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Perspective

Energy Poverty and Low Carbon Energy Transition

Dalia Streimikiene [1,*] and Grigorios L. Kyriakopoulos [2,*]

[1] Lithuanian Energy Institute, Breslaujos 3, LT-44403 Kaunas, Lithuania
[2] School of Electrical and Computer Engineering, National Technical University of Athens, Heroon Polytechniou 9, Zografou Campus, GR-15780 Athens, Greece
* Correspondence: dalia.streimikiene@lei.lt (D.S.); gregkyr@chemeng.ntua.gr (G.L.K.)

Abstract: In the recent two decades of recorded literature, energy poverty is increasingly understood as a multi-dimensional issue caused by the low-carbon energy transition. In this study, a literature review was performed, the outcome of which confirmed the contentious nature of energy poverty at the regional and international levels of analysis. Furthermore, the collected literature enabled the identification of those domains under which energy poverty is prevailing. The impacts of the current COVID-19 pandemic and the Russian-Ukrainian war on energy prices and energy poverty were also considered key issues of interest in recently published studies (published within the last five years). While all the collected studies in the literature review covered a wide geographical context worldwide, a comprehensive analysis of nurturing energy poverty sources and their consequences was primarily and foremost understood in the household sector, which was the research focus of this study, accordingly. Moreover, future research guidelines that should be drawn regarding energy poverty alleviation were also proposed.

Keywords: energy poverty; low carbon energy transition; challenges

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1. Energy Poverty as a Multi-Parametric Issue: Literature Overview

Recently, energy poverty has become a contentious issue that causes disagreement and competitive arguments regionally and globally. In this context, an impressive and ongoing plethora of relevant publications have been issued on energy poverty, either as a situational reality or as a precautionary condition that all countries have to reconcile with, sooner or later. In an attempt to better organize and coherently approach this plethora of relevant productions, this perspective study organized the relevant literature reviews in alignment with the chronological criterion of the last five years of publication (period of 2018-onwards), as well as the sectoral criterion of households, since it is anticipated that energy poverty is gradually affecting and directly impacting urban and densely populated areas globally, where there are not adequate alternative choices to confront the energy poverty occurrence. The literature search was conducted in September 2022 at the Scopus database by setting the following keywords: "Energy", "Poverty", "Households". The sub-criteria of this literature search were: (a) the last five years of documents' year of publication: "2018–2022", (b) the three keywords to be altogether placed in the "article title", and (c) the English-written publications, which represented 90% of the total documents yielded. The snowballing method was also applied, i.e., the reference list of a selected paper during the literature search was used to identify additional papers on this topic. In the end, 53 documents were yielded, organized, and allocated into the key aspects/dimensions of reviewing, as shown in Figure 1 below:

(A) The economic dimension, referring to energy poverty and energy vulnerability in developed and developing European countries, focuses on welfare losses, housing policies, and economic concerns. This key aspect of reviewing was further organized into the following spatial contexts of literature studies: Northern Europe, Central Europe, and Mediterranean Europe.

(B) The geographical dimension, referring to the geographical context/coverage of reviewing, includes the continents of Asia (mainly China, followed by India and Pakistan) and America.
(C) The in-field dimension, referring to energy poverty and large-scale spatial analyses, focuses on the regional level of analysis and typical infrastructure works involved in similar studies.
(D) The human dimension, referring to energy poverty and its socio-cultural features and anthropocentric considerations, concentrates on the human adaptation and the community involvement in a global prospect of energy poverty.

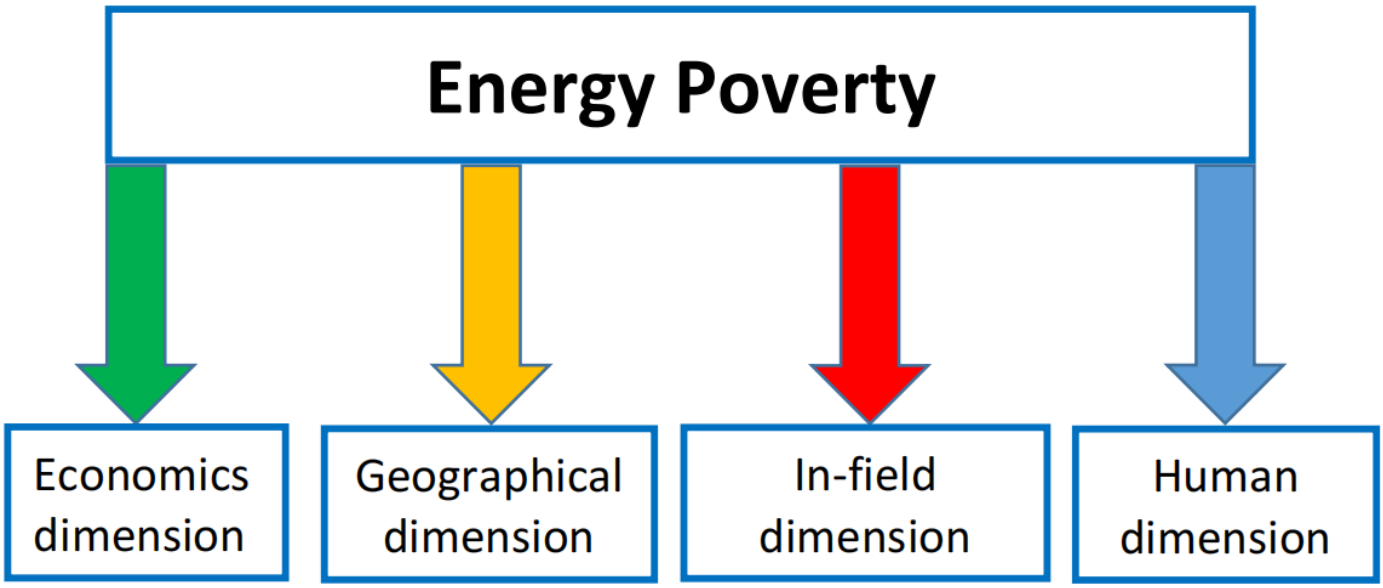

Figure 1. The profile of literature review allocation on energy poverty studies among the four main dimensions of analysis (source: author's own study).

Based on the aforementioned literature organization, the key aspects/dimensions A and B were developed in the form of informative tables, while the key aspects/dimensions C and D were deployed in a systematic and creative descriptive-narrative text. Then, the main argumentation issues were subjected to an argumentation analysis in the "Discussion" section, while the concluding remarks of this literature review were signified in the "Conclusions" section, accordingly.

2. Economic Dimension: Energy Poverty and Energy Vulnerability in Developed and Developing European Countries: Welfare Losses, Housing Policies, and Economic Concerns

The first pillar of energy poverty is unavoidably related to energy vulnerability and access to reliable energy sources among developed and developing countries. In this respect, there has been a plethora of relevant studies produced during the time and in varied areas worldwide. Therefore, in this perspective paper, it was decided that the relevant organization of this plentiful literature production would fall under the geographical criterion, among European countries, and under the sectoral criterion of household-focused studies. The relevant literature production is presented in Table 1 in reverse chronological order of publication, from the newest to the oldest, per European territory: North, Central, and Mediterranean, respectively.

Table 1. Allocation of research and objectives and main outcomes among developing and developed countries in Europe (Source: Authors own study).

References	Research Objectives and Main Outcomes	Year/Territory
[1]	The exploration of vulnerability to heating-related energy poverty in Swedish single-family housing was developed by analyzing factors that influence households' self-perceived ability to pay for heating as well as their self-perceived flexibility capital. The study provided a better understanding of energy vulnerability while showing that integration of energy vulnerability with flexibility capital can enhance researchers' understanding of those challenges offered by a transitioning energy system in both Sweden and globally.	2022/North Europe
[2]	The study reviewed indices for energy poverty assessment from households' perspectives and identified 34 indexes for energy poverty assessment. The study provided valuable insights for selecting the best indicators for energy poverty assessment.	2021/North Europe
[3]	The study found that energy poverty in developed and industrialized economies, such as Germany has been associated with household composition, educational attainment, labor force status, energy-inefficient housing, and the heating system in place.	2021/North Europe
[4]	The study dealt with hidden energy poverty emerging from residents' reactions to their impaired situation. The case study in Austria shows that self-restriction in energy use and properly defined energy poverty cases should be assessed in alignment with high energy expenditures in association with low-income and poor housing conditions.	2022/Central Europe
[5]	The study analyzed the changes in energy poverty in Poland during 2010–2018 and revealed a slow but visible decrease in energy poverty in the country. The study found that investments in RES had a positive impact on energy poverty reduction.	2021/Central Europe
[6]	The coping strategies of energy-poor households in urban settings in France, Spain, Austria, and North Macedonia were assessed. Based on the interviews among energy vulnerable households, the study showed that these strategies are manifold and complex, being related to household empowerment and the depletion of energy vulnerable households' resilience reserves that are induced and guided by coping strategic and structural lock-ins.	2021/Central Europe
[7]	The assessment of the effectiveness of the two measures in reducing winter energy poverty: Thermal social allowance (TSA) and thermal energy cheque (TEC) were performed in Spain, showing that the main imitations in the design of the TSA led to a reduction in winter energy poverty of only 1%, whereas the implementation of the TEC reduced it by 11%. These two measures were proven as ineffective medium-long-term policies since they are expensive and they do not consider other energy poverty characteristics, such as that of low energy efficiency of housing.	2021/Mediterranean Europe
[8]	The study provided a survey of 384 households in Northern Greece, which had high dependence on energy needs, especially at the half-year mark. The study revealed that energy poverty affects a significant proportion of households surveyed, but only in Greece.	2020/Mediterranean Europe
[9]	For a better understanding of the energy poverty in Portugal, a case study combining the use of an energy poverty vulnerability index, while deploying a detailed quantitative analysis in which 3092 civil parishes were interviewed at 100 households in ten hotspots, was based on proper mapping-based planning. Results revealed that besides the phenomenologically accepted situation that households are reasonable to be comfortable feeling both cold in the winter and hot in the summer at homes, either in the winter or in the summer, there is a subtle attitude hinting the social-recognized problem of energy poverty and, then, to activate citizens to confront its negative consequences to their well-being and good health.	2019/Mediterranean Europe

Based on Table 1, it can be deduced that energy poverty is a multi-faceted and multi-parametric issue that intensively impacts household activities and financial priorities, thus, necessitating different estimation strategies and plans to be followed. In this respect, financial inclusion should be materialized by instrumenting access to funding sources, such as micro-financing households by local banks with attractive interest rates, especially for female-headed households. Indeed, financial inclusion can significantly alleviate energy

poverty, but it can also positively affect health and income, which are significant determinants of energy poverty. Therefore, smart-energy policies are capable of nurturing suitable financial conditions for alleviating energy poverty [10].

3. Geographical Dimension

The second pillar of energy poverty is literature related to a wide, global, geographical coverage of reporting energy poverty, especially in Asia (mainly China, followed by India and Pakistan), America, and Africa (mainly South Africa, followed by Kenya and Nigeria). In this respect, there has been a dedicated plethora of relevant studies that were organized in this perspective paper under the geographical criterion of referencing. The relevant literature production is presented in Table 2 in reverse chronological order of publication, from the newest to the oldest, per continent: Asia, America, and Africa, respectively.

Table 2. Allocation of research studies on energy poverty globally (Source: Authors own study).

References	Research Objectives and Main Outcomes	Year/Territory
[11]	Energy self-restriction at households in China was assessed, and the main findings showed that living in (a) large, old, and low-level insulated apartments that are also deprived of energy service equipment and (b) rental housing are linked with energy poverty. The distinct characteristics between energy poverty and non-energy poverty are linked to the area of residence and to the energy installations. Self-restriction restrains energy consumption and worsens the energy poverty situation in households.	2022/Asia
[12]	The energy poverty index was developed for South Asia (2001–2018) by quantifying the size and scope of energy poverty while investigating the relevance of socio-economic positions in multi-dimensional energy poverty. The variables of analysis were the place/position of the houses, the number of occupants, as well as the age of the main caregiver for them. The study revealed that Bhutan's energy poverty index was the highest one, followed by the Maldives and Bangladesh. Contrarily, India and Pakistan were proven to be the least energy-poor countries. This study also proposed policies to eradicate energy poverty and to support policymakers in developing and implementing regional strategies.	2022/Asia
[13]	Energy poverty assessment was performed using China Family Panel Studies (CFPS) data. The income levels and the energy decision-making were determined by the impact of cognitive capability on household energy poverty, showing the supportive role of cognitive capability against energy poverty eradication in China.	2022/Asia
[14]	The multi-dimensional energy poverty index for six provinces was deployed in China. This research was organized into three states of local households' energy poverty, scaled as: multi-dimensional, severe multi-dimensional, and non-multi-dimensional. It can be signified by the lowering of multi-dimensional energy poverty among these six provinces. Indeed, the majority of the households had migrated to better states, thus implying a non-energy poverty trap in China. However, there were vulnerability risks for some households returning to poverty.	2022/Asia
[15]	The household survey in China revealed that tightening environmental regulations can cause greater energy affordability problems for households using non-clean energy. At the same time, convenient and affordable (at lower prices) clean energy allows households to have access to energy and, at the same time, to control the adverse effects of environmental regulations imposed by households' energy poverty.	2022/Asia
[16]	Based on China Family Panel Studies data, the study investigated the situation of national energy poverty. In particular, the effect mechanism on livelihood was conducted by considering income, expense, insurance, health, and future attitude, all of which counted for a comprehensive index of family life quality. The research findings provided support for policymakers to address energy poverty in China.	2022/Asia
[17]	A northern China-scaled household survey showed that energy poverty was intensified by replacing coal with electricity and gas. Other factors of energy poverty were found to be lower income, less education, and smaller household sizes. It is necessary to denote that the design of energy transition policies for low-carbon transition should take into account its distributional effect.	2022/Asia

Table 2. *Cont.*

References	Research Objectives and Main Outcomes	Year/Territory
[18]	The study deployed two types of energy poverty: (a) extensive and (b) intensive; the latter is considered the net effect and heterogeneity of energy poverty on rural labor wages. The study showed that both these types of energy poverty sustained a significant negative effect on the wages of rural workers. Moreover, intensive energy poverty sustained a higher marginal effect on the wages of rural workers compared to extensive energy poverty. The study showed that the enhancement of energy consumption in rural areas is vital to eliminating energy poverty; thus, policies should take labor force heterogeneity and regional heterogeneity into account.	2021/Asia
[19]	The adjusted multi-dimensional energy poverty index (MEPI) was assessed for Asian countries. The study showed that variables such as house size, household wealth, education, and gender of the head of the household are the main socio-economic determinants of increased multi-dimensional energy poverty. Contrarily, a significant and positive mitigation of multi-dimensional energy poverty was reported for the variables of place of residence, ownership status of housing, family size, and age of the primary breadwinner.	2020/Asia
[20]	The study conducted in the Kerala region revealed that electrified households faced intermittent power outages while they did not have access to power backup facilities. Although most households had access to clean cooking, they also utilized extensive biomass, such as firewood for fuel-wood stacking. The study showed that effective tackling of energy poverty is not only an issue of economic security but also an indicator of how energy policies can consider caring and influencing the habits and customs of citizens/energy consumers.	2022/India
[21]	The set of 15 key energy indicators, representing multiple dimensions of energy poverty, was selected by deploying a principal component analysis (PCA) in India. The four types of households in India were characterized as 'least energy poor', 'less energy poor', 'more energy poor', and 'most energy poor'. It found that 65% of Indian households were evaluated as 'more and most energy poor', showing the high energy poverty in the country.	2020/India
[22]	The study conducted in India found that energy poverty was primarily associated with deprivation in cooking and that a greater incidence of energy poverty was manifesting in larger urban areas. In parallel, complementary measures envisaged energy poverty of energy-poor areas more accurately, thus, shaping appropriate pro-poor energy policies.	2020/India
[23]	An empirical study applying the Multidimensional Energy Poverty Index (MEPI) was conducted in India. It was determined that energy poverty could be considered quite extensive in India, showing substantial variations across national districts. The negative relationship between economic development, was reported and urban development, with energy poverty being the most vital component of economic development in education. Higher levels of education had a positive impact on reducing energy poverty in India.	2019/India
[24]	Multi-dimensional energy poverty was assessed in Pakistan by deploying logistic regression estimates, proving that male-headed households showed a higher probability of being energy poor, while offering foreign remittances to households can increase their annual income and make them less energy poor. Moreover, improving housing conditions and focusing on housing located in urban areas can significantly decrease energy poverty in all quantiles. Overall, provincial and regional differences should allow governmental policymakers to alleviate multi-dimensional energy poverty through more realistic and feasible ways of accessing energy sources.	2021/Pakistan
[25]	The study investigated the ways in which a national grid expansion in Vietnam can be translated into households' electricity use over time, thus, playing an important role in increasing household income through electricity consumption. The study showed that an increase in electricity access could not turn directly into an increased use of electricity for low-income households, but it could stress out the gap between low and high income households. Other influencing factors were the education level of the household head, household size, and type/quality of housing.	2020/Vietnam
[26]	The multi-dimensional energy poverty index (MEPI) was assessed in Bangladesh based on the latest household income and expenditure survey (HIES), showing that energy poverty decreased by 53.79%, 43.51%, and 36.33% in 2005, 2010, and 2016, respectively. It can be also denoted that the health and education status of households can be negatively linked to the multidimensional energy poverty.	2021/Bangladesh

Table 2. *Cont.*

References	Research Objectives and Main Outcomes	Year/Territory
[27]	This study examined the effect of race on energy poverty by conducting surveys with representative U.S. households. It was reported that African-American households were more prone to energy poverty exposure, while health and income were determinant factors by which race could influence energy poverty. Therefore, it was argued that subsidy programs should provide energy at preferentially discounted rates and easy access to populations of specific demographics.	2022/America
[28]	The behavioral factors of a vulnerable population associated with their energy consumption were the research focus of this study. The study showed that energy consumption had increased over the years due to the expansion of the built area, number of occupants, quantity of the equipment, time of the year (summer), and family composition.	2022/America

4. In Field Dimension: Energy Poverty and Large-Scale Spatial Analyses and Infrastructure Works

As it has been already stated at the preceding section, the spatial analyses and the need of infrastructure updating and expansion has been proven vital, especially among fast emerging economies worldwide. In this context, it has been denoted in the relevant literature that the Indian government has undertaken important inroads to address national energy poverty, while recently announcing the electrification of 100% of villages. Yet, approximately 300 million people have no access to electricity, being considered deeply energy poor, having no electricity grid connection in their households, but covering their energy needs through private sector firms that provide off-grid solutions. However, the ever-expanding grid has stressed that such private firms face uncertainty and must redesign their value propositions and strategies. Such strategies take into consideration that grid expansion is generally designed under high social embeddedness, risky mitigation, and remotely located conditions. Moreover, the roles of private sector companies provide reliable and intermittent electricity services, especially among energy-poor communities worldwide that cannot be undermined [29].

From a spatial/geographical point of view that can point out significant implications for domestic policy-making concerned with energy poverty, residential energy efficiency, and energy consumption, especially in alignment with the inability of urban households in the cold-climate zone in densely populated areas, such as northern China, to access sufficient domestic energy services, and thus their vulnerability to energy poverty and the insufficient heating provision [30]. The authors of this study signified households' vulnerabilities in having access to adequate heating sources in their homes. This shortage of effective heating is most pronounced in those households that have no access to efficient and flexible networked infrastructures or are of high quality of construction, compared to the heating provision in urban mega-cities in which state subsidies have been provided (these subsidies can operate as buffers for households from energy-poverty areas) [30].

From an infrastructural point of view, it has been noted in the literature that transformations in energy structures and governance models are vital preconditions to meeting the needs of communities living in rural and remote areas, serving citizens that are particularly vulnerable to energy and economic poverty. This multi-parametric design of models should ideally consider the multi-faceted global climate and social, economic, and environmental interests, as well as the determination of the scale of design: national, state, and local governments, that can be also compatible with embedded energy infrastructure. Among relevant technologies of large-scale infrastructure are those of decentralized solar solutions that can support energy transformation in spatially, economically, and socially disadvantaged communities. However, the deployment of such scales of technology adoption and energy transformation is hamstrung by path dependencies including policy frameworks, business models, and infrastructure. The obstacles of operating successful decentralized solar PV are typically the disconnect between policy makers and implementers, poor coordination amongst stakeholders, as well as limited institutional focus and competence, which should also be guided by political oppositions in setting policy frameworks of running collabora-

tion among businesses, system suppliers, financial intermediaries, distribution companies, civil society, and end users [31]. Similarly, technological ventures of PV-installed electricity generations were reported at buildings in a community (in the case of a social housing district of southern Spain in 2017). In such a case, improvements of up to 33% in the winter and 67% in the summer could be obtained while simultaneously reducing the thermal comfort differences among the regional dwellings. Without being phenomenologically obvious, the subsequent decline of prices through the expansion of distributed energy technologies such as PVs can support an opportunity for positive social changes [32].

Another critical issue that is associated with large-scale infrastructures is the fact that the implementation of systemic solutions for the benefit of energy security necessitates a properly defined problem that, subsequently, supports authorities in devising instruments understood as the operational form of public intervention (a specific action strategy) in order to provide a comprehensive solution to this case-specific problem [33,34]. In such a way, the adopting technologies can support the foundation and monitoring of explicit legal frameworks that are defining energy poverty at a local level of analysis [35]. An indicative technological solution that has been referred to in the literature is the use of geothermal energy as an alternative source of thermal energy, as a measure to reduce low emissions and diminish their consequences from the viewpoint of local ecological security. Therefore, the potential assessment of geothermal energy in increasing the level of energy security was scheduled by lowering, or even eradicating, energy poverty in households, thus, confirming the effectiveness and viability of this energy resource. Other co-evaluations (along with the technological base) are key factors that can be the specific properties of geothermal energy and its relatively low price compared to conventional fossil-fuel-based energy sources [35].

5. Human Dimension: Energy Poverty Socio-Cultural Features and Anthropocentric Considerations

Countries that sustain a large share of their population in energy poverty are unavoidably subjected to increases in appliance and electricity demand. Subsequently, designing solutions that estimate latent demand of energy-poor populations often assume a constant income elasticity of demand, making needful the simulate-estimation of responsiveness of electricity demand at income, accounting for non-linearities, and considering other important drivers. Therefore, data from four developing nations can support the assessment of the implications of policy scenarios to achieve Sustainable Development Goal (SDG 7) under different socio-economic futures and universal policies of electricity services, regardless of the high total electricity demand reported and the low average per capita due to no access to policy features. Other socio-economic characteristics of determining the energy poverty are related to electrical appliances of varied types regarding the country, the climate, the income, and the level of stability on electricity provision. It can also be confirmed that as energy-poor populations gain access to electricity services, the demand is anticipated to rise, but in order for biased conclusions to be made, the heterogeneity of energy must also be considered [36].

Similarly, clean and health-safe sources of energy consist of a global challenge, implying that income smoothing can be prioritized among other energy poverty reduction interventions, mainly among rural households [37–39]. Another challenging issue of energy poverty is its causality in driving the socioeconomic activities of households for domestic or entrepreneurial purposes, especially in terms of the potential danger caused by the lack of access to modern day energy services that have to be accessible and exploitable irrespective of the severity of energy poverty [40] and their implication for resource-poor households [41].

Another socio-economic parameter is related to the spatial allocation of energy poverty, especially in rural and urban contexts. Indeed, low-income households in rural areas are more energy-deprived than those in urban areas. Furthermore, low-income households in both urban and rural areas are mostly deprived in the dimension of heating fuel. This study

recommended that suitable measures to combat energy poverty should be rural–urban specific [42,43]. At this point it can also be signified that almost 91% of households in rural economies are based on traditional fuels for cooking and heating, not being satisfied since they are deprived of modern sources of exploitable energy. Subsequently, energy inequalities in poor settlements could be better addressed by imposing affordable energy tariffs for the poor and creating long-run job positions [44].

The socio-economic determinants of energy poverty are also related to the humanitarian values and cultures that are nurtured, especially in low- and middle-income countries (LMICs) in which young children are highly vulnerable to the adverse effects of household micro-environments. The global interest in this anthropocentric aspect of energy poverty is determined by the UN Sustainable Development Goals (SDGs), specifically SDG 3 up to SDG 7, which urge for a comprehensive multi-sector approach to achieve the 2030 goals. Therefore, it is crucial for researchers to address gaps in understanding the health effects of household micro-environments in resource-poor settings. In this context, a relevant research study examining the associations of household micro-environment variables with episodes of acute respiratory infection (ARI) and diarrhea in Uganda revealed multi-sectoral synergies among energy, water, sanitation, and hygiene factors, thus (mainly African) women empowerment programs can support public health and early childhood illnesses [45].

A portion of the literature production that is devoted to energy poverty is irreversibly related to economic poverty, being a dominant paired factor of energy poverty among millions of households in densely populated areas, as India is. Therefore, primary data on various socio-economic variables (SEVs) that have been collected from thousands of households in Mumbai and that were subsequently analyzed are of particular importance and utmost significance, being more conveniently manipulated under relevant income groups [46]. It was reported that energy poverty mainly depends on households' expenditures, since a large household is unavoidably related to higher expenses on electricity to meet all needs for heating, cooling, and hot water. Moreover, education sustains a subtle affection for energy poverty since energy conservation measures can be effectively linked to energy poverty reduction, especially among households with lower incomes. In such an approach, the achievement of sustainable energy for all households among densely populated areas, such as India, necessitates policies and strategies regarding electricity affordability and increased awareness of energy conservation practices [46].

6. Discussions

Access only to intermittent or unreliable electricity networks is related to welfare losses for households in developing countries and affects their households' willingness to pay (WTP) in order to lower or avoid significant blackout episodes in terms of both annual income and expenditure as a proxy for income [47]. In a similar study, it was suggested that lower-income groups were the main contributors to total poverty compared to higher-income households. While it is a fact that poverty rates are directly determined by the choices of energy consumers, relevant models of household energy poverty can be flexible enough to allow for varied assumptions to be considered under a useful sensitivity analysis [48].

Additionally, the confrontation of energy poverty is inseparably considered in pairing policies and strategies with governmental initiatives and regulations to promote investment in energy infrastructure technologies which can make the energy pricing affordable to poor local communities, thus, reducing their energy vulnerability and drudgery, while improving their income earning activities and livelihood conditions [49]. In such a way, central governments, with the aid of municipalities, can ensure that rural dwellers have unhindered access to modern energy facilities, and at the same time, the young population can be motivated to domesticate rural communities and to be involved in the local socioeconomic activities [49]. However, households have long waited for central governments to solve energy problems, to no avail. Therefore, rural households' welfare, especially among

agricultural-bounded economies, can be improved if investors adopt an installment plan. Nevertheless, it cannot be undermined that businesses (especially small and medium enterprises, SMEs) are concerned about economic gains and that the main source of their profitability comes from the budgets of rural households, as well as the terms of payment on a monthly basis, as well as the feasibility of paying back the household expenses in the long run [50].

From a technological point of view, the literature proposed a crucial intervention towards grid reliability and sustainability, jointly with environmental preservation and gendered energy poverty, all offering benefits of the energy expenditure affordability indicator. In such a way, household financial savings range from 12% to 82% based on the implementation level of distributed storage, and generation as well as the local energy mix plans [51].

From a multi-parametric framework of energy poverty considerations, the following issues have been collected and represented:

- Controlling and regulating households' energy consumption and the emitted huge greenhouse gases (GHG), they can potentially and positively impact energy poverty reduction, implementation of the energy justice principle, and climate change mitigation [52].
- Identifying trust can be valued as an important channel through which ethnic diversity operates, shaping policies regarding social capital in multi-cultural societies and adopting feasible alternative ways to measure energy poverty [53].
- By using quantitative and statistical methods, realistic longitudinal approaches can precisely record the energy efficiency measures that have been adopted in the past, interpreting energy poverty under specific socio-economic conditions and revealing that the improvement of energy efficiency in homes that are at risk of energy poverty has a profound impact on (a) the well-being and quality of life [54] and (b) exploring how the social dimension of energy poverty could be integrated into future policymaking processes [55].
- Linking the utility of localized and remote renewable energy sources (RES) with better spatial planning of land uses [56,57], such as biomass production [58], enables policy makers to determine the optimal budgeting mix through relevant weights of each aspect that guarantees the success of the designed energy-oriented ventures [59].
- Relating the energy poverty planning and proposal with the joint appreciation of the concurring environmental, technological, and technological dimensions of modern energy production schemes [60,61].

Based on the analysis above, the research integration framework for energy poverty is outlined in Table 3 below.

Table 3. Energy poverty overview (Source: authors own study).

Domains \ References	Energy Poverty Framework—Domains of Analysis
	Historical and Situational Background of Energy Poverty
[62]	Energy poverty is related to issues of domestic energy deprivation in many European countries, including Greece, Spain, Slovakia, Poland, Germany, and Belgium. Contrarily, the "energy precariousness" entity has been enshrined in official policies and discourses in France. Energy poverty is also involved in the European "Third Energy Package" and varies among the bodies and organizations that adopted policy documents. It could be also denoted that in the US and Australia domestic energy deprivation has been characterized as an underestimated issue to attract policy attention to date. Energy poverty extensively impacts well-being and health, mainly referring to the inability to access fuels in the home, along with vulnerability to open fires and poor indoor air conditions, especially regarding fumes and smoke from open cooking fires that cause the death of 1.5 million people, mainly women and children, annually. Developed countries are also affected by energy poverty, especially regarding the issues of personal safety, household time budgets, labor productivity, and income. It can be also denoted that energy poverty could be considered a striking gendered problem, since women are more subjected to inadequate energy access, subtle discrimination, and restrict resources for decision-making.

Table 3. *Cont.*

References / Domains	Energy Poverty Framework—Domains of Analysis
	European Union (EU) Context
[62]	In the EU, energy poverty is primarily recognized as an issue emerging from institutional factors, political economies, infrastructural legacies, housing structures, and varied access to utility services. While national-scaled policy measures are feasible and realistic, there is also a need for implementing comprehensive agendas for energy poverty alleviation by transnational bodies, such as the EU. In this respect, geographical perspectives and diversification in developed countries regarding energy deprivation are linked to a greater awareness of its health impacts and amelioration policies. At this point, it is noteworthy to note that mental health issues and well-being are steadily recognized as important topics, followed by episodes of respiratory, circulatory morbidity as well as "excess winter" deaths.
[63]	- Energy poverty valuation is directly related to energy demand, clean generation of energy, strategic position of energy sources, as well as energy justice among all countries worldwide. - A three-fold route of energy poverty valuation in the EU was introduced to: (a) address the demand, access, and affordability of energy. (b) ensure the accessibility to energy sources while coordinating energy market by their import policies. (c) sustainability-oriented achievement, referring to emissions that result from energy generators/producers and the involvement of RES at a level that satisfies the energy demand. - Energy-related targets should be accessible, affordable, safe, and available for today's and future generations. In this framework, a comprehensive framework of energy poverty can utilize real data by using energy goal 7 of the EU, among the sustainable development indicators. Additionally, the proposed evaluation methodology among EU-27 countries could reconcile competitive ideal solutions to achieve accuracy and convergence speed in addressing energy poverty.
	International Context
[62]	- Energy poverty is conceptualized to capture the multi-faceted problems of inadequate access to energy among developing countries, as in the global south, where there are also emerging concerns of economic recession, infrastructural deficiency, social equity, poor education, and public health. All these concerns drive energy poverty and governmental measures to upgrade the socio-technological conditions, advance equity in resources, and improve the quality of everyday life, through energy efficiency and affordability. - Access—equity and investment in systems—are issues. Then, these technological and economic aspects of energy poverty are affecting energy and development. - From a technological perspective, energy poverty in developing countries refers to supply-side issues, stressing out the need to expand electricity grids. Such a technological transfer is based on the experience of developed world countries, but it is further an economics-related issue. Indeed, international organizations such as the World Bank draw policies to extend mainland power grids to meet the energy needs of rural areas, thus, overcoming technological constraints, institutional obstacles, and wider socio-economic barriers and providing access to modern energy through contemporary and safe infrastructure and credible financial capital.
[64]	International government policies through public spending should alleviate energy poverty, but little attention has been devoted to investigating the effects of government spending on energy poverty, especially among developing countries. Therefore, it is crucial to research the influence of government spending on energy poverty. In this study, it was reported that government spending has a U-shaped effect on energy poverty, implying that increases in government spending may alleviate energy poverty until a certain level, whereas excessive spending can impede energy prosperity, and institutional quality could support government spending towards economic growth and the confrontation of income inequality.

Table 3. *Cont.*

References / Domains	Energy Poverty Framework—Domains of Analysis
[65]	The deployment of supervised machine learning algorithms can identify the most pertinent and multi-faceted socio-economic aspects of energy poverty, showing that among them the most prevalent are that of: wealth of a household, home size, marital status of residents, as well as place of residence. It was also argued that those socio-economic determinants have policy significance to eradicate severe energy poverty, offering incentives and allocating resources, especially for those "energy-marginalized and poor" susceptible developing countries of Asia and Africa.
	Proposals—Guidelines—Challenging Issues of Energy Poverty
[62]	- Two contemporary issues of high energy interest and research investigation are the conceptual understanding of the terms of energy- and fuel-poverty, as well as, the determination of the governance implications and plethora of terminologies that convey the lack of energy services in the home. Considering the practices proposed to cover "energy poverty" and "fuel poverty" terms, it is noteworthy that both approaches are linked to interpret domestic energy deprivation jointly with human poverty, human geography, environmental policies, and social practices, guises, and forms of adequate domestic energy delivery. - It cannot be undermined that traditional scientific contexts and literature of policy thinking regarding energy and fuel poverty have become untenable considering the abundant conditions and practices of capturing energy demand worldwide. - Energy services can be better developed in order to measure and monitor energy delivery in homes, which is mainly attributed to the number of energy units consumed by the carrier, as well as indoor temperature and illumination characteristics. Therefore, the absence of this metric properly leads to an inadequate description of the utility and the satisfaction received by the end-energy consumption users, partly because the effectiveness of energy services in meeting the requirements needed—foremost that of a comfortable and well-functioning home—is largely dependent on subjective variables.

7. Conclusions

In conclusion, it can be signified that there is an imperative need for energy poverty to be approached in an integrated and carefully designed strategic planning for low carbon energy transition. Such a plan cannot be appreciated as an "all-in" solution that could be transferred and applied to all places at all times, but it entails the consideration and appreciation of the multi-faceted and distinct characteristics of: economic, technological, innovative, social, and cultural consideration. Only by incorporating and co-evaluating all these dimensions at an integrated level of allocated and case-specific weights could it result in effective and sustainable solutions for energy poverty eradication, energy justice implementation, energy safety provision, climate change mitigation, and public health protection, along with the abiding economic benefits and budgeting savings that can be achieved for local households and commercial energy consumers.

Energy poverty alleviation strategies implemented in line with the low-carbon energy transition should consider important determinants of multi-dimensional energy poverty and need to be better shaped and targeted, taking into account the diversity of households in terms of region, location, income, gender, age, education, behavioral factors, etc. The indicators of multi-dimensional energy poverty and other energy poverty frameworks were created to help decision-makers analyze the situation and assess the effectiveness of implemented policies and measures. Though there are dozens of indices and indicator frameworks created to evaluate energy poverty, there is no best indicator, as the phenomenon of energy poverty is highly context-dependent and for specific countries experiencing specific issues of energy poverty on a low-carbon energy transition path, the different indicators can be applied for energy poverty assessment and monitoring.

Future studies are necessary in the field of energy poverty and low carbon energy transition ranging from developed to developing economies is an important problem, however, the main difference between developed and developing economies approaching low carbon transition in terms of energy poverty as in developing countries energy poverty

is mainly linked to energy affordability due to limited access to modern energy supply services. In developed economies, energy poverty is mainly linked to income poverty and increasing energy prices due to the fast penetration of renewables and world energy price shocks, though all households have access to modern energy services due to developed and advanced energy infrastructure. At the same time, people in developing countries are facing problems, such as low electrification rates and the use of environmentally harmful fuels for cooking, such as biomass; and the transition to low-carbon energy, which puts an additional burden on them.

Future research is necessary for analysis of multi-faceted energy poverty phenomena in low carbon energy transition by putting high priority for policies and measuring target alleviation of energy poverty in specific given context and regions that have their own problems and determinants of energy poverty.

In this respect, the inability to attain a socially and materially necessitated level of domestic energy services require energy policies and designers to consider specific energy demand claims in the residential domain, as that of: (A) Domestic energy deprivation is a multi-faceted issue that is predominately determined by the ineffective operation of the socio-technological pathways for covering household energy needs, and as such it should be utmost analyzed by a comprehensive understanding of the fundamentals and operation of different energy services, mainly that of heating and lighting, in homes. (B) The ability to conceptualize and value vulnerability aims at encapsulating the sources of domestic energy deprivation via comprehensive analytical matrices. Subsequently, the identification of the main components and the implications of offering energy services under conditions of vulnerability should relate to domestic energy deprivation worldwide. Conclusively, fuel- and energy-poverty should be considered as different forms of domestic energy circumstances that also impede social inclusion, modern lifestyles, customs, and activities that all identify contemporary societies. In such a way, energy services play a decisive role in people's lives and nurture a "people-centred" approach to policymaking that stands beyond technical issues and should be driven to meet people's needs and priorities in energy.

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