Highlights

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- First scientometrics study of energy poverty (EP) focused on theoretical developments
- The field shows 2 independent starting points, instead of one as generally believed
- Energy justice derives from EP literature and has served as a conciliatory perspective towards consensus
- The evolution of EP theory shows a convergent trend towards a consensual concept
- The field is young as there is still wide theoretical and methodological divergence

The evolution of energy poverty theory: a scientometrics approach

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Abstract

Energy poverty describes a condition of energy-related social deprivation of households, usually associated to inadequate access to energy services, to dissatisfaction of basic energy needs, or to excessive payment for energy. Despite the research has grown significantly and substantial progress has been made, there is still theoretical divergence, and many decision-makers continue having an antiquated definition of the phenomenon, far away from recent advances. To aid advancing the field towards theoretical consensus and pushing recent research achievements into policy-making, the present paper maps the evolution of energy poverty theory through a scientometrics approach applied to 1025 records of the specialized literature in the period 1978-2020. This approach accounts for and synthesizes the information flows among and within the theoretical and authoring spaces of the field, which allows disclosing major themes and trends. The field shows two independent start points: energy poverty with focus on access and basic needs, and fuel poverty (targeting developing and European countries, respectively). The two conceptions remained mostly separated until 2010. Afterwards, their relationships became closer, hence they started influencing each other. More recently, energy justice has gained relevance in the field, leading to broader insights and serving as a conciliatory perspective. Furthermore, there are several central author clusters, which have dominated over the field, mainly focused on European thought, even though with a broader perspective. The

evolution of energy poverty theory shows a convergent trend towards a consensual concept. Yet, the field is far from reaching consensus as many works that explore new paths of theoretical and methodological development are added every year . If the field wants to become more globally pertinent, authors should increase collaboration outside their main clusters, and under-represented countries should increase their participation. The history of the field has been very exciting so far and it will become even more so.

Keywords: Energy Poverty, Energy vulnerability, Fuel poverty, Energy justice, Scientometrics, Network Analysis

1. Introduction

The phenomenon of energy poverty describes a condition of energy-related social deprivation of households. It could be understood as the "inability to realize essential capabilities as a direct or indirect result of insufficient access to affordable, reliable and safe energy services, taking into account available reasonable alternative means of realising these capabilities" [1] or the "inability to attain a socially and materially necessitated level of domestic energy services" [2]. This phenomenon is most commonly associated to the lack of access to modern energy flows such as electricity, to the dissatisfaction of basic energy needs, or to the excessive payment for energy services [3].

Nowadays, it is recognized as one of the greatest challenges that both developing and developed states will face in the coming decades [4, 5] considering the significant effect of energy use on human well-being, economic growth, climate change, and sustainable development [6, 7]. Therefore, a growing number of worldwide efforts and dedicated institutions have emerged to fight against this phenomenon such as the EU Energy Poverty Observatory and the UN Sustainable Development Goals [8, 9]. However, these efforts are hindered by the lack of theoretical and methodological consensus [10, 11, 12].

Two of the major challenges in the field to reach theoretical consensus are: 1) The variety of forms that energy poverty could take depending on the context; and 2) The multidimensional nature of this phenomenon's causes and consequences, which are also context-dependant [13]. For instance, in developed countries, this problem is mainly represented by affordability issues, excess winter and summer mortality, a poor household technological base and detriment to public participation; while, in developing countries, the main focus is on modern energy services supply issues, inhumane living

conditions, limited economic opportunities and respiratory problems due to indoor pollution [5, 14].

Despite the energy poverty research field has grown significantly, almost exponentially in the last decade[15, 16], and significant advances to the original conceptualization of the phenomenon have been made, there is still significant theoretical and methodological divergence in the literature. Moreover, many politicians and policy-makers (and some researchers) still have an antiquated and oversimplified definition of the phenomenon, far away from recent advances. For example, those that consider either electricity access or affordable thermal comfort during winter as the unique determining factor of energy poverty [17, 18]. In addition, the literature is mainly focused in countries at the extreme of the development spectrum, leaving middle-income countries less represented [19].

To aid advancing the field towards theoretical consensus and pushing recent research achievements into policy-making, the present paper maps the evolution of research on energy poverty and related concepts through a scientometrics approach applied to specialized literature since the 1970s. This approach allows identifying existing theoretical perspectives, understanding coincidences and contrasts among them, and disclosing major influences and trends in the field.

This study differs from other scientometrics & bibliometric analyses in the literature because it focuses on disclosing the theoretical and methodological development in the field through accounting for and synthesizing the information flows within the literature. Therefore, it does not include the traditional description of the internal (e.g., keywords clusters) and external (e.g., institutions and journal information) bibliometric characteristics of the database as most studies of this kind, but rather it builds from the different characteristics and citation network metrics towards defining the evolution of the theoretical paths throughout the field's history. In addition, the database of the study also differs from that of other studies because it was built from several bibliographic databases, hence it includes grey and white literature, which allows capturing most of the theoretical developments on energy poverty (see Subsection 2.1 for a detailed description of the database).

The oldest bibliometric study in the literature was published by *Li et al* [20] in 2015, who performed a bibliometric analysis of 269 documents with the search keywords of fuel/energy poor and fuel/energy poverty from Web of Science (WoS) in the period 1981 and 2013. They concluded that the field was interdisciplinary and mainly focused on developed countries. In addition,

they found the most influential publications and authors, and identified five hot research objectives from keywords' frequencies, namely fuel access, energy efficiency, physical health, electrification and income poverty. In the same vein, *Urquiza et al* [19] analyzed 120 WoS publications to identify the main keywords related to the published works either focused on energy poverty from the affordability perspective or the access perspective (see Section 3.2). They found, for example, that the affordability perspective was mainly related to keywords such as "fuel", "heating", "poverty", and "housing"; while the access perspective was related to "modern", "solar", "lighting" and "rural". Furthermore, *Brown et al* [21] applied a term co-occurrence analysis of 270 WoS publications to pinpoint the main factors of the energy burden that US household experience. They identified that high energy burden overlaps with low income, unfavorable weather conditions, inefficient end-use devices and other socioeconomic demographics.

More recently, three scientometrics studies of the field were published in 2021. *Ulucak et al* [22] perform an bibliometric analysis on 521 WoS documents with the search keywords of fuel/energy poverty, energy deprivation and fuel/energy precariousness in the period 2000-2021 . They identified several clusters of authors, keywords, institutions, bibliographic coupling etc., though they described them superficially without deepening into the theoretical implications of the analysis. *Xiao et al* [16] pursued mapping the trends in energy poverty research in the period 1999-2019 by the analysis of 1026 WoS documents with the search keywords of fuel/energy poor and fuel/energy poverty. Their study confirmed the interdisciplinary nature of the research field. Notably, they found that keywords in the field suffered processes of creation, integration, expansion and extinction, reflecting the transition of research scope in the literature. for example, essential keywords of "thermal comfort" and "bioenergy" in the period 1999-2010 disappeared, while "renewable energy" and "energy efficiency" gained relevance in 2016-2019. Moreover, they identified six focus clusters with 45 representative papers: Energy poverty definition, Evaluation methods, Coping policies, Energy justice, Technological strategies and Carbon emission effect. Finally, *Primc et al* [15] performed a bibliometric analysis of 670 documents with the search keywords of fuel/energy poverty from the Scopus database in the period 2004-2019. They aimed at providing a quantitative differentiation of the fuel poverty and energy poverty concepts and identifying overall patterns and emerging topics in the literature. They identified form a keywords co-occurrence analysis five focus clusters: Social aspects of energy transition,

Health & demographics, Energy policy, Emissions and Energy efficiency & building stock. In addition, They discussed knowledge gaps and future research trends in the areas of energy transition implications, technological solutions, policy development and methodological approaches. Regarding the conflict between fuel poverty and energy poverty, they called for the merging both concepts into a holistic definition.

2. Methods

This section describes the bibliographic database, the construction of the citation network (Subsection 2.1), and the scientometrics methodologies applied to energy poverty literature (Subsection 2.2).

2.1. Bibliographic database

Bibliographic data was obtained from the Energy Vulnerability Bibliographic Database of the School of Government and Public Transformation at Tecnológico de Monterrey (forthcoming), which was built over the course of six years through a systematic literature review approach (SLR). This SLR searched for bibliographic records that contain the terms *energy poverty*, *energy vulnerability*, *energy deprivation*, *energy justice*, among others, from Google Scholar, Web of Science and the publication database of the EU Energy Poverty Observatory. The combination of databases allows the inclusion of grey literature records that are overlooked by conventional bibliographic databases such as reports and white papers ¹. The latter is particularly relevant for the energy poverty field because, as it is primarily a policy-focused field [15], there are many documents of this kind that effectively contribute to theory and methodological approaches ².

The initial database was refined to discard records from another field, repeated entries and previous versions & preprints, for example, records that included *energy deprivation* in nutrition science were discarded. Further processing included the homogenization of authors, correction of document types and deletion of reviews of other documents in the database. Furthermore,

¹Several works have pointed out the disadvantages of using only one bibliographic search engine for scientometrics analysis, which depend on the type of the studied research field studied, see , e.g., [23, 24, 25]

²For example, the output from the WoS search overlooked seminal works, for example, Boardman’s [26, 27], Hill’s [28, 29] and Moore’s [30]

as the database focuses on theoretical and methodological developments, records that only centered on technological solutions (e.g., the design of renewable energy systems or thermal insulation materials) or did not directly deal with energy poverty in the household (e.g., energy justice studies with macroeconomic focus) were discarded as well. In addition, each record was given a relevance classification (High, Medium, Low and Null) during the SLR according to its theoretical and/or methodological contribution. For example, a high-relevance record is a document of significant quality that 1) proposes a concept, metrics or analysis framework; 2) performs a detailed critical or comparative analysis of methodologies or concepts; and/or 3) focuses on previously overlooked locations or populations.

The version of the database we used consists of 1025 records. It includes journal papers (64.1%), reports (11.32%), books and book chapters (8.69%), dissertations (4.78%) and unpublished works (11.11%). The earliest publication is from the year 1978 and the latest from 2021 (published before December 2020). It includes other attributes of each record, beside the conventional bibliographic information (such as keywords, abstract, title, authors, etc.), for example, energy poverty-related concept, metric type and country under study.

The database did not include citation connections among records, which is a disadvantage of combining search engines. Therefore, we built a citation network, i.e., directed graph that relates articles with other articles that cite them, from scratch. To do so, we performed text search within the reference lists of most records in the database (those with available PDFs or website versions) and a manual search for records whose PDFs presented problems for text search and for records only physically available (36 records were discarded as their reference lists could not be found). Finally, we confirmed the consistency of citations (e.g., consistency between citer’s year and citee’s year). All tasks were carried out with the software EndNote X8, MS Excel and RStudio.

2.2. *Scientometric Analysis*

Scientometrics is discipline that aims to synthesize the knowledge creation, development and management in the scientific production of any field, through quantitative analysis of bibliographical information as well as other science-related information such as grants, geographic data or research programs [31]. It includes bibliometric statistical analysis of published articles,

authors, dates, keywords, citations, etc. to disclose their role in the development of the field. Moreover, by analysing the citation and co-citation patterns in published works in the database, it unveils pivotal scientific documents and illustrates the links and information flows among them [32]. The combination of these and other analysis (e.g., data visualization analysis) allows finding hints and patterns in the development of any research field.

Our analysis track the citation, co-authorship and thematic evolution of scientific publications on "energy poverty" using tools of network theory analysis and data visualizations techniques to comprehend the seemingly chaotic development of energy poverty research. Particularly, the analysis mainly consists of a citation network (or theoretical space) that establishes thematic modules and their historical distribution, a burst detection histogram that reveals most relevant topics along time, and a bipartite network (or authorship space) that reveals research communities and their publication evolution. All tasks were carried out with the software Tableau (<https://www.tableau.com/>), Sci2tool (<https://sci2.cns.iu.edu/>) [33], and Gephi (<https://gephi.org/>).

Thematic modules from the citation network (or theoretical space)

In order to obtain some insights into the structure of large complex networks it is useful to identify communities of nodes that are more interconnected [34]. In citation networks, such communities may have topics or approaches in common. The partitions on the network are qualified by the so-called modularity of the partition, a scalar value between -1 and 1 that measures the density of links inside communities in comparison to links between communities. We calculated the modularity classes for the theoretical space with the algorithm developed by *Blondel et al* [35] and *Lambiotte et al* [36] in Gephi, resulting in a modularity of 0.340 and 130 communities – see Subsection 3.2 and Figure 2–. In addition, we temporally segmented the theoretical space using the Network Z splitter plugin in Gephi –see Figure 3. This temporal perspective allows displaying which communities developed earlier.

Relevant topics in time from the burst detection histogram

Publications of scholarly papers are events that can be ordered as discrete time series spaced by regular intervals. Using Kleinberg’s burst detection algorithm included in Sci2Tool [37], we can identify sudden increases in the frequency of the words used, in this case, in publication titles – see Figure 4. This algorithm "generates a list of the word bursts in the document stream, ranked according to the burst weight, together with the intervals of

time in which these bursts occurred” [37]. Particularly, we used the default parameters of the algorithm and included a normalization process provided by Sci2Tool that separates text into word tokens.

Research communities with the bipartite network The bipartite network is a network where nodes and connections are indexed according to two partitions [38]. In the case of the theoretical space, nodes were indexed by an authorship partition and a document partition, which derived in a co-authorship network. We estimated the modularity classes of this network in Gephi, resulting in 557 author communities, 11 of which belongs to a central co-authorship component. Finally, the bipartite network was split, separating authors from documents and aligning them according to publication date –see Figure 5, which allows identifying the periods of time where the different communities have contributed to the field.

3. Results and discussion

3.1. Theoretical space

The citation network defines the theoretical space of the field, i.e., the literature that contains the overall knowledge of energy poverty and vulnerability (Table 1).

Table 1: Theoretical space statistics

Item	Value
No. of Authors:	1761
No. of Articles (nodes):	1,025
No. of Citations (edges):	9,068
Avg. No. of Connections (i.e., Degree):	10.085
Network Diameter (i.e., largest path length):	15
Avg. Path length:	3.836

Figure 1 shows the giant component of this space, which includes 899 interconnected nodes (87.71% of the articles) after discarding disconnected single nodes (i.e., records that do not cite or are not cited by other records in the database). As the field is evolving rapidly, many of these disconnected nodes could join the giant component eventually. This giant component describes the information flows between records, which help reveal the theoretical evolution in the field.

Each record in the theoretical space has an average number of connections or degree of 10.085 (Table 1), which includes the average number of

references any record cites (in-degree connections) and the average number of citations it receives (out-degree connections) within the network. The higher the degree, the higher participation of any record in the information flows within the field. Moreover, while all records have in average 3.836 degrees of separation between each other (or average path length), the largest degrees of separation (or Network diameter) between nodes is 15. The path length of any record show its maximum degree of separation to all records in the network. The theoretical space has grown in diameter and average path length in the last decade from 6 and 2.09, respectively in the period 1978-2010, which shows that the publication spree of the 2010's increased the scope and structural divergence of the field. However, the average distance between any high-relevance records is 2.07 and a maximum of 5, which shows that the main theoretical contributions are closer to each other despite the overall divergence in the field.

Clearly, there is a section of the theoretical space that is denser (to the right in Figure 1), where most records are located, This section has a network diameter of 13 and an average path length of 2.5. In addition, there is no clear agglomeration of records by relevance. Instead, high, medium, low and null relevance records are distributed over the entire network.

The figure also shows the citation numbers of each record in the network by the size of the nodes. The densest section of the theoretical space contains most of the documents with the highest out-degree. Among those, the top five most cited records (Table 2) have more than 150 citations and are mostly highly relevant. Notably, none of these records coincides with the top most cited records identified by Li et al [20] in their 2015's review. In addition, four out of the top five most cited records are published in the last decade, which shows the recent boom in the field.

Figure 1: Citation network for the energy poverty data set, color coded according to relevance and citation (out-degree)

Table 2: Top most cited papers

Record	R	C	CC	BC
Boardman, B.(1991). Fuel poverty: from cold homes to affordable warmth [26]	High	271	0.5246	654.2
Boardman, B.(2013). Fixing fuel poverty: challenges and solutions [39]	High	175	0.5226	7584.5
Moore, R.(2012). Definitions of fuel poverty: Implications for policy [40]	High	161	0.3728	1287.0
Bouzarovski, S. and Petrova, S.(2015). A global perspective on domestic energy deprivation: Overcoming the energy poverty–fuel poverty binary [2]	High	160	0.2616	21463.7
Thomson, H. and Snell, C.(2013) Quantifying the prevalence of fuel poverty across the European Union [41]	Medium	152	0.3404	3644.9

Notes: R: Relevance, C: Citation or out-degree, CC: Closeness centrality and BC: Betweenness centrality

Records’ betweenness and closeness centrality metrics help identify the impact of each record on the information flows within the theoretical space.

On the one hand, the theoretical space has an average and maximum betweenness centrality of 432.1 and 29134, respectively, which indicates a positive skewed distribution towards low betweenness centrality values (see Appendix A). Records with high betweenness centrality values (Table 3) are important because they have helped gather and summarize a large quantity of existing information from previous records and have distributed it to the rest of the theoretical space. Therefore, they account for and support the main information flows and knowledge development in the network. Remarkably, only the record of Bouzarovski and Petrova [2] belongs to the top most cited papers and those with highest betweenness centrality. In addition, despite not having the highest betweenness centrality, the most cited papers in Table2 have a value above the average, which indicates that they have had a significant role in the consolidation of information flows and the development of knowledge in the theoretical space.

Table 3: Top documents by betweenness centrality

Record	R	C	CC	BC
Healy, J. D. and Clinch, J. P. (2002). Fuel poverty in Europe: A cross-country analysis using a new composite measurement [42]	High	58	0.4146	29133.8
Ruse, J.-L.(2020). Fuel Poverty and Cold-Related Ill Health [43]	Medium	2	0.2938	28432.8
Chesshire, J. and Lehmann, P. (2015). Understanding Fuel Poverty [44]	Medium	2	0.2289	26959.9
Thomson, H.(2015). Fuel Poverty in the European Union: A Multi-Methods Study [45]	High	2	0.1866	26556.5
Bouzarovski, S. and Petrova, S.(2015). A global perspective on domestic energy deprivation: Overcoming the energy poverty–fuel poverty binary [2]	High	160	0.2616	21463.7

Notes: R: Relevance, C: Citation or out-degree, CC: Closeness centrality and BC: Betweenness centrality

On the other hand, the theoretical space has an average and maximum closeness centrality of 0.3 and ~ 1 , respectively, which indicates a slightly positive skewed distribution (see Appendix A). The higher the closeness centrality value of a record, which implies that the record is directly and indirectly connected to a large number of records in the network, the more important role of the record in building paths for information flows and aiding the dissemination of information across the theoretical space. Counterintuitively, there is a significant number of records with the highest closeness centrality (over 100), see Appendix A. These correspond to records that have built new information paths, though without contributing to the dissemination of information yet (most of them are relatively recent documents from 2019-2020). As the network grows, these new paths they have helped create either continue developing or stall. Among the records with the highest closeness centrality, five with some of the highest betweenness centrality are shown in Table 4. These represent records that have helped build new information paths, which have already shown functionality in the network. Particularly, they have introduced to the network new methodological approaches (e.g.,

big data or multi-sourced data frameworks) or explored relationships to related areas (e.g., health or life satisfaction). Moreover, none of the records with the highest closeness centrality belong to the most cited papers nor the top records by betweenness centrality ³. In fact, the records with highest closeness centrality have lower than average citation and betweenness centrality values. Nevertheless, the most cited papers in Table 2 have a closeness centrality above the average, which indicates that they have also had a significant role in the dissemination of information across the theoretical space.

Table 4: Relevant documents with high closeness centrality

Record	R	C	CC	BC
Karpinska and Smiech (2020). Invisible energy poverty? Analysing housing costs in Central and Eastern Europe [46]	High	40	~ 1	486.9
Oliveras et al (2020). Energy poverty and health: Trends in the European Union before and during the economic crisis, 2007–2016 [47]	Low	24	~ 1	374.2
Spiliotis et al (2020). A multi-sourced data based framework for assisting utilities identify energy poor households: a case-study in Greece [48]	High	39	~ 1	272.1
Hassani et al (2019) Big Data and Energy Poverty Alleviation [49]	High	40	~ 1	166.6
Druica (2019). Energy Poverty and Life Satisfaction: Structural Mechanisms and Their Implications [50]	High	28	~ 1	140.1

Notes: R: Relevance, C: Citation or out-degree, CC: Closeness centrality and BC: Betweenness centrality

³However, remarkably, the top five records by betweenness centrality within the first years of their publication had the highest closeness centrality, which reduced in the following years at the same time that their betweenness centrality grew. The latter implies that when they were published, they helped build new information paths, which subsequently became fundamental for knowledge development in the field.

Figure 2: Citation network color coded according to modularity. Size of nodes is according to out-degree.

3.2. Thematic modules

From the modularity partition of the citation network, we have identified five relevant modularity classes or thematic modules (Figure 2)⁴, which are described below:

The first thematic module, *Traditional Fuel Poverty*, is characterized by documents and studies that are focused on Boardman’s original fuel poverty definition, i.e., “[Fuel poverty] occurs when a household could not have adequate energy services for 10 per cent of its income” due to a combination of high energy prices, low income and energy inefficiency at home [26]. Most

⁴Other modularity classes were obtained by the modularity partition, but they were discarded as non-relevant, either because: 1) they were very small; 2) none of their records has a significant theoretical or methodological contribution; or 3) they consist of a single record not connected to the network.

studies of this module measure energy poverty through affordability and expenditure metrics, such as the Boardman’s 10% rule, Hill’s Low-Income-High-Cost indicator and Moore’s minimum energy expenditure requirement measurement. The main geographical focus is on European countries, though there are few other developed countries under study, e.g., Japan, Australia and the US. This thematic module is best represented by the following (most productive) authors: Brenda Boardman, Bérangère Legendre, John D. Healy, Shinichiro Okushima and Sefa Awaworyi Churchill; and the following most connected (high degree) papers [26], [40], [41], [29] and [51].

The second thematic module, *Energy Poverty in the Developing World*, is characterized by records that are focused on the energy access perspective of energy poverty in the developing world, derives from the literature that deals with energy basic needs, and relates to sustainable development goals and human development. It includes several different definitions of the phenomenon such as the one by Pachauri and co-authors [52], “a lack of access to adequate, reliable, affordable and clean energy carriers and technologies for meeting energy service needs for cooking and those enabled by electricity to support economic and human development” , and the one by Reddy [11], “the absence of sufficient choice in accessing adequate, affordable, reliable, high-quality, safe, and environmentally benign energy services to support economic and human development”. Most studies of this module measure energy poverty through access-related indicators, such as binomial access metrics, the Nussbaumer’s Multidimensional Energy Poverty Indicator, the minimum energy requirements to meet basic needs approach and the World Bank’s Multitier Energy Access Framework. This thematic module is best represented by the following authors: Shonali Pachauri, Benjamin K Sovacool, Morgan D Bazilian, Douglas F Barnes and Patrick Nussbaumer; and the following most connected papers [53], [54], [55], [12] and [56].

The third thematic module, *Energy and Fuel Poverty Merging*, is characterized by records that aim creating consensus between the fuel poverty and energy poverty perspectives of the two first modules. It is best described by Bouzarovski and Petrova’s definition “the inability to attain a socially and materially necessitated level of domestic energy services” [57, 2]. This definition is based on energy services as the basis to relate the living experience of the energy poor in developed and developing countries and leads to a vulnerability approach (i.e., understanding risk factors of falling into energy poverty). There is a wide diversity of measuring approaches for energy poverty and energy vulnerability in this class, standing out spatial and

composite approaches. In addition, the works of this module includes justice, spatial and structural considerations in the discussion of energy poverty. The main geographical focus is on European countries, though the presence of developing and middle-income countries (e.g., Chile, China and Nigeria) is significant. This thematic module is best represented by the following authors: Stefan Bouzarovski (i.e., the most cited author within the network), Sergio Tirado-Herrero, Saska Petrova, Harriet Thomson and Sofia-Natalia Boemi; and the following most connected papers [2], [58], [8], [59] and [60].

The fourth thematic module, *Broad Energy Justice*, discusses the links between energy poverty and energy justice from a broad justice perspective. Also, it includes seminal works of the energy justice field, which were derived from energy poverty theory. This modularity class is mainly connected to the other modules by Day and co-authors’s work “Conceptualising energy use and energy poverty using a capabilities framework” [1], where they define energy poverty as “an inability to realise essential capabilities as a direct or indirect result of insufficient access to affordable, reliable and safe energy services, and taking into account available reasonable alternative means of realising these capabilities”. This work is relevant as it introduces the Nussbaum and Sen’s capabilities framework [61] into energy poverty theory. In addition, the works of this module are mainly theoretical and focus on both developed and developing countries. This thematic module is best represented by the following authors: Kirsten E H Jenkins, Darren McCauley, Benjamin K Sovacool and Gordon Walker; and the following most connected papers [1], [62], [63], [64] and [65].

The fifth thematic module, *Traditional Fuel Poverty Meets Energy Justice*, has significant overlap with the third thematic module regarding the inclusion of justice considerations; though it differs from the latter as it is more related to the traditional fuel poverty definition. The works in this class does not discuss the premise of fuel poverty but tries to improve it so it becomes more justice oriented. For instance, it deals with the links to other vulnerabilities (e.g., health, poverty, etc.) and other factors that are not considered in the traditional theoretical view (e.g., energy services for transport). From this module, the influential Middlemiss and Gillard’s definition [66], “the inability of certain households to acquire the energy services required to live a decent and healthy life”, was derived. The geographical focus is on European and other developed countries, exclusively. This thematic module is best represented by the following authors: Stefan Bouzarovski, Lucie K Middlemiss, Raúl Castaño-Rosa, Philippa Howden-Chapman and Neil

Simcock; and the following most connected papers [39], [67], [66], [68] and [69]. Apparently, based on the thematic core and the most relevant authors of this thematic module, it must have appeared as a transitional module between the first thematic module and the third. However, instead of declining with the consolidation of the third module, it has continued growing and has remained self-contained.

The role of the first module Traditional Fuel Poverty in the development and support of information flows in the theoretical space is significant, compared to other thematic modules, as its records have the largest average citations of 15.1; a large average value of closeness centrality (0.3514), which implies that this module has helped disseminate information across other modules; and an above-average value of betweenness centrality (554.9) that shows its theoretical and methodological contribution to the field. The relationship between the third and fifth module is evident based on their records' network metrics. They have the second and third position in average citations per record (12.5 and 10.9, respectively) and the two largest average betweenness centrality per record (900 and 715.4), which confirms that these modules have been fundamental in the theoretical development of the field. However, the third module Energy and Fuel Poverty Merging has had a limited role in the construction of information paths and knowledge dissemination across the network based on its lowest average closeness centrality per record (0.2801). Finally, the second and fourth thematic modules have had a limited role in the theoretical development, as suggested by their low average betweenness centrality per record of 194.9 and 282.8, respectively. Nonetheless, these modules have particularly contributed to the dissemination of knowledge and construction of information paths across the theoretical space, based on their average closeness centrality per record of 0.3537 and 0.3422, respectively.

3.3. Historic development

Figure 3 shows the distribution of the citation network in Figure 2 in time. The network shows two main independent start points, instead of one as generally believed: one that belongs to the module Energy Poverty in the Developing World and the other to the Traditional Fuel Poverty module. As shown in the figure, the two different conceptions developed mostly separated before 2010. However, from this year on, they started influencing each other, which led to the core works of the Energy and Fuel Poverty Merging and Broad Energy Justice modules. Particularly, the latter module started

Figure 3: Citation network split in temporal intervals along the z axis. Color coded according to modularity. Size of nodes according to out-degree.

gaining relevance in the field, consolidating the concept of energy justice as a conciliatory perspective in the field (notably, this module has almost the same level of connections to every other module).

The parallel development of the two original perspectives is also evident in the temporal word burst detection analysis (Figure 4)⁵ as words concerning the thematic modules Traditional Fuel Poverty and Energy Poverty in the Developing World dominated in the period 1978-2010. For example, the headlines "develop-" (-ing/-ed/-ment), "world", "fuel" and "econom-" (-y/-ic). Meanwhile, in the period 1995-2013, terms related to energy poverty solutions—such as "alleviation", "renewable" and "electrification"—and related to spatial distribution and vulnerable populations—such as "rural", "poor" and "urban"—gained relevance. Two burst periods for the term "fuel" occurred in between 2008-2014 due to a large growth in the number of documents released within the Traditional Fuel Poverty module. Moreover, the use of the term "access" significantly grew after the establishment of the Sustainable Development Goal No. 7 *Ensure access to affordable, reliable, sustainable and modern energy for all* in 2015. Finally, the relevance of the

⁵it shows the most used terms detected in the titles of the publications along the studied period

Figure 4: Word temporal burst detection

justice perspective in the field is also evident.

Even though the field is integrating and seems to be building towards consensus, it is still very divergent, and no leading perspective is evident Figure 3 –also shown by the path length metrics in Subsection 3.1. Just in the last five years, more high-relevance records have been released than in the previous 37 years. In addition, no module is losing presence in the field, even, surprisingly, most modules share the same growth rate in the number of records released in recent years.

3.4. Author communities

The bipartite network reveals 13 central author communities (Figure 5), which have gained dominance over the field. Nine of these communities (with colors dark blue, peach, crimson, yellow, lilac, etc.) are composed by 205 authors (11.6% of total authors), including Stefan Bouzarovski, Lucie

Figure 5: Bipartite temporal network.

K. Middlemiss and Ute Dubois, and have produced 159 documents (15.6% of total records). Most authors of these communities focus on European countries, even though with a more global perspective. Particularly, Stefan Bouzarovski (the most productive and cited author in the network with 41 records and 820 A-type citations, see Table 5) and co-authors have worked towards a theory that could accommodate both developing and developed country contexts, see Subsection 3.2. These communities have contributed the most to the thematic modules of Traditional Fuel Poverty, Energy and Fuel Poverty Merging and Traditional Fuel Poverty Meets Energy Justice. Furthermore, three other central communities (with colors moss green, pale yellow and marigold) are composed by 66 authors, including Benjamin K. Sovacool⁶ and Rosie Day, which have produced 55 documents. The authors in these communities have focused on energy justice theory and its considerations to energy poverty. Therefore, they constitute the central group of authors of the Broad Energy Justice module with about a third of the documents in the module. In addition, the case of the orange central community with 9 documents and 28 authors, led by Morgan D. Bazilian, is peculiar as these authors have proximity with the rest of central communities despite having mostly studied developing countries. Their works exclusively belong to the Energy Poverty in the Developing World module, though with a clear influence of the fuel-poverty-related central communities.

Table 5: Top five most cited authors

Author	A-type / All citations	NR	AC	ACC	ABC
Bouzarovski, S.	820 / 1067	41	26.0	0.3592	1668.08
Boardman, B.	540 / 551	8	68.9	0.3702	1107.90
Thomson, H.	422 / 490	22	22.3	0.2947	2474.16
Snell, C.	396 / 458	13	35.2	0.2694	1856.60
Liddell, C.	358 / 382	11	34.7	0.2883	1210.76

Notes: NR: No. of authored records, AC: Average citations per record, ACC: Average closeness centrality per record and ABC: Average betweenness centrality per record.

⁶Benjamin K. Sovacool and Christine Liddell are the only two coincidences with the most relevant authors identified by Li et al [20] in their 2015’s review, which shows the fact that the field is young and develops at a fast pace.

Remarkably, despite Brenda Boardman is considered as the founder of the field and is one of the most influential authors (with 540 type-A citations out of 551 total citations, only surpassed by Stefan Bouzarovski, see Table 5), she does not belong to any central communities as she has mostly worked alone, evenly contributing to the modules Traditional Fuel Poverty and Traditional Fuel Poverty Meets Energy Justice. These two modules have few other relevant related communities. For example, the lime green and turquoise communities, respectively led by Richard Moore and Bérangère Legendre and composed by 13 authors / 7 works, and 7 authors/ 9 works. While the first deals with the evaluation and design of fuel poverty metrics within the Traditional Fuel Poverty Meets Energy Justice module, the latter focuses on French energy poverty case studies within the Traditional Fuel Poverty module.

The Energy Poverty in the Developing World module has few noticeable author communities besides the previously mentioned. The most important is led by Shonali Pachauri, one of the most influential authors for energy poverty measurement in developing countries (with 242 type-A citations). Notably, its size (i.e., 31 authors / 23 works) pales in comparison to central communities and it does not hold any central position in the network. One other community has a significant contribution to the module, i.e., the dark green community with 6 documents and 4 authors, led by Douglas F. Barnes; while the production of the rest of the documents in this module was distributed over hundreds of authors without significant communities. The latter shows that the energy poverty perspective for the developing world is not dominated by any group of authors.

Finally, the rest of the authors in the network are placed in the periphery in trivial communities (something evident, considering that 80.1% of all authors have contributed to producing only one document). This periphery of authors has contributed the most to the Energy Poverty in the Developing World module with 42% of its documents, followed by the Traditional Fuel Poverty and Energy and Fuel Poverty Merging modules, each with 17.5% each of its documents. Nonetheless, despite the triviality of author communities, these authors have contributed significantly to the theoretical development of the field with 97 high-relevance records.

4. Conclusions

In this paper, we map the theoretical evolution of the energy poverty research field through a scientometrics approach, mainly based in network theory analysis of a citation network of 1025 documents of the specialized literature in the period 1978-2020.

Our analysis shows that the field started with two independent origins: energy poverty with focus on access and basic needs, which has been mainly centered on low-income developing regions, and fuel poverty with focus on affordability, which has been mainly centered on European and other developed countries. Despite these two are broadly acknowledged by the research community, it is generally believed the field had one origin in the side of fuel poverty. The concepts developed separately during the period 1978-2010. After this period, information from each side started flowing to one another. The dissemination of knowledge between them led to discussions about the fundamental coincidences and differences between these two original concepts. This ultimately gave birth to broader theoretical perspectives about the phenomenon and the concept of energy justice. Even though, energy justice constitutes the parent theoretical framework of energy poverty, it has evolved in parallel to the energy poverty field in the last decade, serving as a conciliatory perspective in the search towards a consensual conceptual construct of energy poverty.

Along the historical evolution, five schools of thought have emerged in the field. Two of them related to the original concepts, i.e., Traditional Fuel poverty and Energy Poverty in the Developing World. Two schools of thought that pursues a broader theoretical perspective of the phenomenon and inherited features from both original schools of thought, i.e., Energy and Fuel Poverty Merging and Broad Energy Justice. The latter focuses on social justice implications of energy poverty, while the former pursues a holistic framework that could accommodate the multiple conceptualizations of the phenomenon. Incidentally, these two schools have several theoretical and methodological overlaps. The last school of thought Traditional Fuel Poverty Meets Energy justice represents an intermediate state between the Traditional Fuel Poverty and the two schools of thought of Energy and Fuel Poverty Merging and Broad Energy Justice. Nonetheless, despite these two schools have a sound theoretical framework, and are successful to a certain degree in synthesizing previous theoretical developments, they have not become dominant over the field. Instead, every school of thought have contin-

ued growing and become stable. This resembles the punctuated equilibrium assumption in evolutionary theory, which states that once a distinct species appears, it becomes stable, without significant evolutionary changes⁷. The latter suggests that the current schools of thought are likely to continue for a long time while others will appear without any of them becoming dominant. The lack of convergence of schools of thought may affect the future of the field since the missing agreement in definitions and measuring approaches has hurt global awareness of the problem and halted the development of adequate policies and solutions, as pointed out by many authors.

Notably, there are many different conceptual definitions of energy poverty in each school of thought, especially in the school of Energy Poverty in the Developing World. This shows the difficulty of reaching conceptual consensus, even within each school of thought, whose constitutive works share similar theoretical, methodological or application considerations. Nonetheless, two energy poverty definitions in the literature stand out Day and co-authors' concept under the capabilities framework [1] and Bouzarovski and Petrova's concept under the consideration of a common condition of energy poor households [2]. One from the school of Broad energy Justice and the other of the school of Energy and fuel Poverty Merging. These two have been fundamental in synthesizing the information flows of previous developments and for the dissemination of this information across schools of thought, as these two connect to works of every other school. Particularly, *Day et al's* definition has found more influence in the school of Energy Poverty in the Developing World, probably for its relationships with general poverty theory. As these concepts belong to the most influential works in the theoretical space, despite being relatively recent; so far, they represent the best opportunities for reaching a generally agreed-upon definition.

Furthermore, there are several central author communities, mainly focused on European countries, which have gained dominance over the field. Their contributions in the last decade have been fundamental for developing and connecting schools of thought, synthesizing information flows, proposing conceptual and methodological approaches, and relating research with policy-making. However, their research has been kept within their current

⁷This phenomenon is also referred to as the Lindy effect in antifragility theory, which is considered a core characteristic of historical developments that are dominated by rare, but important, events –such as the in the development of science and innovation [70]

co-authoring networks, hence overlooking collaboration with hundreds of authors from other countries and regions. Other authors that do not belong to central communities are arranged into many small communities with little chance of influencing the field, despite these authors account for about half of the highly relevant works in the literature, regarding theoretical and methodological contributions. This fact reduces the global scope that the field pursues, hurting further theoretical convergence.

The evolution of energy poverty research shows a convergent trend towards a consensual theory, where high-relevance works have been mainly responsible for theoretical confluence and development, while some other works have helped expand the scope of the field and spread the knowledge across the theoretical space. Yet, the field is far from reaching consensus as many works with significant theoretical and methodological contributions are added every year. The latter implies that the energy poverty field is still young, and that its future structure and most influential works may be yet to be discovered.

Despite the significant progress in the field, considerable efforts of the wider energy poverty research community remain to be done so to reach a universal energy poverty theory. Particularly, if the field wants to become more globally pertinent, authors should increase collaboration outside their main communities and underrepresented countries, either as research producers or case studies, should increase their participation. The latter is fundamental for capturing multiple spatial and cultural perspectives, and for getting away from a paternalistic approach in the practice of energy poverty alleviation and policy-making.

Works like ours, together with bibliometric studies and focalized reviews, are fundamental to spread the main theoretical developments across the field and to highlight the more advanced schools of thought. Also, they help overcome the large cost imposed on newcomers into this exponentially growing field, e.g., researchers from understudied countries, and to raise awareness in decision-makers of the most recent theoretical developments. As a direction of future research, our work should keep updating along with the field's evolution and incorporate other quantitative and qualitative information of each records into the analysis, for example spatial data and characteristics of measuring techniques.

The history of the field has been very exciting so far and it will become even more so.

Figure B1: Betweenness centrality histogram.

Appendix A. Centrality histograms

References

- [1] R. Day, G. Walker, N. Simcock, Conceptualising energy use and energy poverty using a capabilities framework, *Energy Policy* 93 (2016) 255–264. doi:<https://doi.org/10.1016/j.enpol.2016.03.019>.
- [2] S. Bouzarovski, S. Petrova, A global perspective on domestic energy deprivation: Overcoming the energy poverty–fuel poverty binary, *Energy Research & Social Science* 10 (Supplement C) (2015) 31–40. doi:<https://doi.org/10.1016/j.erss.2015.06.007>.
- [3] H. S. K. Nathan, L. Hari, Towards a new approach in measuring energy poverty: Household level analysis of urban india, *Energy Policy* 140 (2020) 111397. doi:<https://doi.org/10.1016/j.enpol.2020.111397>.

Figure B2: Closeness centrality histogram.

- [4] A. Halff, B. K. Sovacool, J. Rozhon, Energy poverty: global challenges and local solutions, NA, Oxford Scholarship Online, Oxford, 2014.
- [5] N. Simcock, H. Thomson, S. Petrova, S. Bouzarovski, Energy poverty and vulnerability: a global perspective, NA, Routledge, 2017.
- [6] S. Carley, S. Desai, M. D. Bazilian, Energy-based economic development: Mapping the developing country context, Report, Fondazione Eni Enrico Mattei Milano (2012).
- [7] D. I. Stern, The role of energy in economic growth, *Annals of the New York Academy of Sciences* 1219 (1) (2011) 26–51.
- [8] S. Bouzarovski, Energy poverty:(Dis) assembling Europe’s infrastructural divide, NA, Springer, 2017.
- [9] P. Villavicencio Calzadilla, R. Mauger, The un’s new sustainable development agenda and renewable energy: the challenge to reach sdg7 while achieving energy justice, *Journal of Energy & Natural Resources Law* - (2017) 1–22. doi:<https://doi.org/10.1080/02646811.2017.1377951>.
- [10] F. Birol, Energy economics: A place for energy poverty in the agenda?, *The Energy Journal* 28 (3) (2007) 1–6.
- [11] A. K. N. Reddy, Energy and social issues, United Nations Development Programme, New York, NY, 2000, book section 2, pp. 39–60.
- [12] M. González-Eguino, Energy poverty: An overview, *Renewable and Sustainable Energy Reviews* 47 (2015) 377–385. doi:<https://doi.org/10.1016/j.rser.2015.03.013>.
- [13] S. Bouzarovski, S. Tirado Herrero, Geographies of injustice: the socio-spatial determinants of energy poverty in poland, the czech republic and hungary, *Post-Communist Economies* 29 (1) (2017) 27–50.
- [14] S. Samarakoon, A justice and wellbeing centered framework for analysing energy poverty in the global south, *Ecological Economics* 165 (2019) 106385. doi:<https://doi.org/10.1016/j.ecolecon.2019.106385>.

- [15] K. Primc, M. Dominko, R. Slabe-Erker, 30 years of energy and fuel poverty research: A retrospective analysis and future trends, *Journal of Cleaner Production* 301 (2021) 16. doi:10.1016/j.jclepro.2021.127003.
URL <GotoISI>://WOS:000662896900006
- [16] Y. M. Xiao, H. Wu, G. H. Wang, H. Mei, Mapping the worldwide trends on energy poverty research: A bibliometric analysis (1999-2019), *International Journal of Environmental Research and Public Health* 18 (4) (2021) 21. doi:10.3390/ijerph18041764.
URL <GotoISI>://WOS:000623544600001
- [17] E. Dugoua, J. Urpelainen, Relative deprivation and energy poverty: when does unequal access to electricity cause dissatisfaction?, *International Journal of Energy Research* 38 (13) (2014) 1727–1740. doi:https://doi.org/10.1002/er.3200.
- [18] J. D. Healy, J. P. Clinch, Fuel poverty, thermal comfort and occupancy: results of a national household-survey in ireland, *Applied Energy* 73 (3) (2002) 329–343. doi:https://doi.org/10.1016/S0306-2619(02)00115-0.
- [19] A. Urquiza-Gómez, C. Amigo-Jorquera, M. Billi, R. Calvo, J. Labraña, T. Oyarzún, F. Valencia, Quality as a hidden dimension of energy poverty in middle-development countries. literature review and case study from chile, *Energy and Buildings* 204 (2019) 109463. doi:https://doi.org/10.1016/j.enbuild.2019.109463.
- [20] K. Li, S. Y. Pan, Y.-M. Wei, A bibliometric analysis of energy poverty research: results from sci-e/ssci databases, *International Journal of Global Energy Issues* 38 (4-6) (2015) 357–372.
- [21] M. A. Brown, A. Soni, A. D. Doshi, C. King, The persistence of high energy burdens: A bibliometric analysis of vulnerability, poverty, and exclusion in the united states, *Energy Research & Social Science* 70 (2020). doi:https://doi.org/10.1016/j.erss.2020.101756.
- [22] R. Ulucak, R. Sari, S. Erdogan, R. A. Castanho, Bibliometric literature analysis of a multi-dimensional sustainable development issue: Energy

- poverty, *Sustainability* 13 (17) (2021) 21. doi:10.3390/su13179780.
URL <GotoISI>://WOS:000694481800001
- [23] L. I. Meho, K. Yang, A new era in citation and bibliometric analyses: Web of science, scopus, and google scholar (2006). arXiv:cs/0612132.
 - [24] R. Prancutė, Web of science (wos) and scopus: The titans of bibliographic information in today's academic world, *Publications* 9 (1) (2021). doi:10.3390/publications9010012.
URL <https://www.mdpi.com/2304-6775/9/1/12>
 - [25] K. Yang, L. I. Meho, Citation analysis: A comparison of google scholar, scopus, and web of science, *Proceedings of the American Society for Information Science and Technology* 43 (1) (2006) 1–15. arXiv:<https://asistdl.onlinelibrary.wiley.com/doi/pdf/10.1002/meet.14504301185>, doi:<https://doi.org/10.1002/meet.14504301185>.
URL <https://asistdl.onlinelibrary.wiley.com/doi/abs/10.1002/meet.14504301185>
 - [26] B. Boardman, *Fuel poverty: from cold homes to affordable warmth*, NA, Belhaven Press, London, 1991.
 - [27] B. Boardman, *The Cost of Warmth: An Energy Efficient Approach to Overcoming Fuel Poverty*, NA, National Right to Fuel Campaign, 1984.
 - [28] J. Hills, *Fuel poverty: the problem and its measurement*, Report 1465-3001, Centre for Analysis of Social Exclusion, London School of Economics and Political Science (2011).
 - [29] J. Hills, *Getting the measure of fuel poverty: Final report of the fuel poverty review*, Report 1465-3001, Centre for Analysis of Social Exclusion, London School of Economics and Political Science (2012).
 - [30] R. Moore, T. Bridgeman, D. Croft, P. Guertler, I. Preston, *Improving the hills approach to measuring fuel poverty*, Report, Centre for Sustainable Energy (2012).
 - [31] J. D. Millán, F. Polanco, J. C. Ossa, J. S. Béria, J. N. Cudina, *La cienciometría, su método y su filosofía: Reflexiones epistémicas de sus alcances en el siglo xxi*, *Revista Guillermo de Ockham* 15 (2) (2021) 17–27. doi:10.21500/22563202.3492.

URL <https://revistas.usb.edu.co/index.php/GuillermoOckham/article/view/3492>

- [32] M. Fetscherin, D. Heinrich, Consumer brand relationships research: A bibliometric citation meta-analysis, *Journal of Business Research* 68 (2) (2015) 380–390.
- [33] Sci-Team, Science of science (sci2) tool, Indiana University and SciTech Strategies 379 (2009).
URL <https://sci2.cns.iu.edu>.
- [34] V. Vasiliauskaite, F. E. Rosas, Understanding complexity via network theory: a gentle introduction (2020). **arXiv:2004.14845**.
- [35] V. D. Blondel, J.-L. Guillaume, R. Lambiotte, E. Lefebvre, Fast unfolding of communities in large networks, *Journal of Statistical Mechanics: Theory and Experiment* 2008 (10) (2008) P10008. **doi:10.1088/1742-5468/2008/10/p10008**.
URL <http://dx.doi.org/10.1088/1742-5468/2008/10/P10008>
- [36] R. Lambiotte, J. C. Delvenne, M. Barahona, Laplacian Dynamics and Multiscale Modular Structure in Networks, *arXiv e-prints* (2008) **arXiv:0812.1770arXiv:0812.1770**.
- [37] J. Kleinberg, Bursty and hierarchical structure in streams, in: *Proceedings of the Eighth ACM SIGKDD International Conference on Knowledge Discovery and Data Mining, KDD '02*, Association for Computing Machinery, New York, NY, USA, 2002, p. 91–101. **doi:10.1145/775047.775061**.
URL <https://doi.org/10.1145/775047.775061>
- [38] Z. Zhou, A. A. Amini, Optimal bipartite network clustering., *J. Mach. Learn. Res.* 21 (2020) 40–1.
- [39] B. Boardman, *Fixing fuel poverty: challenges and solutions*, NA, Routledge, 2013.
- [40] R. Moore, Definitions of fuel poverty: Implications for policy, *Energy Policy* 49 (Supplement C) (2012) 19–26. **doi:https://doi.org/10.1016/j.enpol.2012.01.057**.

- [41] H. Thomson, C. Snell, Quantifying the prevalence of fuel poverty across the european union, *Energy Policy* 52 (Supplement C) (2013) 563–572. doi:<https://doi.org/10.1016/j.enpol.2012.10.009>.
- [42] J. D. Healy, J. P. Clinch, Fuel poverty in europe: A cross-country analysis using a new composite measurement, unpublished (2002).
- [43] J.-L. Ruse, Fuel Poverty and Cold-Related Ill Health, Taylor & Francis, Boca Raton, FL, 2020.
- [44] J. Chesshire, P. Lehmann, Understanding fuel poverty, Report, Chesshire Lehmann Fund (2015).
- [45] H. Thomson, Fuel poverty in the european union: A multi-methods study, Thesis, Social Policy and Social Work (2015).
- [46] L. Karpinska, S. Śmiech, Invisible energy poverty? analysing housing costs in central and eastern europe, *Energy Research & Social Science* 70 (2020) 101670. doi:<https://doi.org/10.1016/j.erss.2020.101670>. URL <http://www.sciencedirect.com/science/article/pii/S2214629620302450>
- [47] L. Oliveras, A. Peralta, L. Palència, M. Gotsens, M. J. López, L. Artazcoz, C. Borrell, M. Marí-Dell’Olmo, Energy poverty and health: Trends in the european union before and during the economic crisis, 2007–2016, *Health & Place* (2020) 102294doi:<https://doi.org/10.1016/j.healthplace.2020.102294>.
- [48] E. Spiliotis, A. Arsenopoulos, E. Kanellou, J. Psarras, P. Kontogiorgos, A multi-sourced data based framework for assisting utilities identify energy poor households: a case-study in greece, *Energy Sources, Part B: Economics, Planning, and Policy* (2020) 1–23.
- [49] H. Hassani, M. R. Yeganegi, C. Beneki, S. Unger, M. Moradghaffari, Big data and energy poverty alleviation, *Big Data and Cognitive Computing* 3 (4) (2019) 50.
- [50] E. Druică, Z. Goschin, R. Ianole-Călin, Energy poverty and life satisfaction: Structural mechanisms and their implications, *Energies* 12 (20) (2019) 3988. doi:<https://doi.org/10.3390/en12203988>.

- [51] B. Legendre, O. Ricci, Measuring fuel poverty in france: Which households are the most fuel vulnerable?, *Energy Economics* 49 (Supplement C) (2015) 620–628. doi:<https://doi.org/10.1016/j.eneco.2015.01.022>.
- [52] S. Pachauri, N. D. Rao, Advancing energy poverty measurement for sdg7, *Progress in Energy* 2 (4) (2020) 043001.
- [53] P. Nussbaumer, M. D. Bazilian, V. Modi, Measuring energy poverty: Focusing on what matters, *Renewable and Sustainable Energy Reviews* 16 (1) (2012) 231–243. doi:<https://doi.org/10.1016/j.rser.2011.07.150>.
- [54] S. Pachauri, D. Spreng, Energy use and energy access in relation to poverty, *Economic and Political weekly* 39 (3) (2004) 271–278.
- [55] K. Li, B. Lloyd, X.-J. Liang, Y.-M. Wei, Energy poor or fuel poor: What are the differences?, *Energy Policy* 68 (Supplement C) (2014) 476–481. doi:<https://doi.org/10.1016/j.enpol.2013.11.012>.
- [56] S. Pachauri, A. Mueller, A. Kemmler, D. Spreng, On measuring energy poverty in indian households, *World Development* 32 (12) (2004) 2083–2104. doi:<https://doi.org/10.1016/j.worlddev.2004.08.005>.
- [57] S. Bouzarovski, The ‘hidden’ geographies of energy poverty in post-socialism: Between institutions and households, *Geoforum* 38 (2) (2007) 224–240. doi:<https://doi.org/10.1016/j.geoforum.2006.02.007>.
- [58] H. Thomson, S. Bouzarovski, C. Snell, Rethinking the measurement of energy poverty in europe: A critical analysis of indicators and data, *Indoor and Built Environment* 26 (7) (2017) 879–901. doi:<https://doi.org/10.1177/1420326x17699260>.
- [59] S. Bouzarovski, S. Petrova, R. Sarlamanov, Energy poverty policies in the eu: A critical perspective, *Energy Policy* 49 (2012) 76–82. doi:<https://doi.org/10.1016/j.enpol.2012.01.033>.
- [60] S. Bouzarovski, Energy poverty in the european union: landscapes of vulnerability, *Wiley Interdisciplinary Reviews: Energy and Environment* 3 (3) (2014) 276–289. doi:<https://doi.org/10.1002/wene.89>.

- [61] M. Nussbaum, A. Sen, *The quality of life*, Clarendon Press, 1993.
- [62] K. E. H. Jenkins, D. McCauley, R. J. Heffron, H. Stephan, R. Rehner, Energy justice: A conceptual review, *Energy Research & Social Science* 11 (Supplement C) (2016) 174–182. doi:<https://doi.org/10.1016/j.erss.2015.10.004>.
- [63] B. K. Sovacool, Fuel poverty, affordability, and energy justice in england: Policy insights from the warm front program, *Energy* 93 (Part 1) (2015) 361–371. doi:<https://doi.org/10.1016/j.energy.2015.09.016>.
- [64] R. Galvin, *Inequality and Energy*, NA, Academic Press, London, 2020.
- [65] K. Bickerstaff, G. Walker, H. Bulkeley, *Energy Justice in a Changing Climate: Social equity and low-carbon energy*, NA, Zed Books Ltd., 2013.
- [66] L. K. Middlemiss, R. Gillard, Fuel poverty from the bottom-up: Characterising household energy vulnerability through the lived experience of the fuel poor, *Energy Research & Social Science* 6 (Supplement C) (2015) 146–154. doi:<https://doi.org/10.1016/j.erss.2015.02.001>.
- [67] C. Liddell, C. Morris, Fuel poverty and human health: A review of recent evidence, *Energy Policy* 38 (6) (2010) 2987–2997. doi:<https://doi.org/10.1016/j.enpol.2010.01.037>.
- [68] G. Walker, R. Day, Fuel poverty as injustice: Integrating distribution, recognition and procedure in the struggle for affordable warmth, *Energy Policy* 49 (Supplement C) (2012) 69–75. doi:<https://doi.org/10.1016/j.enpol.2012.01.044>.
- [69] K.-M. Brunner, M. Spitzer, A. Christanell, Experiencing fuel poverty. coping strategies of low-income households in vienna/austria, *Energy Policy* 49 (Supplement C) (2012) 53–59. doi:<https://doi.org/10.1016/j.enpol.2011.11.076>.
- [70] N. N. Taleb, *Antifragile: Things that gain from disorder*, Vol. 3, Random House, 2012.