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Analysis of Energy Poverty in 7 Latin American Countries Using Multidimensional Energy Poverty Index

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Abstract: Energy poverty is a serious problem affecting many people in the world. To address it and alleviate it, the first action is to identify and measure the intensity of the population living in this condition. This paper seeks to generate information regarding the actual state of energy poverty by answering the research question: is it possible to measure the intensity of energy poverty between different Latin American countries with sufficient and equivalent data? To achieve this, the Multidimensional Energy Poverty Index (***MEPI***), proposed by Nussbaumer et al., was used. The results present two levels of lack of access to energy services: Energy Poverty (EP) and Extreme Energy Poverty (EEP). The last one, is a concept introduced by the authors to evaluate energy poverty using ***MEPI***. Results of people living on EP (EEP within parentheses) are as follow: Colombia 29% (18%), Dominican Republic 32% (14%), Guatemala 76% (61%), Haiti 98% (91%), Honduras 72% (59%), Mexico 30% (17%) and Peru 65% (42%). A clear correlation between the Human Development Index (HDI) and ***MEPI*** is displayed, however some countries have relatively high values for the HDI, but do not perform so well in the ***MEPI*** and vice versa. Further investigation is needed.

Keywords: energy access; energy poverty measurement; energy indicators; energy index; multidimensional energy poverty index; Latin America

1. Introduction

Energy is needed to provide cooked food, comfortable temperatures, lighting, drinking water and drainage, essential medical care and basic material for education and communication, while enabling all kinds of devices to be used. Additionally, energy services enable productive activities such as agriculture, trade, manufacturing, industry and mining to occur, and the lack of energy access can contribute to poverty and privations, as well as economic decay [1,2].

The UN Agenda acknowledges the role of energy access in the fulfilment of different Sustainable Development Goals [3], however, due to its complexity and the several aspects that involves, defining energy poverty is not an easy task [4] and there is no agreement on what energy poverty means [5]. Seeking to have a general understanding of the concept, the World Energy Assessment defined energy poverty as the absence of sufficient choice in accessing adequate, affordable, reliable, high-quality, safe, and environmentally benign energy services to support economic and human development [1].

In parallel, the Human Development Index (HDI) is assumed to be related to the energy consumption. HDI is assessed by life expectancy at birth; mean of years of schooling for adults aged 25 years and more, and expected years of schooling for children of school entering age; and the gross national income per capita [6]; living standard is related to energy services.

On one side, the lack of access to reliable energy sources hinders economic growth, particularly in poor economies; and on the other, energy consumption carried out with the current world energy matrix conducts to the emission of large amount of Green House Gases (GHG), which, accumulated in the atmosphere, are the principal cause for the anthropogenic global climate change [7]. To address these two issues, reductions of energy poverty and climate change mitigation must take place in a sustainable way, considering the social, environmental and economic issues.

In recent years, the energy poverty investigation conducted has been primarily focussed on developing countries, where most of the people that are facing these situations inhabit. In this sense, it is important to mention that in 2016 more than one billion persons did not have access to electricity in the world, mainly in Africa and Asia; while in 2017 about 2.8 billion women and men lacked access to clean cooking facilities; and a third of world's population, 2.5 billion people, relied on traditional biomass to food preparation [8]. To evaluate energy poverty in a scientific way may be the basis and the guarantee to formulate and implement public policies to alleviate the problem [9].

Viewed from a different perspective, energy poverty is recognized as a form of energy injustice, which takes place on the final stage of the energy system, where the persons benefit from energy use [10]. In addition, some authors see energy poverty as a problem of social justice, because it implies the deprivation of services needed to satisfy human needs [11].

Energy security and the alleviation of energy poverty are also key factors to overcome several of the development challenges that today´s society is facing, such as poverty reduction, inequality, climate change, food security, health and education [12]. Understanding the variety and distribution of present and future energy needs is a relevant goal especially for governments, with the aim to meet such needs. The academic sector must participate in this task. In this sense, there is two key aspects to achieve energy security: access to energy and energy use [13]. This work focuses on access to energy services.

The energy resources and the ways that they are delivered may be considerably different from one country to other, nevertheless, the services demanded are possibly very similar all over the world [14]. However, the economic imbalance that exist in the world reflects the imbalance in the energy consumption [14]; and the poorest three quarters of the world population consumes less than ten percent of global energy use, highlighting the severe and continuous global energy inequities [15].

The global energy matrix is going through a transition, and the world leaders are facing a disjunctive known as the energy trilemma [15], involving the linked and commonly competing problems: energy security, climate change mitigation and energy poverty. In the trading between the three components of the trilemma, energy poverty often loses, despite that it cannot be easily unravel from the drivers of the other two components [15].

The present study seeks to contribute to generate information regarding the actual state of energy poverty by conducting an evaluation in Latin America. To achieve this, the present work is going to answer the research question: is it possible to measure the intensity of energy poverty between different Latin American countries?

The originality of the investigation lies on four issues: 1) Even if the Multidimensional Energy poverty Index (***MEPI***) is a well-known method, it has not been used for the evaluation of energy poverty in Mexico. 2) This is the first study that shows the state of energy poverty in several countries in Latin America using relatively homogeneous information. 3) In this work, the term Extreme Energy Poverty (EEP) is introduced for the ***MEPI*** evaluation, which enables a distinction for the people facing energy poverty. Public policies should prioritise people on EEP. 4) The followed approach, allows to compare countries with large differences in their socio economic backgrounds.

The analyzed countries have different socio demographic context, and feature distinct economic levels. To acquaint information in this regard, information from the Development Assistance Committee (DAC) list of ODA Recipients was reviewed. The list shows all countries and territories that can receive Official Development Assistance [16].

The seven countries analyzed in this evaluation are the following: Mexico appears as Upper Middle-Income Country, as well as Colombia, Dominican Republic and Peru; Guatemala and Honduras are listed as Lower Middle-Income Countries; and Haiti appears as Least Developed Country [17].

The results obtained in the assessment, can be used as an information source for policy makers to address the problem. The study is presented as follows: Section 2 shows the results from the literature review, in which scientometric techniques were used to choose the methods for the energy poverty evaluation. The data used, as well as a detailed explanation for the followed methodology in the analysis is presented in Section 3. Section 4, Results, shows the outcomes for the energy poverty evaluation for seven countries in Latin America. It is presented a discussion for the key findings in Section 5, and finally, in Section 6 some conclusions are presented.

2. Literature Review

A scientometric study was performed to know the most important papers published in the Web of Science in this topic. Scientometrics is the application of bibliometric techniques to database of reference information, such as the Science Citation Index (SCI) and the Social Science Citation Index (SSCI). It is a well-known technique of Literature Based Discovery that uses mathematic technics and statistic tools to examine the characteristics of scientific research and can be used as a sociological instrument in science [18]. To do the analysis, the first step was a literature search included only the key words energy poverty or fuel poverty, which throw 1203 scientific papers. Published in 1983 and conducted at University of York, the first article explained the energy poverty concept as "the inability to afford adequate warmth at home" [19], although there is a reference to an anonymous paper published in 1981 which cannot be accessed from the Web of Science. The interest on energy poverty is relatively recent, because from 1981 to 1999 only 9 articles were published. With a slight increase each year, 21 studies on energy poverty were performed in 2010. Since 2011, the interest on the subject rise, and 259 studies were published in 2019. The h-index for this set of papers is 63, which indicates that 63 articles has at least 63 citations each.

The topic has been of particular concern in England, where 308 studies have been conducted until March of 2020. United States (154), Spain (89), Australia (88) and Scotland (62) complete the list of top five countries working on energy poverty. In Mexico, the first paper regarding energy poverty was published in 2015, and until 2019 only six studies have been performed, which may indicates that energy poverty is not a subject of special relevance in the country, and states the need to carry out analysis that encompass the Mexican context.

The five Universities that have done the most investigation regarding energy poverty are University of London, University of Manchester, Columbia University, University of Sussex and National University of Singapore, which three are located in England, and one in USA and other in Singapore. In Mexico, Colegio de la Frontera Norte and Colegio de México, are the two main institutions working on energy poverty [11,20], other institutions that have done work in that regard are Instituto Mora, Tecnológico Nacional de México, Universidad Autónoma de Nuevo León and Universidad Nacional Autónoma de México. Whilst in Latin America, Central University of Ecuador recently worked identifying energy poverty in that country [21]. It is important to notice that despite energy poverty affects many people in Latin America, there is not enough research on the topic from the Universities in this region.

As mentioned, the main objective of the present study, is to evaluate the situation of energy poverty that population in Latin America is facing. Indicators and indexes are key elements in order to complete this, and for that reason, after the first approach the words indicator or index was combined with the first search that included the terms energy poverty or fuel poverty. Within these considerations, there are 175 scientific papers published since 2003, strengthen the idea that the study of energy poverty started recently.

More detailed information regarding the literature review can be found in the Appendix A—Scientometric Analysis on Energy Poverty Indicators. The appendix presents the method used for the citation mining; uses of a logistic methodology in order to foresee the evolution tendency of the area; presents the scientometric results; and shows the results of the citation mining in the mentioned articles. Finally, the appendix presents some concluding remarks.

In the Appendix A, the evolution of scientific production in the field of energy poverty is presented in Figure A1; the articles published by country are presented in Table A1; the top 20 authors in the field are presented in Table A2; the research with a least two addresses in different countries from the authors is presented in Table A3; the most prolific organizations are presented in Table A4; the top 10 references on the field are presented in Table A5; the number of papers by document type are presented in Table A6; the most relevant and frequent words are presented in Table A7; the most important two words phrases are presented in Table A8; and the top 10 journals on the field are presented in Table A9. The most relevant information is shown in the next paragraphs.

Until 2014, less than 10 articles were published per year. However, 19 papers were published in 2017, 33 in 2018 and 50 in 2019, indicating too, that there is an increasing interest on the topic. It is important to notice that the one paper published in 2003 addressed the issue from a health perspective, and not from evaluations of access to energy services [22].

Once again, England is the country that has shown most interest on the subject, and 30 of the 175 articles published related to indicators on energy poverty are from institutions there. Other countries that produce papers regarding the topic are Spain, Germany, Greece and China, with 28, 13, 9 and 9 papers produced respectively. The main organizations working on energy poverty indicators are University of Sevilla, University of Manchester, National Technical University of Athens, International Institute for Applied Systems Analysis IIASA and Universidad Politécnica de Madrid. The h-index for this collection is 26.

The 175 publications regarding energy poverty indicators can be categorized in five main groups: article, review, proceedings paper, early access and book chapter, which one of particular interest was the reviews one. In it, there was found 15 documents, where some of them address directly with energy poverty and in some others the topic is approached as a secondary issue. In the latter set, some papers raise the issue from a health perspective and other focusses on access to energy and sustainability. The studies, which analyze the perception of optimal indoor environmental conditions of aged people that live in industrialized countries and its socio-economic consequences [23]; suggest that reducing fuel poverty can play a key role determining health burdens associated with cold weather [24]; establish that housing investment improving thermal comfort in households can lead to health improvements and suggest that affordable warmth can also reduce absences from school or work [25]; present benefits of solar energy utilization, one of which is that solar energy is a viable alternative to approach the energy poverty issue [26]; state that lack of access electricity, one of the main aspects of energy poverty, is linked to poverty and harms human development [27]; and present the energy situation of some African countries where the factors responsible for energy poverty that those countries are facing are also discussed [28].

The reviews that use indicators and indexes to directly address energy poverty, state that energy poverty measurement cannot be operational at global level, because of its multidimensional nature and complexity, and indicate that dimensions and a uniform set of indicators need to be adopted for global comparisons [29]; claim that policies and programs aimed to reduce energy poverty often fail on reaching those affected by the problem and develop an index to assess the relative fuel poverty vulnerability of households [30]; establish the risks of elaborate and report energy poverty statistics in an uncritically way and propose multiple-indicator approaches that take into account the shortcomings of the implemented methods [31]; propose a methodology for refinement fuel poverty indicators that allows a multi-scale mapping of fuel poverty [32]; propose an index that performs the evaluation of energy poverty using various methods [9]; and use the Multidimensional Energy Poverty Index [12]. The last article, appeared in the scientometric analysis as the most cited paper of reviews category regarding directly with energy poverty.

The Multidimensional Energy Poverty Index presents a contemporary methodology, which in general, is well accepted for the research regarding incidence and intensity of energy poverty. It is important to highlight that the ***MEPI*** is not only able to measure how many people are facing energy poverty, but the degree of energy poverty those people suffer. This methodology offers a high degree of repeatability, which is desirable given the approach of this investigation. The authors acknowledge that there is a variety of methods to measure energy poverty, however, this work is not a reviewing of methodologies, and the use of the ***MEPI*** can answer the previously presented research question. Additionally, it is flexible with the information needed, nevertheless the data available for the evaluated countries fits the original approach. For these reasons, the ***MEPI*** was selected to conduct the energy poverty evaluation in Latin America. The results, may provide be a very useful starting point for the creation of public policies to addresses the problem. More information regarding this methodology, can be found in the next section.

3. Materials and Methods

3.1. Data Base

The energy poverty analysis is divided in two sections, on account that there are two sources of information for the selected countries. In the first section, Mexico is evaluated; whilst in the second, Colombia, Dominican Republic, Guatemala, Haiti, Honduras and Peru are assessed. Extracting compatible data from different sources is fundamental to measure the differences in energy poverty between countries. More information regarding the information sources is presented in the next paragraphs.

For the evaluation of energy poverty in Mexico, the information used was obtained from the National Survey of Incomes and Expenditures in Households (Encuesta Nacional de Ingresos y Gastos en los Hogares, ENIGH), carried out for National Institute of Statistics and Geography (Instituto Nacional de Estadística y Geografía, INEGI) in 2016. Database for ENIGH is composed of eleven tables of normalized data that includes information associate to three levels or groups: dwelling, household and household´s members [33].

The design of the sample is probabilistic, so the results can be extensive for the whole population. The design is stratified and by clusters, where the last unit of selection is the dwelling and the observation unit is the home. First, it is built a set of Primary Units of Sampling (PUS) which covers all the national territory. This PUS are made up groups of dwellings with differentiated features for three different areas: High urban; Urban supplement; and Rural. Then, the PUS are stratified in sets of dwellings with similar features. In a parallel way, four socio economics levels are formed. The PUS from the sample was selected by means of a probabilistic sample proportional to the size of the PUS. The survey has a confidence interval of 90% [33].

Analyzed information encompasses 69,169 dwellings in which 257,805 persons reside. Due to the fact that the survey used for the evaluation encompasses socioeconomic data concerning the dwellings and the people who live in them, it is expected that the results can disclose information about the relationship between poverty and energy poverty, which is an important element when addressing the problem, although it is not analyzed in this work.

To evaluate the situation on energy poverty in Latin America among countries that have similar sociocultural backgrounds, can deliver important lessons. To select countries to do it, is not a simple task, and ideally it would be done with all the Latin countries in the American continent. However, the main barrier is the lack of reliable and homogeneous information to carry out the analysis. Fortunately, information published by the Demographic and Health Surveys (DHS) Program was found, which allowed to analyze the energy poverty situation in six additional Latin American countries.

DHS Program is funded by the United States Agency for International Development (USAID), and since 1984 has supplied technical support to more than 300 surveys in more than 90 countries, cooperating on global understanding regarding health and demographic trends in developing countries [34].

To collect homogeneous and comparable data across countries, DHS Program have been developed standard model questionnaires, along with a written description with the reasons for including certain questions or sections. The surveys are nationally representative population-based surveys with relatively large sample sizes; there are three questionnaires: for the Household; a Women's questionnaire; and Men's questionnaire [34].

Due to the USAID politics implications, several Latin American countries did not allow or only allowed partially the realization of surveys, and for this reason, only six countries were selected for the analysis, mainly for the most recent year of published information.

Selected countries are Colombia, Dominican Republic, Guatemala, Haiti, Honduras and Peru. Information regarding year of the survey, number of dwellings in the sample (in parenthesis, number of dwellings evaluated after data filtering) and information availability is shown in Table 1. Even though the survey applied to the six countries was virtually the same, in some of them, not all the questions were answered.

Table 1. Information of the countries selected for the analysis.

Country	Year	Data	Availability
Colombia	2015	44,164 (44,164)	Partial
Dominican Republic	2013	11,464 (10,851)	Partial
Guatemala	2014–15	21,383 (21,262)	Complete
Haiti	2017–18	13,405 (13,202)	Complete
Honduras	2011-12	21,362 (20,794)	Partial
Peru	2014	27,218 (25,915)	Complete

For this reason, the variables and the weights considered on the methodology had to be adjusted for Colombia, Honduras and Dominican Republic, where the information was not complete. For Colombia, it was assumed that if the fuel used for cooking was not clean, it was an indication from the non-existing adequate conditions for the activity in the dwelling. Regarding Honduras, it is not possible to know from the survey if people in the dwellings have access to electricity. Although the question is in the file, the space for the answer is empty for all of the dwellings. For this case, this variable was not taken into account in the evaluation, and the weights for the other variables remained the same. This has the aim of replicability for the countries evaluated, both in this assessment and in the work that Nussbaumer et al. performed. A similar consideration was followed for the evaluation of Dominican Republic, where the variables that are unknown are: accessibility to land line telephone or cellular phone in the dwelling.

Thus, the results do not represent a complete comparison and are displayed as an illustrative model that delivers meaningful information regarding energy poverty situation that certain countries are facing. An equivalence table of variables for both of the databases used in the analysis are shown in Table 2.

Table 2. Variable equivalence for the databases used in the evaluation.

Survey	Variable	Type of Cooking Fuel	Food Cooked on Stove or Open Fire	Has Access to Electricity	Has a Fridge	Has a Radio or Television	Has a Phone Land Line or a Mobile Phone
ENIGH	Name	combustible	estufa_chi	disp_elect	num_refri	num_radio, num_tva, num_tvd	telefono, celular
	Description	More used fuel to prepare or heat food in the dwelling	Presence of chimney to evict smoke when cooking	Source of electricity in the dwelling	Number of refrigerators on the household	Number of radios on the household, Number of analogue televisions on the household, Number of digital televisions on the household	Telephone line on the household, Mobil telephone on the household
DHS	Name	HV226	HV239, HV240	HV206	HV209	HV207, HV208	HV221, HV243A
	Description	Type of cooking fuel	Food cooked on stove or open fire, Household has a chimney hood or neither	Whether the household has electricity	Whether the household has a refrigerator	Whether the household has a radio, Whether the household has a television	Whether the household has a telephone, Whether the household has a mobile phone

However, it is important to present the analysis because it shows a timely energy poverty evaluation for these countries during the decade from 2011 to 2020. Besides, it is considered that the access to energy services do not change significantly in a period of six years. As Table 3 shows the HDI has a small change between the year of the survey and its value for the year 2018.

Table 3. Human Development Index (HDI) for the evaluated countries, both for the year of the survey and for 2018.

Country	Year of the Survey	HDI at the Year of the Survey	HDI at 2018
Colombia	2015	0.753	0.761
Dominican Republic	2013	0.712	0.745
Guatemala	2014–2015	0.647	0.651
Haiti	2017–2018	0.503	0.503
Honduras	2011–2012	0.600	0.623
Mexico	2016	0.764	0.767
Peru	2014	0.752	0.759

3.2. Multidimensional Energy Poverty Index

The methodology selected to conduct the energy poverty analysis in Latin America is the one that Nussbaumer et al, 2012 [12] used, which captures a set of energy deprivations that affects people, by means of 5 dimensions and 6 indicators that represent basic energy services. A person is in an energy poverty condition if the combination of deprivations faced exceeds a predefined threshold. Dimensions and variables used in the analysis are shown in Table 4.

Table 4. Dimensions and variables including their weight (in parenthesis) for the Multidimensional Energy Poverty Index (***MEPI***) calculation.

Dimension	Indicator (Weight)	Variable	Deprivation Limit (Poor if …)
Cooking	Modern cooking fuel (0.2)	Type of cooking fuel	Use any fuel besides electricity, LPG, kerosene, natural gas or biogas
	Indoor pollution (0.2)	Food cooked on stove or open fire (no hood/chimney) if using any fuel beside electricity, LPG, natural gas or biogas	True
Lighting	Electricity access (0.2)	Has access to electricity	False
Services provided by means of household appliances	Household appliance ownership (0.13)	Has a fridge	False
Entertainment/education	Entertainment/education appliance ownership (0.13)	Has a radio or television	False
Communication	Telecommunication means (0.13)	Has a phone land line or a mobile phone	False

Data from Nussbaumer et al., 2012 [12].

To carry out the evaluation, the methodology uses the Multidimensional Energy Poverty Index (***MEPI***), which measures energy poverty on $\boldsymbol{d}$ variables across a population of $\boldsymbol{n}$ individuals. The matrix $\boldsymbol{Y = [y_{ij}]}$ represents the states matrix $\boldsymbol{n\ x\ d}$ for $\boldsymbol{i}$ persons through $\boldsymbol{j}$ variables. $\boldsymbol{y_{ij} > 0}$ indicates the state of individual $\boldsymbol{i}$ on variable $\boldsymbol{j}$. Row vector $\boldsymbol{y_i = (y_{i1}, y_{i2}, \ldots, y_{id})}$ represents the states of individual $\boldsymbol{i}$ on the different variables, and column vector $\boldsymbol{y_j = (y_{1j}, y_{2j}, \ldots, y_{nj})}$ shows the states distribution in variable $\boldsymbol{j}$ through the individuals.

A weighting vector $\boldsymbol{w}$ is composed of w_j elements corresponding to the weight that is applied to variable $\boldsymbol{j}$. It is defined by:

$$\sum_{j=1}^{d} W_j = 1 \quad (1)$$

The deprivation threshold z_j on variable $\boldsymbol{j}$ is established; then, all individuals with deprivations on any variable are detected. Subsequently, it is defined the deprivation matrix $\boldsymbol{g} = [g_{ij}]$ where each element g_{ij} is determined by:

$$g_{ij} = \begin{cases} w_j, & y_{ij} < z_j \\ \mathbf{0}, & y_{ij} \geq z_j \end{cases} \quad (2)$$

In ***MEPI*** calculation, elements on the states matrix are non-numerical, and for that reason the threshold is defined as a set of conditions to be fulfilled. Later, a column vector $\boldsymbol{c}$ of deprivations counts is built, where the *ith* entry indicates the sum of deprivations that $\boldsymbol{i}$ person is facing, where:

$$c_i = \sum_{j=1}^{d} g_{ij} \quad (3)$$

The dwellings on energy poverty condition are identified with the definition of a limit $\boldsymbol{k} > 0$, which, is applied to the column vector $\boldsymbol{c}$: a dwelling is considered on energy poverty if its weighted deprivation count c_i exceeds $\boldsymbol{k}$. The censored vector of deprivation count is represented by $\boldsymbol{c(k)}$, which is different to $\boldsymbol{c}$ for it counts zero deprivations to the persons that are not identified on multidimensional energy poverty.

$$c_i(k) = \begin{cases} 0, & c_i \leq k \\ c_i, & c_i > k \end{cases} \quad (4)$$

Headcount ratio $\boldsymbol{H}$ represents the proportion of population considered as energy poor, and is calculated with $\boldsymbol{H = q/n}$, where $\boldsymbol{q}$ is the number of persons on energy poverty ($c_i > k$), and $\boldsymbol{n}$, the total number of the sample. $\boldsymbol{H}$ indicates the *incidence* of multidimensional energy poverty. The average of the censored weighted deprivation count $\boldsymbol{c_i(k)}$ represents the *intensity* of multidimensional energy poverty, and is calculated by:

$$A = \sum_{i=1}^{n} \frac{C_i(k)}{q} \quad (5)$$

MEPI captures information regarding incidence and intensity of energy poverty, and is defined as ***MEPI* = *H* × *A***. When $\boldsymbol{H}$ and $\boldsymbol{A}$ are calculated, the number of persons in each dwelling are included.

It is not a goal from the present evaluation to assess which variables or weights to use for the construction of the ***MEPI***. The selected approach seeks to ensure repeatability across countries. It is true that variables and the weights may be different in Latin America in relation to Africa, more than that, every country and even from one region to another within these countries the variables and the weights could be different; however, this research does not cover this vast issue.

4. Results

To assess energy poverty in Latin America ***MEPI*** methodology was used. First, an evaluation for Mexico was conducted using information from the ENIGH survey, carried out for INEGI in 2016. Then, using information published by the DHS Program, Colombia, Dominican Republic, Guatemala, Haiti, Honduras and Peru were evaluated.

For Mexico, with a deprivation limit $\boldsymbol{k}$ of 0.3, 10,518 dwellings are facing energy poverty, which corresponds to the 15.2% of the evaluated dwellings, dealing with an average intensity of 0.5. Using values for $\boldsymbol{k}$ of 0.2 and 0.4, the dwellings on energy poverty are 12,046 (17.4%) and 5607 (8.1%) respectively. This information is shown on Table 5.

Table 5. Dwellings facing energy poverty with different deprivation limits.

Dwellings	Population Facing EP	Headcount Ratio H	Intensity of EP A	$MEPI$	Electrification Rate (%)	Modern Cooking Fuel (%)
$k = 0.3$	10518	0.1521	0.4983	0.0758	99.26	83.09
$k = 0.2$	12046	0.1742	0.4681	0.0815	99.26	83.09
$k = 0.4$	5607	0.0811	0.5985	0.0485	99.26	83.09

ENIGH sample includes 69,169 dwellings and a total of 257,805 persons, meaning that in average, there is 3.73 persons per dwelling. Evaluation shows that with a deprivation limit $k = 0.3$, 42,549 people are facing energy poverty (which is equivalent to the 16.5% of the sample), with an intensity of 0.49. Results of people on energy poverty, percentage and intensity are shown in Table 6 with different values for k.

Table 6. People facing energy poverty with different deprivation limits.

Persons	Population Facing EP	Headcount Ratio H	Intensity of EP A	$MEPI$	Electrification Rate (%)	Modern Cooking Fuel (%)
$k = 0.3$	42549	0.1650	0.4870	0.0804	99.39	81.21
$k = 0.2$	46531	0.1805	0.4675	0.0844	99.39	81.21
$k = 0.4$	21311	0.0827	0.5889	0.0487	99.39	81.21

Some studies consider the relation between expenses on energy and total incomes of people in the dwellings as a key element in the analysis of energy poverty [35]. In the present evaluation, it was found that only in 984 dwellings (9.4% of total dwellings on EP) the expenses on energy acquisition exceeds 10% of total incomes. This may be due to the fact that electricity in Mexico is subsidized, as well as that the fuels used for cooking may not have a monetary cost, or in the worsts cases, that the access to basic energy services in dwellings is really limited.

It was also found that there is no income in some dwellings, even if there are expenses on energy, and that in 1226 dwellings facing energy poverty there is no money expenditure on energy acquisition, which suggests that there are families living on such extreme poverty that forces them to prioritize the payments on food, clothing and dwelling, leaving aside energy expenditure, and thus restricting its development.

The methodology proposed by Nussbaumer et al. was also used for the analysis of the other countries. However, in this work people in the evaluated dwellings that cannot access at least one of the basic energy services, are going to be considered on energy poverty (EP), and it is going to be introduced the term extreme energy poverty (EEP), which indicates that the deprivations sum in the evaluated dwellings arrives to the minimum value of 0.3 (the one that Nussbaumer et al. accounted).

Analysis shows that the people in Haiti are facing the worst EP situation of all the evaluated countries, where 97.9% percent of the population lack at least one basic energy service, with an average intensity of 0.57 and a ***MEPI*** of 0.56, as shown in Table 7. Guatemala and Honduras are also dealing with a severe estate of energy deprivations, with an EP percentage of 76.0% and 72.2% and a ***MEPI*** of 0.34 and 0.32 respectively. In Peru, 65.4% of the population has no access to all of the basic energy services defined on previous sections, with a ***MEPI*** of 0.27 and an intensity of 0.41. Colombia and Mexico are facing similar situations of EP where 29.1% and 29.7% of the people evaluated have at least one deprivation respectively, Colombia with an average intensity of 0.40 and a ***MEPI*** of 0.12; and Mexico with an average intensity of 0.34 and a ***MEPI*** 0.10. In the Dominican Republic, 32.0% of the population is living on EP, with an average intensity of 0.30 and a ***MEPI*** of 0.10. Figure 1 shows the share of people facing energy poverty in the selected countries, whilst Figure 2 presents ***MEPI***, both taking into account the two levels of energy poverty.

Table 7. Results of energy poverty (EP) analysis for the evaluated countries.

Country	People on the Sample	People on EP	*H*	*A*	*MEPI*	People on EEP
Colombia	162,459	47,335	0.29	0.4	0.12	29,647
D. Republic	40,297	12,900	0.32	0.3	0.1	5,559
Guatemala	102,280	77,738	0.76	0.45	0.34	62,965
Haiti	59,282	58,051	0.98	0.57	0.56	54,269
Honduras	99,528	71,830	0.72	0.44	0.32	58,370
Mexico	257,805	76,609	0.3	0.34	0.1	42,549
Peru	101,383	66,303	0.65	0.41	0.27	42,421

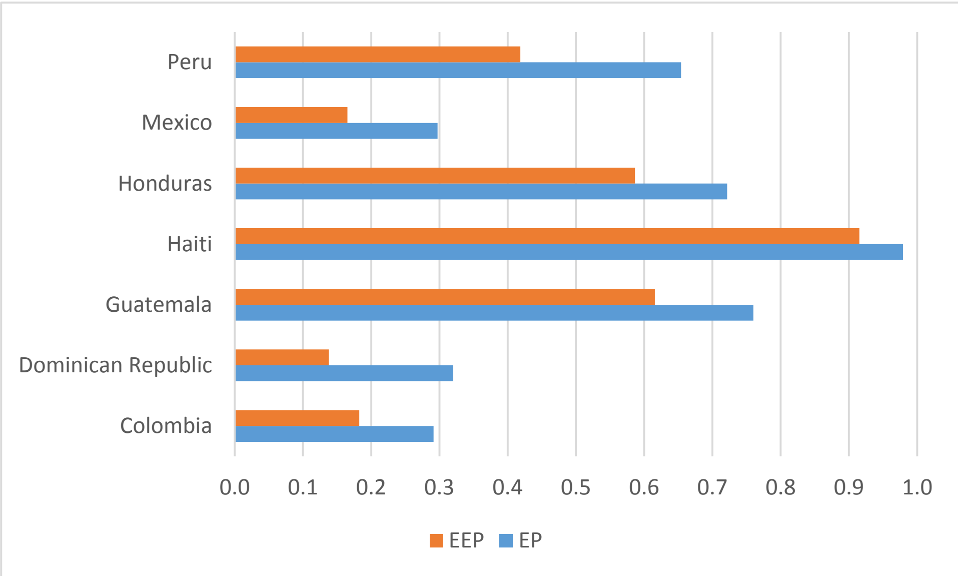

Figure 1. Share of population facing energy poverty for the evaluated countries.

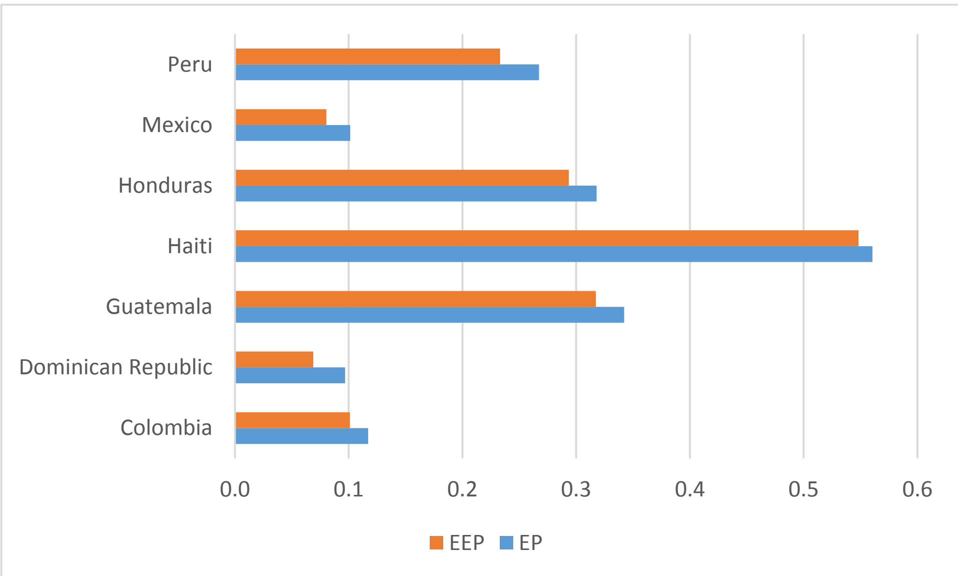

Figure 2. Multidimensional Energy Poverty Index for the evaluated countries.

It is logical to think that there is a nexus between the access to basic energy services and the quality of life that exists in the selected countries. For that matter, the existent relation between the ***MEPI*** and the Human Development Index (HDI) is presented. In this respect, the ***MEPI*** and the HDI for the seven Latin American countries evaluated in this study, indicates a correlation between the access to basic energy services in the dwellings, and the quality of life of the people living within them, as shown in Figure 3. Additionally, the results obtained from the present evaluation, were contrasted with the results that Nussbaumer et al. obtained from the evaluation of several African countries, as shown in Figure 4. In both cases, the ***MEPI*** used is the one that takes the deprivation limit $k = 0.3$. This indicates that the determination coefficient r^2 is equal to 0.83 when only Latin American countries are include; and when the African countries are incorporate to the calculation, r^2 is equal to 0.71.

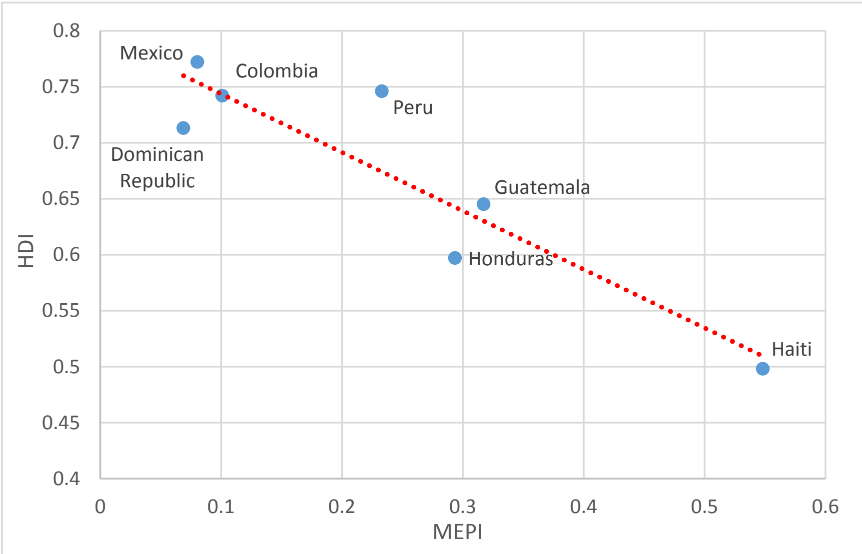

Figure 3. Relation between the ***MEPI*** and the HDI for the Latin American countries. Determination coefficient (r^2) equals to 0.83.

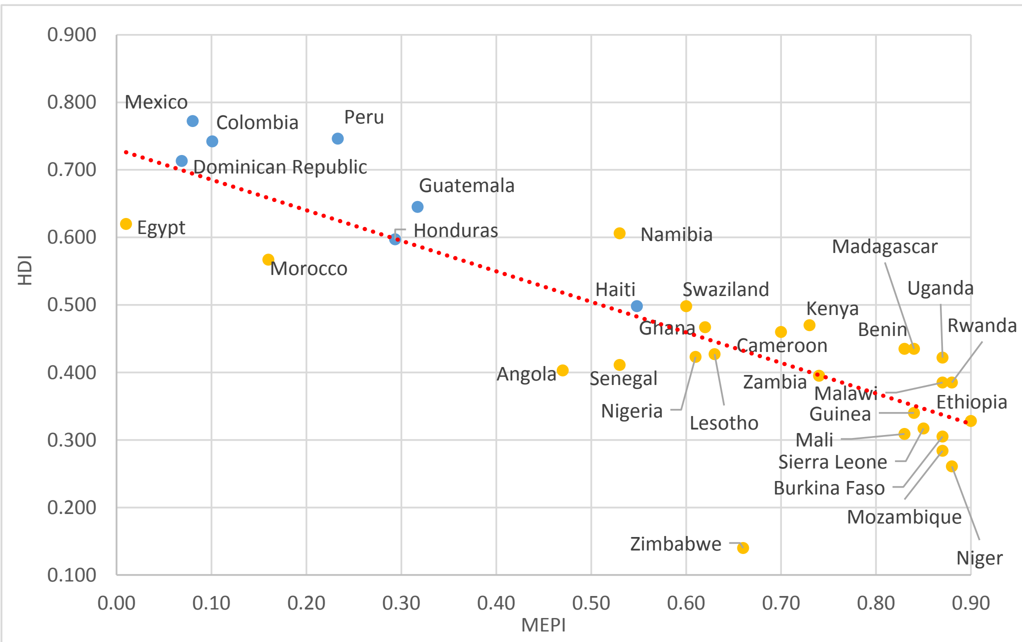

Figure 4. Relation between the ***MEPI*** and the HDI for both the Latin American countries (blue circles) and the African countries that Nussbaumer et al. (2012) analyzed (orange circles). Determination coefficient (r^2) equals to 0.71.

5. Discussion

Energy services are necessary for human development, both at individual and collective levels. The lack of access to reliable, affordable, and sustainable energy sources can difficult individual and social growth. One crucial measure to reduce the number of persons that have energy deprivations is to assess the degree of access to basic energy services that exists in the dwellings. In this sense, the present study contributes to create a general overview regarding energy poverty in Latin America.

The seven Latin American countries evaluated have a severe problem regarding the access to basic energy services; of which Haiti has the worst performance, with Guatemala and Honduras registering serious problems too. In Mexico, 29.7% of the population is living on energy poverty, lacking at least one of the basic energy services; whilst the country has 16.5% of persons facing extreme energy poverty, which means that lack a minimum of 30% of the services. This data, highlights that there is still much to develop as a country; and stress the urgent need to take actions in order to be able to provide adequate, affordable, reliable, high-quality, safe, and environmentally benign energy services for the population.

The sociodemographic context of analyzed countries does not allow us to present a global result, and far less to propose measures that could fit every one of them. However, the relation between ***MEPI*** and HDI suggests that measures with the aim to reduce energy poverty might contribute to economic development and social welfare as well.

One limitation of the study is that the six indicators (and their weights) used to carry out the evaluation regarding access to basic energy services in the dwellings, were selected in a technical and semi arbitrary way, without truly taking into account the perceptions of the people living in the dwellings. Authors recommend that a social approach, all together with a technical evaluation, can provide more valuable information regarding the energy poverty phenomenon in a specific country or region. This with the aim to make a more complete analysis and, thereby, propose measures that might be able to reduce energy deprivations in a sustainable way, paying particular attention to the social thrust.

6. Conclusions

Introduction of the EEP concept using ***MEPI*** methodology is an important contribution to the energy poverty research field. It allows us to see not only the people that cannot have access to basic energy services, but to distinguish the degree of their deprivations. The elaboration of public policies addressing energy poverty should be prioritized to people in this condition.

The approach used allows us to compare countries with large differences in their socio economic backgrounds. This is an important point and one of the reasons not to modify the variables and its weights in this first approach. When keeping the same weights that Nussbaumer et al. used for Africa in the evaluation of seven countries of Latin America, some interesting findings appear: there are two clouds of data when contrasting the ***MEPI*** with the HDI, one where most of the African countries lie but Morocco and Egypt; and other with all but one of the Latin American countries, Haiti. So, since there is not new variables or weights in the assessment, important questions arise. Why is Haiti in the African cloud? Or why Morocco and Egypt show a good performance in the ***MEPI***, despite their HDI is not relatively high? This may indicate that the HDI is an incomplete indicator that needs to be improved? Furthermore, how does the governance maturity and the strength of the energy system in each country affect the access to energy services for the population?

It may appear appealing to evaluate countries that have a smaller range of years from survey to survey, but perhaps the losses in the important findings that arise are bigger than the gains in the precision of the assessment. For example, if Haiti was eliminated from the evaluation, the range of years gets reduced from six to four years, however, it would not be noticed that it appears in the second cloud of countries, those with not so strong energy systems.

A correlation between the ***MEPI*** and the HDI, clearly exists. Nevertheless, from this evaluation the vector's direction is unknown, that is to say, it is impossible to know who affects whom. Additionally, some countries have relatively high values for the HDI, but do not perform so well in the ***MEPI*** and vice versa. So further investigation is needed.

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Appendix A. Scientometric Analysis on Energy Poverty Indicators

Appendix A.1. Introduction

The research on Energy Poverty is a growing field in general, and methodologies to measure it has increased both in quantity and quality of publications. This works analyzes all the papers registered in the Core Collection of Web of Science (Thomson Reuters) that appear under the search: ("Energy poverty" OR "Fuel poverty") AND (index OR indicator). The search was done taking into consideration titles, abstracts and key words of papers published worldwide since 1900 to March 14, 2020.

It is noteworthy that WoS is the one of the most important data bases of scientific information in the world and that there is a bias towards papers written in English. Notwithstanding, it is consider that the sample is significant for the study of the impact and pertinence of this research topic.

Recently, the analysis of citation mining [36,37] has been applied to study the characteristics of Mexican science in two of the most important journals Nature and Science [38] and to depict Ibero-American science [39].

The appendix is organized as follows: first, it is presented the method used for the analysis of the citation mining in Appendix A.2. In Appendix A.3 a logistic method is applied in order to foresee the evolution tendency of the area. In Appendix A.4 it is shown the scientometric results, and in Appendix A.5 the results of the citation mining in the mentioned articles are provided. Finally, the appendix presents some concluding remarks.

Appendix A.2. Methodology

The citation mining methodology is based on the application of a combination of bibliometric techniques and text mining for the analysis of the bibliographic data [36,37]. In this case study, the objective has been defined as the research papers on Energy Poverty indicators written up until March 2020 that are part of Web of Science's Core Collection. This includes: Science Citation Index Expanded (SCI-Expanded), Social Sciences Citation Index (SSCI), Arts & Humanities Citation Index (A&HCI), Conference Proceedings Citation Index- Science (CPCI-S), Conference Proceedings Citation Index- Social Science & Humanities (CPCI-SSH), Book Citation Index– Science (BKCI-S), Book Citation Index– Social Sciences & Humanities (BKCI-SSH) and Emerging Sources Citation Index (ESCI). The used search criteria was to include all the papers that have in its title, abstract or keywords the following phrases and word combinations: ("Energy poverty" OR "Fuel poverty") AND (index OR indicator). The search resulted in 175 papers.

This set was analyzed by the software tool that our research group has developed for this purpose [40], a text mining algorithm. Whilst the bibliometric stage is exclusively done by counting similar data from different fields on such bibliographic records, the text mining stage uses an entropy based algorithm to find the most relevant words in the abstracts of the records. This algorithm is based on the research done by Ortuno et al. (2002) [41]. The distance between two occurrences of a particular word occurring in the text of an abstract was compared to the standard deviation of all words in all abstracts. A normalized standard deviation higher than 1 indicates that the distribution of the word within a particular abstract is not random allowing us to determine which words or strings of words can be considered relevant for that particular text. The reasoning behind this assumption is that the standard deviation is an analogous indicator to entropy [42] and can sometimes play a role as a measure of order (or disorder). The advantage of this particular technique is that it does not require a labor-intensive revision of individual words to extract the keywords from a text but rather provides a ready-made list of the most frequently occurring words and strings of words whose distribution within a text is not random and, therefore, likely to be significant. This technique has been used to analyze topics on highly visible science [39].

The prospective analysis is based on the notion that all biological, social and economic systems within a closed space have a natural cycle of birth, growth and saturation. Hence if a time series has shown in the past a "natural growth", then its cumulative growth in time must have the shape of an "S" curve, also known as the logistic function. It was applied a logistic regression, which is a canonical link function, meaning that parameter estimates under logistic regression are fully efficient, and tests on those parameters are better behaved for small samples. So it was analyzed the scientific production over time of the different sets that were classified in the first place, and applied the interactive logistic fit algorithm to it.

Appendix A.3. Prospective Analysis

By adjusting a time series to a life cycle model it is possible to predict its future tendency, under the premise that the effects of the external environment won't change (Business As Usual). The Figure A1 shows the results of such approximations with its coefficient of determination r^2.

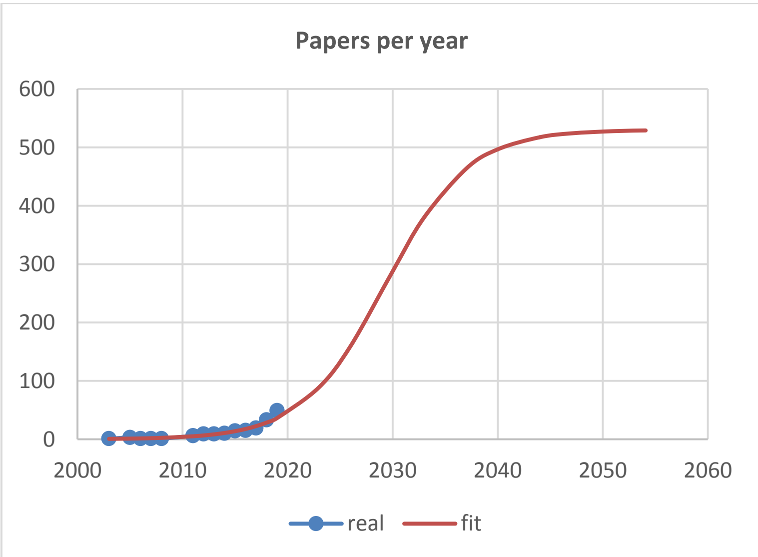

Figure A1. Evolution of scientific production in the field. Saturation circa 2040, with approximately 500 papers per year (r^2=0.8899).

Appendix A.4. Bibliometric Results

The bibliometric analysis was primarily based on the quantity of published articles, its origin and publishing journal. Where origin refers to the institution and home address of the author. In this first section it is presented the results of the bibliometric analysis.

Table A1 shows the countries with the most significant contributions to the area, those with a contribution of at least 1%. It is important to highlight that this means that at least one author of said paper has an address in the country. Table A2 presents the top contributors in the field.

Table A1. Papers published by country (individual contribution greater than 2% of total of papers).

Countries	Papers	%	Countries	Papers	%
ENGLAND	30	17%	SCOTLAND	6	3%
SPAIN	27	15%	CHILE	6	3%
GERMANY	13	7%	BELGIUM	6	3%
GREECE	9	5%	PORTUGAL	5	3%
PEOPLES R CHINA	9	5%	SINGAPORE	5	3%
USA	8	5%	ITALY	5	3%
JAPAN	8	5%	AUSTRALIA	5	3%
NIGERIA	7	4%	SOUTH AFRICA	4	2%
FRANCE	7	4%	ROMANIA	4	2%
AUSTRIA	6	3%	POLAND	4	2%
IRELAND	6	3%	SWEDEN	4	2%

Table A2. Top 20 authors contributors in the field (since the 20th name in the list has 3 papers, it was included all the authors with that amount of publications).

Authors	Number of Papers	Authors	Number of Papers
RUBIO-BELLIDO, C	5	MORRIS, C	3
PAPADA, L	5	THOMSON, H	3
KALIAMPAKOS, D	5	NUSSBAUMER, P	3
BOUZAROVSKI, S	5	LIDDELL, C	3
MARRERO, M	4	MCKENZIE, P	3
ROBINSON, C	4	SOLIS-GUZMAN, J	3
CASTANO-ROSA, R	4	GROH, S	3
PEREZ-FARGALLO, A	4	HERRERO, ST	3
SOVACOOL, BK	4	GOUVEIA, JP	3
PACHAURI, S	4	LINDLEY, S	3
WALKER, R	3	MAXIM, A	3
PULIDO-ARCAS, JA	3		

An interesting component, worth analyzing, is the collaborations among countries in these papers. It was found out that most of the research is done within one country. In Table A3 it is shown those contributions.

Table A3. Research with author's addresses in at least two different countries.

Countries	Number of Articles	Countries	Number of Articles	Countries	Number of Articles
AUSTRALIA-ENGLAND	2	ECUADOR-SPAIN	1	AUSTRIA-SOUTH AFRICA	1
GERMANY-USA	1	BELGIUM-USA	1	AUSTRIA-GERMANY	1
AUSTRIA-GHANA	1	ENGLAND-FRANCE	1	INDONESIA-SINGAPORE	1
IRELAND-SPAIN-USA	1	ENGLAND-NIGERIA-USA	1	BULGARIA-CYPRUS-LITHUANIA-PORTUGAL-SPAIN	1
JAPAN-SWEDEN	1	BELGIUM-ENGLAND	1	PEOPLES R CHINA-USA	1
GERMANY-ROMANIA	1	IRELAND-PEOPLES R CHINA	1	AUSTRALIA-PEOPLES R CHINA-SINGAPORE	1
BELGIUM-KENYA-NETHERLANDS	1	AUSTRALIA-PEOPLES R CHINA	1	ENGLAND-IRELAND	1
AUSTRIA-NIGERIA-SWEDEN	1	BRAZIL-SCOTLAND	1	AUSTRIA-BANGLADESH-GERMANY	1
ENGLAND-SCOTLAND-SWEDEN	1	BELGIUM-SPAIN	1	ENGLAND-WALES	1
AUSTRIA-SWITZERLAND	1	SLOVAKIA-UKRAINE	1	ENGLAND-IRAN-SWEDEN	1

It is clear that the countries that have more collaboration with others are England and Austria. England collaborates in 9 papers and Austria in 6. In this regard, it was considered that another aspect worth revising is the institutions that produce the papers. The Table A4 show the most prolific intuitions on the topic.

Table A4. Most prolific organizations.

Organization	Number of Articles	Organization	Number of Articles
UNIV SEVILLE	8	NATL UNIV SINGAPORE	4
UNIV MANCHESTER	7	BEIJING INST TECHNOL	4
NATL TECH UNIV ATHENS	6	UNIV ULSTER	3
UNIV POLITECN MADRID	5	UNIV ZARAGOZA	3
INT INST APPL SYST ANAL	5	UNIV STRATHCLYDE	3
UNIV LEEDS	4	UNIV IBADAN	3
UNIV BIO BIO	4	NOVA UNIV LISBON	3

In the Table A5 it is presented the papers that have been cited the most by the contributions in this set.

Table A5. Top 10 references on the field.

Paper	Number of References
Boardman B, 1991, FUEL POVERTY COLD HO	64
Moore R, 2012, ENERG POLICY, V49, P19, DOI 10.1016/j.enpol.2012.01.057	52
Bouzarovski S, 2015, ENERGY RES SOC SCI, V10, P31, DOI 10.1016/j.erss.2015.06.007	47
Thomson H, 2013, ENERG POLICY, V52, P563, DOI 10.1016/j.enpol.2012.10.009	40
Hills J., 2012, GETTING MEASURE FUEL	36
Nussbaumer P, 2012, RENEW SUST ENERG REV, V16, P231, DOI 10.1016/j.rser.2011.07.150	33
Boardman B, 2010, FIXING FUEL POVERTY: CHALLENGES AND SOLUTIONS, P1	31
Pachauri S, 2004, WORLD DEV, V32, P2083, DOI 10.1016/j.worlddev.2004.08.005	28
Bouzarovski S, 2012, ENERG POLICY, V49, P76, DOI 10.1016/j.enpol.2012.01.033	27
Liddell C, 2010, ENERG POLICY, V38, P2987, DOI 10.1016/j.enpol.2010.01.037	27

From those 175 papers, the Table A6 shows the type of documents that have been published on the topic. We can see that most of them are research articles, and 15 are reviews. The most cited review on the field is Nussbaumer et al: Measuring energy poverty: Focusing on what matters, with 104 cites.

Table A6. Type of document published.

Type of Document	Number of Papers
Article	143
Review	15
Proceedings Paper	12
Article; Proceedings Paper	2
Article; Early Access	2
Article; Book Chapter	1

Appendix A.5. Text Mining

In this section the results of the analysis done with the text mining of the abstracts of the papers examined are shown. In Table A7 it is presented the relevant words extracted from the abstracts. The top 15 for each country organized by relevance and frequency are presented.

Table A7. Most important (relevant and frequent) words.

HEALTH	HOMES	MOUNTAINOUS
VULNERABILITY	BIOGAS	DEATHS
POOR	SOLAR	FIELD
STUDIES	EU	EXCESS
WINTER	INCLUDED	INDIA
AFFORDABILITY	SUSTAINABILITY	EMISSIONS
SECURITY	TRANSPORT	NIGERIA
IMPACTS	INCIDENCE	FOCUSED
COLD	IMPROVEMENT	PARTICIPANTS
MORTALITY	LOWINCOME	PROJECTS

With the same methodology it was obtained two word phrases, as presented in Table A8.

Table A8. Most important two word phrases.

HOUSEHOLD ENERGY	SOLAR WATER
ENERGY SECURITY	ELECTRICITY ACCESS
EXCESS WINTER	ENERGY SERVICE
SOCIAL HOUSING	OLDER PEOPLE
THERMAL COMFORT	HEALTH IMPACTS
MOUNTAINOUS AREAS	ENERGY RESOURCES
ENERGY VULNERABILITY	TRANSPORT POVERTY
POVERTY VULNERABILITY	SOLAR ENERGY
ENERGY PERFORMANCE	POOR HEALTH
ENERGY DEVELOPMENT	HEALTH OUTCOMES
ELECTRICAL ENERGY	ADEQUATELY WARM
WINTER DEATHS	

With this table the topics that are being addressed emerge and it can be distinguished the lines of research. Finally, it is presented in Table A9 the journals where most of the research is being published. The nature of these journals is an indicator of the type of research work done in the field.

Table A9. Top 10 journals on the field (all the journals with 3 papers were included).

Journal	Number of Papers
ENERGY POLICY	30
ENERGY AND BUILDINGS	18
ENERGY	8
RENEWABLE & SUSTAINABLE ENERGY REVIEWS	7
ENERGY RESEARCH & SOCIAL SCIENCE	7
ENERGY FOR SUSTAINABLE DEVELOPMENT	6
SUSTAINABILITY	6
INDOOR AND BUILT ENVIRONMENT	3
ENERGY ECONOMICS	3
SUSTAINABLE CITIES AND SOCIETY	3
ENERGIES	3
APPLIED ENERGY	3

Appendix A.6. Concluding Remarks

The analysis of all the research papers published on journals registered in the Web of Science, with the search criteria (“Energy poverty” OR “Fuel poverty”) AND (index OR indicator) in its title, abstract or keywords, revealed the behavior of the scientific community in the field. It is possible to show the journals where most of their research is being published; the name of the most prolific authors, as well as the most cited; the collaboration with other counties; the strongest areas in the field; and the evolution of the community as a whole. Also, a logistic algorithm to data series on publications per year was applied, to make a prospective analysis. This analysis combined with the historical information on the institutional milestones provides a better understanding of the influence of different parameters on the productivity of this particular scientific community.

The previous results allow fostering research areas, collaborations and knowledge transfer strategies between different research groups and leaders, in order to enhance the productivity of this important scientific field.

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