied.

The obtained results show that Bulgaria, Rumania, Greece, Latvia and Lithuania are among the countries that display the highest index. The countries with the lowest index are Denmark, Sweden, Finland, the Netherlands and Slovakia, among others. The distributed generation contributes to reduce energy poverty in all countries. In fact, Ireland, France, Luxembourg, Slovenia, Finland and Sweden, have shown greater capacity than others to respond to changes in the distributed generation.

Keywords: Energy Poverty, Synthetic Indicator, Factorial Analysis, Distributed Generation.

1. Introduction

The concept of energy poverty (EP) has its origin in England in 1973 as a consequence of the energy crisis, as the increase of the price of energy meant that many families were unable to maintain their houses at a suitable temperature. As of that moment the problem came to be considered as a phenomenon in its own right rather than just another aspect of poverty. In the decade of the 80s, energy poverty had been named broadly by Bradshaw and Hutton, (1983), but it was not until 1991 when Boardman (1991) established the first definition of this phenomenon: *"Energy poverty is the incapacity of a household to obtain suitable energy services (in the home) for 10% of its income"*.

Associated to energy poverty, Bouzarovski and Petrova (2015) introduce the concept of energy vulnerability as "*the propensity to experience a situation in which the home does not receive a suitable amount of energy services"*. This definition gives a more dynamic approach to energy poverty, as it is not a permanent condition but temporary that may be modified by internal or external factors to the home.

In the context of the European Union, according to the EU Survey on Income and Living Conditions (EU SILC) elaborated by Eurostat in the year 2018, 7.4% of homes had problems to maintain their house at a suitable temperature, although there are great differences between the various countries, varying from 33.7% for Bulgaria to 1.6% for Austria.

Currently, the International Energy Agency (IEA) defines energy poverty as a "lack of access to modern energy services […] defined as household access to electricity and clean cooking facilities (e.g. fuels and stoves that do not cause air pollution in houses)".

In this work we approach the study of energy poverty for the 28 countries that constitute the European Union from a multidimensional perspective in 2008 and 2017. We are aware that working on a national scale is a limitation of the study, as stated by Sareen et al. (2020) "... current efforts risk failing to actually alleviate energy poverty due to selection biases, perverse policy effects, regressive cost burden distribution and exclusion of energy poor people from support schemes through misrecognition and imprecise targeting "; however, it has been necessary given the availability of data.Variables that gather the perceptions and declarations of the households on their access to energy will be considered and socioeconomic variables (poverty and inequality, among others). From these variables, energy poverty will be studied through the elaboration of an Energy Poverty Index (EPI), applying the multivariant technique Principal Component Analysis (PCA). This technique is used to describe a set of data in terms of new uncorrelated variables (components) and is based on interrelationships between the different variables, not on causal relationships between them, therefore it is different approach to regression. The components are ordered by the amount of original variance they describe, so the technique is useful for reducing the dimensionality of a data set and allows to build synthetic indicators. These indices have the advantage over those obtained with other multidimensional techniques that they do not consider subjective weightings. Principal component analysis has been used by many authors to obtain synthetic poverty indices: Coromaldi and Zoli (2007) have made a multidimensional analysis of poverty with data for Italy; have used PCA to determine the configuration of energy poverty determinants in each EU-27 country through the creation of an index Herman,(2014) analyzes the working poverty and its determinants in the European Union and Cho et al. (2010) have used the principal component analysis for the construction and simplification of the Water Poverty Index.

In this context, distributed generation renewable resources such as photovoltaic, small hydro or micro wind could play an important role to reduce energy poverty. Renewable Distributed Generation (RDG) consists in the generation of electricity by means of many small renewable energy sources installed in points close to the consumption[1], so it reduces electricity losses, increases efficiency, increases electric system reliability and reduces fossil fuel energy dependency. Moreover, RDG offsets investments in generation, transmission, or distribution facilities that would otherwise be recovered through rates. Therefore, RDG could contribute to decrease energy poverty by reducing electricity supply costs and increasing energy affordability[2]. As Allan et al. (2015) point out, by connecting electricity generators closer to the point of use, the scope of infrastructure needed to transport electricity is reduced, as are the costs associated with transmission and distribution. According to the Department of Trade and Industry (2007), approximately 6.5% of the electricity generated is lost when it is transmitted and distributed to consumers, which would represent great savings potential with RDG. In addition, distributed generation can lead to potential cost reductions in terms of deferring the required investments and upgrades associated with infrastructure and centralized

[1] For example, by analyzing the current geographical distribution of the PV installed capacity in Spain (available at https://www.esios.ree.es/es/mapas-de-interes/mapa-instalaciones-fotovoltaicas), it should be noted that PV installations are widely spread around the country, so they are located close to the load and many are small in size.

[2] For example, Oldfield (2011) presented a qualitative review of literature on the potential role of intelligent communication technology, web-based standards, and smart grid technology to alleviate energy costs and improve access to clean distributed energy in developed and developing countries.

generation plants. Basically, the positive effects of RDG on energy poverty depends on the personal RDG investment cost for low-income households. Some authors have found that those most likely to adopt microgeneration are high-income households (Balcombe et al. 2010). Thus, financial supports could increase for the integration of small renewable energy sources installed in low-income household buildings. Moreover, RDG integration depends on the smooth conversion of unidirectional grid systems to bidirectional grid systems (Damsgaard et al. 2015.). Some RDG could be a grid-connected decentralized production unit (prosumers) with two types of exchanges with the grid: energy imports when the local production is insufficient to match the local consumption and energy exports when local production exceeds local consumption. Thus, their effect on energy poverty will depend on the distribution of the total costs of the system between consumers and prosumers and the final electricity bill. Prosumers can save money in their electricity bill or receive payments through interaction with the grid, increasing energy affordability. Basically, the positive effects of RDG on energy poverty depends on the personal RDG investment cost for low-income households. Some authors have found that those most likely to adopt microgeneration are high-income households (Balcombe et al. 2010). Thus, financial supports could increase for the integration of small renewable energy sources installed in low-income household buildings. Moreover, RDG integration depends on the smooth conversion of unidirectional grid systems to bidirectional grid systems (Damsgaard et al. 2015.). Some RDG could be a grid-connected decentralized production unit (prosumers) with two types of exchanges with the grid: energy imports when the local production is insufficient to match the local consumption and energy exports when local production exceeds local consumption. Thus, their effect on energy poverty will depend on the distribution of the total costs of the system between consumers

and prosumers and the final electricity bill. Prosumers can save money in their electricity bill or receive payments through interaction with the grid, increasing energy affordability. In this work we are going to study the impact of the integration of distributed electricity generators on energy poverty.

We are going to quantify the Energy Poverty Index for the 28 members of the EU in 2008 and 2017 by using a principal component analysis. Furthermore, a synthetic indicator for the year 2017 has been constructed considering, additionally, RDG. The comparison of both indices (with and without the inclusion of RDG) allows to draw conclusions on the effect that distributed generation has on energy poverty.

The paper is organized as follows: Section 2 contains a literature review about the composite indexes on energy poverty and the effects of RDG on energy poverty. In Section 3, the *Energy Poverty Index* is calculated by using principal components. The variables used and the calculation methodology are described. In addition, the results for EU-28 in the years 2008 and 2017 are presented, allowing to track the evolution of energy poverty over time. The effect of the renewable small-scale units of electricity generation on the Energy Poverty Index in 2017 are analysed in Section 4. Also, a sensitivity analysis is carried out on the effect that the changes in the RDG have on energy poverty in each country of the EU-28. Section 5 includes the results and some policy recommendations to reduce energy poverty that emerge from the analysis and, finally, Section 6 presents the conclusions of the study.

2. Literature review

The study on the causes and nature of energy poverty can be carried out by means of two types of indicators:

i. Indicators based on perceptions and declarations of the households, such as the incapacity to maintain the house at an adequate temperature in the cold months, delay in the payment of invoices or leaks, damp or rot in the home, among others. In the context of the European Union these data come from the EU Survey on Income and Living Conditions (EU-SILC) elaborated by EUROSTAT.
ii. Indicators based on expenses and income of the household: the percentage of annual expenses on energy of annual income (Boardman, 1991) or Low Income-High Cost (LIHC) [3].

The use of one approach or the other frequently leads to differing conclusions, thus Tirado and Jiménez (2018) indicate that in Spain for the period 2006-2014 the figures based on perceptions and declarations of the home show a worsening of the situation, whereas the data based on expenses and income indicate some improvement in recent years.

The first group of measures is a subjective approach since they are based on appreciations of the households, whereas the other type of indicators may be, in principle, more objective. Most of the empirical studies on the subject combine both approaches. In the European context, Dubois and Meier (2016) show that energy poverty rates are particularly severe in the countries of eastern and southern Europe and that there are different profiles of inequality across the continent. Scarpellini et al. (2015) carry out a descriptive analysis of the main determinants of energy poverty in 615 households in the region of Aragón (Spain). Thomson et al. (2017) assess the different statistical options for measuring energy poverty in Europe and they present options for improving existing

[3] According to the Hills Report (DECC, 2015) a home is considered in a state of energy poverty if the equivalent cost necessary in domestic energy to maintain a level of suitable comfort is over the average and if discounting that cost from their equivalent income, the result is an amount below the threshold of monetary poverty.

data. Costa-Campi et alt. (2019) analyze the relationship between energy poverty, energy consumption and elements related to household income.

Some authors manifest the need to define indicators that combine both approaches, thus Vallvé (2016), referring to energy poverty, indicates: "Independently of the denomination given, this phenomenon should be measured from a compound indicator that includes all these dimensions and not just from a simple single indicator".

It seems that a unanimous consensus exists in stating the need to use multidimensional indicators that represent, with the greatest possible reliability, the existing reality (Castaño-Rosa et al., 2020, Sokołowski, et al., 2020). Different approaches exist within this multidimensional approach, fundamentally due to the way to determine the weightings necessary for the construction of the index. In this sense we can refer to the following situations:

i. The weightings are determined exogenously to the dimensions considered, that is to say, the weighting refers, in general terms, to the number of dimensions and categories that constitute them.
ii. The weightings are determined endogenously to the dimensions. In this case, the weightings can be established according to their explanatory level, that is to say, the weighting will take a higher value the greater the capacity of explanation of the dimension of the studied phenomenon.

Two trends can be derived from these situations, referring to the construction of indices to measure energy poverty from a multidimensional perspective. Within the first approach, without being exhaustive, we can refer to the work of Okushima (2017), who proposes the construction of a boolean matrix (whose elements are 0 and 1), referring to the verification of certain conditions related to the considered dimensions, and on which is applied a measurement proposed by Foster-Greer-Thorbecke (2010). In the paper of Tirado and Bouzarovski (2014) the existence of a geographical energy divide in Europe provides a starting point for exploring the relationship between energy transitions. On the other hand, Maxim et al. (2016) propose an indicator: the Compound Energy Poverty Indicator (CEPI) to analyze energy poverty in the EU. . Meyer et al (2018) present a “barometer” based on objective and subjective dimensions to quantify energy poverty in Belgium. Aristondo and Onaindia (2018) determine energy poverty using the indicators proposed by Chakravarty and D'Ambrosio (2016), quantified on three dimensions of energy poverty, equally weighted. Wang et al. (2015) propose an indicator based on those indices that are applicable for the case of China (distinguishing between rural and urban areas), which is made up of four categories. Within this approach, but applying fuzzy methodology, Bollino and Botti (2017) analyze energy poverty in the countries of the EU for the year 2014.

In the second approach indicated, with endogenous determination of the weightings, we can refer to the work Gerundo et al. (2020) propose an index applying fuzzy analysis in order to define a Composite Vulnerability Index for Italy. Sokołowski et al. (2020) define a multidimensional index of energy deprivation with five dimensions and analyze the case of Poland. On the other hand, Durán and Condori (2016) made a multidimensional study for Argentina from 6 variables related to energy poverty, applying analysis of principal components. They obtain two indicators, one of them related to the access to energy and the other with the economic burden of said access, summarizing them later in a General index of Energy Poverty.

In this work we apply this last approach, considering multidimensionality as a starting point of the study of EP and constructing a synthetic indicator of energy poverty based on the application of the factorial technique of principal components.

Regarding the effect of RDG deployment on energy poverty, there are some studies focusing on its benefits: Chaurey and Kandpal (2010) link RDG based on Photovoltaic technology to poverty reduction in India; Deichmann et al. (2011) show how RDG will likely play an important role in expanding rural energy access in rural Sub-Saharan Africa; Baruah and Enweremadu (2019) investigate the prospects of distributed renewables based on farm manure and solar radiation resources in the reduction of energy poverty in the Republic of South Africa; Bonatz et al. (2019) study the interlinkages between energy poverty and low carbon development in China and Germany.

3. Determination of a synthetic indicator of energy poverty

As indicated previously, the synthetic index is calculated having applied the factorial multivariant technique of principal components, which is frequently applied with this aim, given its relative simplicity and its intuitive interpretation. Factorial analysis is a statistical technique whose main objective is data reduction; it is used to explain the correlations between the variables in terms of a smaller number of magnitudes called factors.

Among the main advantages that the application of the PCA method entails, we can point out the following: it is not necessary for the analyst to determine the value that the weighting of each initial indicator should take, but these can be calculated from the results of PCA. The use of this methodology has spread especially in cases where there is no consensus among experts on the relative importance of the variables, since the weights associated with the simple indices are derived from the information provided by each of them, that is, the weight will be higher the higher the explanatory power of the simple index.

A second advantage is that the PCA method provides uncorrelated components, that is, the synthetic indicator considers the possible relationships between the simple indicators and avoids the distortion in the results caused by the double counting of the information. This method defines the main components independently and, therefore, they do not correlate with each other, so each of them provides information not contained in the rest.This technique is used in very different areas. We can mention, among many other fields, its use in studies on well-being (Distaso, 2007; Ivaldi et al., 2016); economic disparities or poverty (Bin, 2015; Pasha, 2017) or sustainability (Arbolino et al., 2018 and Jiang et al., 2018).

Following the works of Thomnson and Bouzarowski (2018) and Thomson et al. (2017), the construction of the synthetic indicator has been carried out considering the availability and quality of the information and the relevance of the indices used.

On the other hand "Measuring energy poverty is a difficult task. It is a private condition, being confined to the home, it varies over time and by place, and it is a multi-dimensional concept that is culturally sensitive. The choice of measurement approach is also contingent on whether energy poverty incidence is to be measured at the panEuropean, national or regional level for monitoring and benchmarking purposes, or whether a finer grained dataset is needed to identify energy poor households at the local scale for policy delivery." (Thomson et al, 2017).The evolution of the measurement of PE must be accompanied by an evolutionary power to transform the energy sector into one that the public associates with their interests, then the measurement of energy poverty will become participatory. In addition, policy-makers will be able to more easily respond to the needs of society Sareen et al. (2020).

3.1. Simple indicators

The construction of an EPI begins with the definition of a set of simple indicators. The joint consideration of all of them makes it possible to approach the analysis from a much richer multidimensional perspective, giving rise to the configuration of an EPI.

The simple indicators employed are shown in Table 1.

Table 1. Simple indicators

Dimensions	Simple indicators	Units	Denomination
Economic inequality and poverty	Gini Index	--	Gini
	Percentage of people at risk of poverty after social transfers	%	Poverty
Material deprivation	Percentage of homes incapable of maintaining the house adequately warm	%	Inadequately warm
	Intensity of the material deficiency[4]	Nº of elements	Deficiency
	Percentage of homes with late payment (supply accounts)	%	Late payment
	Percentage of homes with severe material deprivation	%	Deprivation
Economics	Gross Domestic Product per capita[5]	%	GDP
	Expenditure on energy in the homes[6]	‰	Energy expenditure
Distributed generation	Ratio Distributed Generation of hydropower (<1MW) / Non-distributed Generation	--	Mini Hydro
	Ratio Distributed Generation of hydropower (1-10 MW) / Non-distributed Generation	--	Small Hydro
	Ratio Distributed Generation of wind power/ Non-distributed Generation	--	Wind
	Ratio Distributed Generation solar energy / Non-distributed Generation	--	Solar

Source: Own elaboration

We propose the following dimensions for the construction of a synthetic indicator of energy poverty: i) dimension of inequality and poverty of income, ii) dimension of material deprivation, iii) economic dimension and iv) dimension of distributed generation. The dimension of inequality and poverty (i) is constituted by the Gini index and the percentage of people at risk of poverty after social transfers. The Gini index measure inequality in the distribution of income, variable very related to energy poverty

[4] Average number of elements of material deprivation among the people with difficulties to make ends meet.
[5] Percentage of the total of the EU28, based on millons of euros at current prices.
[6] Refers to the structure of the expenditure on consumption.

(Kyprianou et al., 2019; Bouzarovski and Tirado Herrero, 2017), a higher level of income inequality may be associated with a greater energy poverty (EU Energy Poverty Observatory; Papada, 2016; Maxim et al. 2016).

The dimension of material deprivation (ii) is centered on different aspects that are habitually considered as factors that intervene in energy poverty, as seen, for example, in the works of Maxim et al. (2016), which include diverse indices that they classify in categories, one of which refers to well-being and material deprivation and that includes the percentage of homes incapable of maintaining the house at a suitable temperature and those that delay payment. The work of Mohr (2018) considers the EP variables relative to the temperature of the houses and their level of insulation. Lawson et al (2015) compare different approaches to energy poverty in New Zealand, analyzing the lack of elements which cause houses to have an unsuitable temperature.

In the economic dimension (iii) we have considered two indicators: the GDP per capita and the expenditure on energy. Maxim et al. (2016) reflect the expenditure on energy as a dimension of EP and indicate that high energy costs, in relation to the income of the individual, make the households more vulnerable. Alkon et al. (2016) study the relevance of the expenditure on energy as an indicator of energy poverty for India, in the period 1987-2010. González-Eguino (2015) and Arto et al. (2016) show the existing relation between economic development (measured through the GDP) and energy consumption and, therefore, with energy poverty.

In addition, in order to analyze the influence of the distributed generation as a tool to alleviate energy poverty, the dimension known as distributed generation has been considered (iv). This dimension includes variables calculated as the ratios of the electricity generated by each distributed electricity technology from renewable sources (RDG: Mini hydropower, small hydropower, wind and solar) in relation to the total of electricity generated by non-RDG technologies. The electricity generated by each technology is its gross electricity production measured as Gigawatt hours and it is obtained from Eurostat. These ratios show the importance of the RDG in relation to the non-RDG. In this sense, Szabó et al. (2013) analyze the impacts of distributed generation with the aim of reducing energy poverty in Sub Saharan Africa. Moreover, Baruah and Enweremadu (2019) show how the inclusion of distributed renewables can reduce energy poverty by rural electrification plans and programs. In addition, Chaurey and Kandpal (2010) link RDG based on Photovoltaic technology to poverty reduction in India.

3.2. Quantification of energy poverty by means of a synthetic index

We start by quantifying energy poverty in 2008 and 2017, the most recent data available for the considered indices being from the latter year and, on the other hand, it is a sufficiently ample time period to allow to determine the changes in EP. The approach used will consist of determining the EPI in both years to see how the energy poverty has varied.

Firstly, the contrast of Kaiser-Meyer-Olkin (KMO) and Bartlett's sphericity test is undertaken. The aim of both techniques is to determine if the application of the factorial analysis is adequate. The results obtained of the KMO are similar, slightly higher in 2017 (0.758) than in 2008 (0.737) and are adequate, given that the closer they are to the unit, the higher the relation between the variables. On the other hand, the probabilities associated to the values of Bartlett's sphericity test coincide in both cases and the results show ($p<0.05$), which is adequate to apply the factorial analysis to the available data. The construction of a synthetic indicator is carried out by obtaining the so-called principal components, which are those that have a greater explanatory capacity. Two principal factors have been retained. Both factors explain 80.85% of the initial variables in 2008 and 77.13% in 2017; therefore, the level of explanation is adequate in both cases. Another aspect to consider in a principal component analysis is the communality that measures how adequately each initial variable is represented by the two factors retained.

The values of the communalities are shown in Table 2.

Table 2. Communalities

Variables	2008	2017
Gini	0.841	0.881
Poverty	0.822	0.752
Deficiency	0.898	0.787
Inadequately warm	0.722	0.799
Energy expenditure	0.830	0.708
GDP	0.717	0.684
Deprivation	0.915	0.914
Delay	0.724	0.646

Source: Own elaboration
Note: Extraction method: Principal Component Analysis
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In general terms, the variables are adequately represented by the retained factors in the two years considered. The level of explanation being somewhat lower in general in 2017, fundamentally in *Delay* or *GDP*, in which values inferior to 0.7 are reached. In 2008, the best represented variables are *Deprivtion* and *Deficiency*, 91.5% and 89.8%, respectively. Whereas in 2017, they are *Deprivation* (91.4%) and *Gini* (88.1%).

In order to facilitate the interpretation of the factors, we are going to perform a rotation on them (Varimax rotation).

The matrices of rotated components in both years are shown in Table 3.

Table 3. Matrix of rotated components

	Components 2008			Components 2017	
	1	2		1	2
Gini	0.917	0.004	Gini	0.939	-0.017
Poverty	0.905	0.052	Poverty	0.867	0.015
Inadequately warm	0.729	0.436	Inadequately warm	0.840	0.306
Deficiency	0.681	0.659	Deprivation	0.747	0.596
Delay	0.651	0.548	Deficiency	0.657	0.596
Deprivation	0.649	0.603	Delay	0.610	0.523
Energy expenditure	-0.159	0.897	Energy expenditure	-0.078	0.838
GDP	-0.301	-0.791	GDP	-0.226	-0.795

Source: Own elaboration
Notes: Extraction method: Principal Component Analysis. Rotation method: Varimax with Kaiser normalization. Rotation converged in 3 iterations

As far as the situation is concerned in both the years considered we can appreciate that the first factor that is related to the variables *Gini*, *Poverty*, *Inadequately warm*, *Deficiency*, *Deprivation* and *Delay* (higher coefficients) represent the vulnerability and the poverty in the homes. This factor shows an explanatory capacity of 62.5% in 2008 and 59.4% in 2017. The second factor is related to the variables *Energy expenditure* and *GDP* (higher coefficients), an axis that gathers economic variables referring to the energy sector and the development of the country. As can be seen, the sign of the coefficient relative to GDP is negative, which can be understood in the sense that the more developed countries tend to present less energy poverty. It shows an explanatory capacity of 18.33% in the first considered year and 17.72% in the second.

In order to construct the synthetic indicator, the factorial scores associated to the initial variables determined from the regression method are considered. The factorial scores matrix allows each principal component to be expounded as a function of the original variables and is the bae for the construction of the corresponding EPI The results obtained appear in Table 4.

Table 4: Factor scores matrix (2008 and 2017)

	Component scores 2008			Component scores 2017	
	1	2		1	2
Poverty	0.340	-0.187	Gini	0.340	-0.222
Deficiencies	0.110	0.165	Poverty	0.307	-0.188
Inadequately warm	0.181	0.044	Deficiencies	0.100	0.183
Energy expenditure	-0.273	0.480	Inadequately warm	0.231	-0.019
GDP	0.069	-0.319	Energy expenditure	-0.218	0.485
Deprivation	0.087	0.194	GDP	0.099	-0.392
Delay	0.124	0.117	Deprivation	0.133	0.163
Gini	0.355	-.0214	Delay	0.100	0.154

Source: Own elaboration

Notes: Extraction method: Principal Component Analysis. Rotation method: Varimax with Kaiser normalization. Factor scores

From the results shown in the previous table and from the explanatory capacity of each factor, the corresponding EPI is defined and determined as the weighted average of the coefficients of the scores of the components by the proportion of the explained variance.

The results which refer to the coefficients that allow to determine the EPI are shown in Table 5.

Table 5. Determination of the EPI, coefficients associated to the variables (2008 and 2017)

Variables	Coefficients (2008)	Variables	Coefficients (2017)
Poverty	17.799	Gini	16.2578
Deficiency	9.874	Poverty	14.9043
Inadequately warm	12.105	Deficiency	9.2184
Energy expenditure	-8.268	Inadequately warm	13.3982
GDP	-1.543	Energy expenditure	-4.3406
Deprivation	8.989	GDP	-1.0695
Delay	9.917	Deprivation	10.7734
Gini	18.303	Delay	8.6598

Source: Own elaboration

The highest coefficients, in absolute value, are those that refer to the variables that present a higher weight in the definition of the index (Poverty, Gini, Inadequately warm, among others). On the other hand, the signs of the coefficients refer to the relationship that each variable has with energy poverty, that is, a positive sign shows a direct relationship (Poverty, Gini, etc.) and a negative sign shows an inverse relationship (Energy expenditure and GDP).

The values of EPI for each one of the countries considered in 2008 and 2017, ordered by quartiles, as well as the rate of variation between both periods appear in Table 6.

Table 6. Synthetic indicator for the countries of the EU. 2018 and 2017

EPI 2017		EPI 2008		Variation rate (%)
First quartile				
Czech Republic	657.1	Croatia	682.80	-16.83
Finland	727.5	Denmark	754.75	-16.64
Netherlands	744.05	Netherlands	774.27	-3.90
Denmark	762.20	Czech Republic	790.11	0.99
Slovakia	768.96	Luxembourg	802.00	-10.90
Sweden	777.35	Sweden	824.79	-5.75
Austria	801.68	Slovakia	863.00	-14.92
Second quartile				
Slovenia	835.51	Finland	872.74	-11.22
Germany	845.53	Slovenia	941.13	-16.29
Belgium	855.28	Austria	942.22	-11.92
Luxembourg	860.61	France	970.72	7.31

France	865.95	Belgium	971.02	-10.79
Malta	913.43	Germany	1010.13	-11.65
Poland	944.14	Ireland	1028.04	-33.21
		Third quartile		
Ireland	957.82	Malta	1033.84	-6.83
United Kingdom	986.83	Estonia	1066.48	-13.46
Estonia	988.93	Spain	1122.80	-7.27
Hungary	1052.79	Hungary	1123.01	-6.25
Spain	1132.44	United Kingdom	1140.25	0.86
Croatia	1203.35	Italy	1279.50	76.23
Italy	1219.01	Cyprus	1352.56	-4.27
		Above the third quartile		
Portugal	1241.78	Poland	1413.76	-20.29
Latvia	1274.02	Greece	1445.07	-23.60
Cyprus	1313.45	Lithuania	1479.31	-2.89
Romania	1421.01	Portugal	1557.89	-26.41
Lithuania	1571.67	Latvia	1667.58	6.24
Greece	1781.12	Romania	1931.16	23.25
Bulgaria	2118.68	Bulgaria	2576.77	-17.78

Source: Own elaboration

The countries located in the first quartiles are those that show lower values of energy poverty and, therefore, are in a better situation with regard to this aspect. On the contrary, the countries that appear in the highest quartiles, are associated with greater values of the indicator and energy poverty. The change in the positioning from a higher to a lower quartile indicates a reduction in the level of energy poverty and vice versa.

As can be seen in the table above, the countries with greater energy poverty (in the third quartile) both in 2008 and in 2017 are Bulgaria, Rumania, Latvia, Portugal, Lituania, Greece and Poland. As is well known, the countries of the South and East of Europe are those that suffer to a greater extent energy poverty. In this sense we can see the works of Papada and Kaliampakos (2016) relative to Greece and of Kryk (2019) on Poland and in which a comparison is made with the European average. In the study of Lenz and Grgurev (2017), the level of power poverty of Bulgaria, Croatia and Romania is considered, indicating that the three countries display relative difficulties, for example, the deficient capacity to maintain homes at an adequate temperature, due to the gas and electricity prices. Simoes et al. (2016) make a geographically disaggregated description of the causes of EP, considering the socioeconomic structure of the households. Mazurkiewicz and Lis (2018) make a comparative study between different countries of Central and Eastern Europe, indicating that countries such as Latvia and Lithuania have serious problems of access to energy and, above all the former, in relation to energy efficiency.

With regard to the countries with lesser energy poverty (those of the first quartile), it is possible to appreciate that there are similarities and differences in both the years considered. The countries that appear in the first quartile in both periods are Denmark, the Czech Republic, the Netherlands, Sweden and Slovakia; however, Croatia and Luxembourg would be amongst the most egalitarian only in 2008 and Finland and Austria only in 2017. In the work of Dubois and Meier (2016) it is shown that Denmark, the Netherlands, Sweden, Luxembourg, Finland and Austria have low values of the indicator referring to affordability; the previously mentioned countries along with the Czech Republic and Slovakia have low levels of the indicator that quantifies the impossibility of maintaining the house at a suitable temperature. Croatia, on the other hand, shows low levels of the indicator of problems of energy efficiency and of the index of deprivation of energy services. Similar results are reached in the work of Thomson et al. (2017) in a comparative study of the European countries, in which they consider energy poverty, the health and well-being of the citizens. Maxim et al. (2016) use an indicator composed of different dimensions to quantify energy poverty, with which they obtain results that are in accordance with those obtained in this work. Likewise, a report made in the European Energy Network (2019) related to energy poverty in European countries, in which different primary indicators are employed such as, among others, the delay in the payment of invoices or energy expenditure, presents similar results to those obtained in this study.

The countries that have improved their position (reduced their level of energy poverty) are Austria, Poland, Finland and Malta. The territories whose position has worsened (increased their level of energy poverty) are Ireland, Croatia, Cyprus and Luxembourg. The remaining countries have held their position within the quartiles and have not experienced variation regarding the value of their synthetic indicator.

As can be appreciated in Table 6, in most of the countries energy poverty has diminished, with some exceptions, namely: Denmark and Spain, where energy poverty has risen slightly (the growth rate is less than 1%); in Lituania and Luxembourg the rate has increased moderately (below 8%) and finally, Croatia and Greece where the rate of growth has been very high. The results for the case of Spain concur with those presented in the Report on Energy Poverty in Spain (2018) of the Association of Environmental Sciences (AES), where the evolution is analyzed of some indicators that show an increase of energy poverty between the years considered in this study. The work of Thomson and Bouzarovski (2018) analyzes the evolution of, among others, the delay in the invoice payment indicator for the period 2010-2016, obtaining results that corroborate those shown in this study.

3.3 Energy poverty and economic development

A classification has been made, bearing in mind the level of household income, in order to consider the differences in the index according to the level of development of the countries. Based on this classification, the possible existence of a relational pattern between energy poverty and the level of development of nations has been analyzed. To do this, the median income of households and EPI have been calculated for both years considered, and the countries have been classified into four groups: according to whether household income and EPI are above or below the median. In this way, the table shown below is obtained.

Table 7. Classification of countries according to the level of development and energy poverty

	Household Income <Me	Household Income >Me
EPI>Me	Spain Slovenia Greece Portugal Estonia Latvia Hungary Poland Lithuania Bulgaria Romania	United Kingdom Italy Cyprus
EPI<Me	Slovenia Czech Republic Slovakia	Luxembourg Denmark Sweden Finland Netherlands Austria France Germany Belgium Malta Ireland

Source: Own elaboration

It can be observed that many countries that present a household income above (below) the median have a low EPI (above) the median. This result indicates the existence of an inverse correlation between both variables. On the other hand, countries such as the Czech Republic, Slovakia and Slovenia have low levels of income and EPI, which may be due, at least in part, to the fact that they have a very low level of economic inequality, which leads to a low level of the index. At the opposite end are countries such as Italy, Cyprus or the United Kingdom with high income and EPI values, which may be derived from the high inequality that exists in these territories. In this sense, we can point out that the correlation coefficient between the household income and EPI variables has been calculated, its value being approximately -0.60 for 2008 and -0.55, for 2017.

4. Distributed generation and energy poverty

We now analyze the effect of distributed generation on energy poverty. To that end a new synthetic indicator will be defined in which, in addition to the variables already considered, variables relative to distributed generation will also be taken into account.

4.1 *The effect of renewable distributed generation on energy poverty*

Next, a new energy poverty index will be constructed, which we will denominate EPI_{RDG} including the variables relative to distributed generation renewable resources: *Mini hydro*, *Small hydro*, *Wind* and *Solar*, which have already been defined as ratios in Table 1.

We started the process of determining the EPI_{RDG} for the year 2017[7] by calculating the KMO measure, for which a value of 0.588 is obtained, which is not very high[8]. However, the value (279.28) and the probability (0.000) obtained in Bartlett's sphericity test are adequate. The number of retained factors is 3 and they provide a level of explanation of the initial variables of 77.64%.

Regarding the communalities and the retained factors, the results obtained are those that appear in Table 8.

Table 8. Communalities and rotated retained components

Variables	Communalities	1	2	3
Gini	0.875	0.926	0.104	-0.078
Inadequately warm	0.803	0.867	-0.058	0.220
Poverty	0.743	0.857	0.086	-0.037
Provation	0.913	0.802	-0.099	0.510
Deficiency	0.795	0.705	-0.007	0.545
Delay	0.666	0.669	-0.221	0.412
Solar	0.863	0.024	0.929	0.004
Mini Hydro	0.852	-0.039	0.922	-0.034
Small Hydro	0.723	0.071	0.840	-0.115
Wind	0.652	-0.087	0.787	-0.156
Energy expenditure	0.729	-0.006	-0.200	0.830
GDP	0.702	-0.293	0.004	-0.785

Source: Own elaboration

Note: Extraction method: Principal Component Analysis. Rotation method: Varimax with Kaiser normalization. Rotation converged in 3 iterations

[7] The EPI_{RDD} has been calculated for the year 2017, since no data was available for all the variables considered in 2008.

[8] Usually, 0.6 is taken as the value from which sample adequacy is acceptable.

In Table 8 it can be appreciated that the variables are, in general terms, adequately represented by the retained factors, the best explained being Deprivation and Gini.

As already indicated, three factors have been retained, the first of which is related to the variables *Gini*, *Poverty*, *Inadequately warm*, *Deficiencies*, *Deprivation* and *Delay.* This is a factor that explains the inequality of the distribution of income and the poverty and vulnerability of the households. The percentage of variance explained associated to this factor is 40.67%. The second factor includes the variables that relate to the sources of distributed generation which we have considered in this work: *Solar, Mini Hydro, Small Hydro* and *Wind*. In other words, it is a factor that relates lower energy poverty with higher distributed generation. Its explanatory capacity is 26.47%. Finally, the third factor related to the variables *Energy Expenditure* and *GDP*, is an axis referring to the energy sector and to the level of development of the country (economic dimension) and it shows an explanatory capacity of 10.69%. As can be observed, the variables associated to the first and third factors coincide with those obtained in the analysis without generation.

The factorial scores and the coefficients corresponding to each variable of the synthetic indicator appear in Table 9.

Table 9. Factor scores and coefficients of the EPI_{DG}

	Component scores			Coefficients EPI_{DG}
	1	2	3	
Gini	0.312	0.002	-0.240	10.1170
Poverty	0.282	0.002	-0.200	9.3078
Deficiency	0.109	0.039	0.196	7.5270
Inadequately warm	0.233	-0.018	-0.054	8.3649
Energy expenditure	-0.177	0.024	0.512	-1.0463
GDP	0.076	-0.077	-0.440	-3.6626
Deprivation	0.150	0.001	0.142	7.6319
Delay	0.132	-0.047	0.095	5.0994
Mini Hydro	-0.029	0.307	0.088	7.8670
Small Hydro	-0.025	0.268	0.003	8.1442
Wind	-0.015	0.250	0.005	6.0594
Solar	-0.018	0.312	0.099	8.5982

Source: Own elaboration. Notes: Extraction method: Principal Component Analysis. Rotation method: Varimax with Kaiser normalization. Factor scores

The corresponding EPI_{RDG} is determined from the results shown in Table 9 and the explanatory capacity of each one of the three retained factors. The results for the different countries considered are shown in Table 10.

Table 10. Classification of the countries in quartiles according to their EPI_{DG}

	Country	EPI_{DG}
First quartile	Czech Republic	419.4
	Finland	457.5
	Netherlands	469.7
	Sweden	489.6
	Slovakia	491.5
	Denmark	493.7
	Austria	513.7
Second quartile	Slovenia	526.5
	Germany	536.1
	Luxembourg	537.8
	Belgium	541.5
	France	546.1
	Malta	574.8
	Ireland	602.9
Third quartile	Poland	619.2
	United Kingdom	622.4
	Estonia	625.1
	Hungary	672.5
	Spain	715.7
	Croatia	765.3
	Italy	776.8
Above the third quartile	Portugal	787.2
	Latvia	808.2
	Cyprus	830.2
	Romania	908.8
	Lithuania	1011.4
	Greece	1126.7
	Bulgaria	13488

Source: Own elaboration

It is possible to appreciate, according to the considered variables, that the countries with the highest energy poverty (above the third quartile) are: Portugal, Latvia, Cyprus, Romania, Lithuania, Greece and Bulgaria. Among those that appear with a lower index (first quartile) are: Slovakia, Austria, Czech Republic, Sweden, Finland, the Netherlands and Denmark. The remaining countries are grouped in intermediate situations (second and third quartiles).

There are only two differences in the grouping of the countries depending on whether we consider EPI or EPI_{RDG}: Ireland which moves from the third quartile to the second, and therefore has improved its level of energy poverty and Poland that has experienced the opposite change (from the second quartile to the third) and, therefore, has worsened its level of EP.

Also, if Table 6 containing the results of EPI for 2017 (without distributed generation) and Table 10 are compared, it can be seen the index decreases for all the countries considered, which shows an inverse relationship between energy poverty and distributed generation , , In this sense, distributed generation could be considered as a measure, among others, that helps reduce energy poverty.

4.2. Characterization of the countries according to their sensitivity in the face of changes in the distributed generation on energy poverty

A country may display a high level of EP, yet, however, respond better than another to policies conducive to reduce that level and vice versa. Countries with initially lesser energy poverty may be less receptive to these policies. For that reason, it may be relevant to determine which countries show greater sensitivity in their level of energy poverty to changes in the distributed generation of electricity; to that end, the elasticity of the EPI_{RDG} with regard to the distributed generation will be calculated in the usual way:

$$\varepsilon_{EPI_{RDG},RDG} = -\frac{\Delta EPI_{RDG}}{\Delta DG}\frac{DG}{EPI_{RDG}}$$

where EPI_{RDG} represents the synthetic indicator which allows to quantify energy poverty and RDG the distributed generation based on renewables in each of the considered countries.

The sign of the elasticity will be negative, since an increase in the use of RDG will be followed by a reduction of the EPI_{RDG} and, therefore of energy poverty, as noted in the previous section.

The elasticities for the different countries of the EU have been calculated, obtaining the results that are shown in the following table:

Table 11: Elasticity energy poverty - distributed generation

Country	Elasticity
Belgium	-0.579
Bulgaria	-0.571
Czech Republic	-0.567
Denmark	-0.544
Germany	-0.577
Estonia	-0.582
Ireland	-0.589
Greece	-0.581
Spain	-0.582
France	-0.586
Croatia	-0.572
Italy	-0.569
Cyprus	-0.582
Latvia	-0.576
Lithuania	-0.554
Luxembourg	-0.600
Hungary	-0.566
Malta	-0.589
Netherlands	-0.584
Austria	-0.560
Poland	-0.525
Portugal	-0.577
Romania	-0.564
Slovenia	-0.587
Slovakia	-0.565
Finland	-0.590
Sweden	-0.588
United Kingdom	-0.586

Source: Own elaboration

As can be observed in the previous table, the elasticities of the different countries are relatively similar, with certain differences, although not very high. The countries that show a greater sensitivity (over 75 percent) of their energy poverty in relation to changes in the Distributed Generation are Ireland, France, Luxembourg, Slovenia, Finland and Sweden. In these cases, relatively small increases in RDG will be followed by reductions, relatively high in the EP. On the other hand, the least sensitive (below 25 percent) countries are Denmark, Lithuania, Hungary, Austria, Poland, Romania and Slovakia. Relatively small variations in RDG, will be followed by small changes in EP.

We have created a graphical representation on cartesian axes, so that in the horizontal axis we have considered the value of the synthetic indicator and in the vertical, the measure of sensitivity (elasticity energy poverty - distributed generation) of the country. To facilitate the interpretation the axes have been moved, taking as starting point the average of the sensitivity and the EPI_{RDG} of the considered countries. Therefore, we are able to establish the following characterization:

Group I: made up of those countries that show a low value of EPI_{RDG} (below average), but whose sensitivity to changes in the RDG is high. In the figure, they are those countries that appear in the left superior quadrant. They are nations well positioned regarding energy poverty and in addition they can reduce it further by means of a greater consumption of RDG. The countries in this quadrant are: Luxembourg, Malta, Finland, Sweden, Ireland, France, Belgium, Germany, the Netherlands and Slovenia. If they introduce policies conducive to increasing the use of RDG, these countries would see their level of energy poverty relatively reduced to a greater extent.

Group II: made up of those countries with EPI_{RDG} that surpasses the mean value of the distribution (high energy poverty) and high sensitivity to changes in the RDG. These are countries that would be able to reduce their EP if they increased their consumption of energy originating from RDG. This corresponds to the upper right quadrant of the figure, in which it is possible to appreciate that the countries in these conditions are Spain, United Kingdom, Greece, Estonia and Cyprus. The EP level of these countries, although high, would benefit from a policy of an increase in the use of RDG.

Group III: the nations that form this group have a high level of energy poverty and low sensitivity to modifications in the consumption of RDG. This group is located in the figure in the lower right quadrant. These countries are badly positioned since they display a high level of EP and they would not be very influenced by a change in the volume of RDG. The countries that make up this group are Bulgaria, Rumania, Lithuania, Italy, Croatia, Portugal, Latvia and Hungary. The policies of an increase in the use of RDG would be less effective in relative terms for this group.

Group IV: made up of those nations with low EP and sensitivity. They occupy the lower left quadrant. Countries in this group are Austria, Slovakia, Czech Republic, Denmark and Germany, countries in a better position regarding their level of EP, but relatively less sensitive to policies of an increase in the use of RDG.

5. Results and discussion

This study has studied the energy poverty for the 28 countries of the European Union through the construction of an Energy Poverty Index (EPI) in the years 2008 and 2017. In addition, the effect of distributed generation renewable resources (RDG) on energy poverty has been analyzed.

The obtained results show that Bulgaria, Rumania, Greece, Latvia and Lithuania are among the countries that display the highest EPI. The countries with the lowest EPI are: Denmark, Sweden, Finland, the Netherlands and Slovakia, among others.

When comparing the values of EPI in both of the years considered it has been obtained that in most nations EPI has diminished, with the exceptions of Denmark, Spain, Croatia, Greece, Lithuania and Luxembourg, in which it has increased, to a greater or lesser extent. That reduction of EPI seems to show the result of several EU policies aimed at reducing energy poverty (Dobbins et al. 2015, Pye et al. 2017) as: (i) Financial interventions for ensuring energy affordability in the short term of vulnerable consumers as social welfare payments, direct payments to specific groups to assist with energy bills or social tariffs; (ii) Energy efficiency programs targeting improvements to the efficiency of building stock, or energy using appliances (Lakatos and Arsenopoulos 2019 provides an overview of the existing financial instruments and successful schemes focused on facilitating the implementation of energy efficiency-related measures); (iii) Educational programs about how consumers are using energy and how energy use can be more efficient through behavior change or external modifications, particularly building retrofits; (iv) Development of smart meters to give the consumers the opportunity to better manage their consumption and also help energy companies identify vulnerable consumers; (v) Information provision to consumer rights and more transparent billing to raise awareness and to improve understanding of market tariffs and energy saving measures; and (vi) Disconnection safeguards to protect vulnerable consumers (e.g. prohibit disconnection). Recently, Doukas and Marinakis (2020) present a Special Issue aims to contribute to the to the design of effective policies and innovative energy poverty schemes for energy efficiency, among others.

Regarding the effect of the deployment of RDG on energy poverty, results indicate that RDG reduces energy poverty in all the EU countries.

In this sense, Allan, et al. (2015) point out that the increased penetration of distributed generation in the UK electricity system could contribute towards lower cost energy supply than that associated with conventional centralized plants, as DG increases savings relating to reduced system transmission and distribution costs.

However, despite their benefits against energy poverty, RDG and Minigeneration energy technologies have to overcome a range of economic, socio-cultural, technical, institutional and environmental barriers to their future dissemination. In fact, Balcombe et al. (2013), Damsgaard et al. (2015) and Yaqoot et al. (2016) point out that the financial barriers (high investment and maintenance costs, poor purchasing power and other spending priorities, lack of access to credit or loss of investment money by moving home) and social barriers (lack of information or awareness) or technological barriers (lack of system performance or reliability) are the most critical barriers to increase the deployment of decentralized renewable energy systems.

With respect to the financial barriers, in order to overcome them, financial incentives such as soft loans or capital subsidies to users are recommended. In that sense, many EU countries have adopted support schemes to encourage electricity generated from renewable sources RES-E (see Del Rio and Mir-Artigues 2014 for a review of support instruments), as feed-in tariffs. Focusing on Germany, Norway and the United Kingdom, Inderberg et al. (2018) explored the major factors that influence private households using photovoltaics for micro-generation and found that a generous and stable support scheme emerged as a major factor in promoting prosuming in national electricity systems, although Norway's low electricity prices work in the opposite direction.

Balcombe et al. (2013) found that although feed-in tariffs have increased the uptake of microgeneration energy technologies in UK, policies do not sufficiently address the most significant barrier which is capital costs. However, the rise of RDG plants increases the support costs, making it an unsustainable long-term policy. For this reason, some of the EU regulators are reducing or stopping this support to RDG. Candas et al. (2019) show that abolishing the feed-in tariff support is possible without stopping the photovoltaic deployment, but only by promoting higher levels of overall self-consumption (i.e. an improvement of the self-consumption between 30% - 40% appears to be crucial for the case of Germany). Some additional support schemes could be introduced in order to stimulate self-consumption, such as the promotion of the installation of microgeneration units per household through rebates or encouragement of conscious load shifting via variable electricity retail prices or smart metering systems. Moreover, further reductions in technology costs may help to reduce the need for support, as Inderberg et al. (2018) highlighted.

Kyprianou et al. (2019) provide an overview of selected policies for the promotion of renewable technologies in households in some EU countries (Cyprus, Spain, Portugal, Bulgaria and Lithuania), focusing on measures for energy poverty alleviation. They indicate that although the general trend is one of increasingly available budgets, maximum grants and capacities allowed for RES-E installations, there are a lack of measures dedicated to promote the integration of RDG in vulnerable households. For example, Cyprus and Spain indirectly promote renewable technologies by means of higher subsidized amounts to vulnerable consumers (assuming they are able to provide the remainder of the investment). In Bulgaria, there are no additional benefits towards low-income households to the adoption of microgeneration renewable energy technologies. Instead, Portuguese low-income households receive direct benefits through programmes promoting improvements in vulnerable households and Lithuania offers low interest (soft) loans to households and a 100% subsidy for low-income families.

Regarding the social barriers, public acceptance, the participation of local communities and awareness of RDG generation have become important issues. For example, Balcombe et al. (2013) pointed out that one of the barriers found is that related with neighborhood disapproval and annoyance as small renewable installations would not be pleasing on the eye and solar or wind farms next to a village could harm rural tourism. Sonnberger and Ruddat (2017) tested the local acceptance of wind farms (acceptance of wind farms situated 500 m from the respondents' homes) in Germany through a survey. For the case of Italy, the analysis carried out by Carrosio and Scotti (2019) suggested that deployment of wind farms is influenced by the way in which territorial context is destabilized by the perturbations of energy landscape.

In this line, Schumacher et al. (2019), by conducting an online survey for German, French and Swiss inhabitants, showed that public acceptance depends on the renewable technology, the dimension of social acceptance (socio-political dimension versus local and community) and previous experience with RES technologies.

It should be noted that the empirical research has been carried out at a national level, but research at a local level could shed more light on the advantages of the RDG to meet the needs of communities living in rural and remote areas. The International Energy Agency (2017) pointed out that the decentralized option will be the most cost-effective for 70% of the population in rural areas in the future. In fact, some researchers (Yadav et al. 2019 and Ulsrud et al. 2018, among others) have shown how decentralised solar technology is a resilient technology that can support energy transformation to socially disadvantaged rural communities. A further study will focus on the effect of the deployment of RDG on energy poverty in rural areas within the EU.Some countries have greater capacity than others to respond to changes in the RDG, that is to say, they show greater sensitivity which allows them, faced with small modifications in the RDG, to respond with a greater reduction of EP. This behavior has been studied by means of the definition of a measure of elasticity between EPI and RDG. The countries with the greatest sensitivity to modifications in RDG (more elasticity) are Ireland, France, Luxembourg, Slovenia, Finland and Sweden.

We have established a classification of the nations according to their EPI and elasticity, dividing them into four groups; the first is constituted by those countries that show a good positioning as a whole, since they not only display lower levels of energy poverty, but also would respond, reducing it even further, to an increase of RDG. This group contains Luxembourg, Sweden, Finland, Germany and the Netherlands, among others. The countries that are in the second group, although they show higher values of EP, would easily respond to a change in the RDG, reducing it; this group includes Spain, Portugal and Greece, among others. The nations that make up the third group are those that are in a worse situation, since besides having high energy poverty, they would respond to a lesser extent to changes in RDG; in this group we can find Bulgaria, Rumania or Italy. Finally, the fourth group is constituted by countries with lower energy poverty, but also with a lower capacity of response to changes in RDG. Among the countries that make up this group are Austria, Denmark and Slovakia.

Those different elasticities indirectly show the divergences in the motivations and barriers that affect the installation of distributed electricity generators from renewable sources among the countries, such as a lack of awareness about the benefits of renewables, personal RDG investment costs, a lack of information to give the consumers the opportunity to better manage their consumption through RDG by using smart meters, among others.

For example, France, one of the countries that has shown a greater sensitivity of their energy poverty in relation to RDG changes have carried out several programs to reduce some of those barriers, such as ACHIEVE (Action in low-income Households to Improve energy efficiency through Visits and Energy diagnosis), ELIH-MED (Energy efficiency in low-income housing in the Mediterranean) or FinSH (Financial and Support Instruments for Fuel Poverty in Social Housing) programs among others.

Moreover, it is highlighted that those countries with high electricity shares of the overall energy consumed in the residential sector can have more scope to benefit from the incorporation of RDG in electricity generation as our empirical application only considers the access of RDG in the electricity generation as a factor related to RDG affecting the energy poverty of EU members. This is the case of Malta or Finland with more than 30% of electricity in the energy consumption mix of the households (Pye et al. 2017).

6. Conclusions

This work is a study of energy poverty for the 28 countries of the European Union in the years 2008 and 2017. In addition, the effect of distributed generation renewable resources (RDG, such as photovoltaic, small hydro or micro wind) on energy poverty has been analyzed.

It has been possible to quantify the level of energy poverty for the 28 countries that currently constitute the EU through the construction of an Energy Poverty Index (EPI). Factorial analysis of principal components has been used for the construction of this index and variables have been considered, grouped in the dimensions referred to as inequality and poverty, material and economic deprivation. The results obtained show that Bulgaria, Rumania, Greece, Latvia and Lithuania are among the countries that display the highest EPI. The countries with the lowest EPI are Denmark, Sweden, Finland, the Netherlands and Slovakia, among others.

When comparing the values of EPI in both of the years considered it has been obtained that in most nations EPI has diminished, with the exceptions of Denmark, Spain, Croatia, Greece, Lithuania and Luxembourg, in which it has increased, to a greater or lesser extent. Moreover, the possible existence of a relational pattern between energy poverty and the level of development of nations has been analyzed. Results indicates the existence of an inverse correlation between income and EPI.

To study the effect of distributed generation renewable resources (RDG) on energy poverty, variables related to RDG has been included in another dimension and recalculating the EPI. The EPI has shown to be reduced in all the countries, which demonstrates the capacity of this new dimension to act as a reducing mechanism of energy poverty.

Some countries have greater capacity than others to respond to changes in the RDG, that is to say, they show greater sensitivity which allows them, faced with small modifications in the DG, to respond with a greater reduction of EP. This behavior has been studied by means of the definition of a measure of elasticity between EPI and RDG. The countries with the greatest sensitivity to modifications in RDG (more elasticity) are Ireland, France, Luxembourg, Slovenia, Finland and Sweden.

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