A literature review on the relationship between energy poverty and artificial intelligence

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Abstract

Within the sustainable development goals, an important element is section seven, which talks about affordable, reliable and sustainable energy. At the European Union level, SDGs7 the subject is of increased importance, with extremely high environmental objectives being imposed, including achieving climate neutrality within the next 20 years. In this framework, energy poverty, which describes the inability of households to meet their basic energy needs (for heating, cooking, cooling, lighting), simultaneously touches on issues of social equity, energy infrastructure, climate change and broad socio-economic impact. In this context, although artificial intelligence (AI) raises issues related to a high technological level and huge energy consumption, therefore a possible negative impact on energy poverty, it nevertheless has a great potential to combat it by identifying, forecasting patterns, preventing, mitigating and correcting energy poverty. Prior work, both our own and from the literature, was analyzed to enhance understanding of energy efficiency and artificial intelligence. In this context, the objective of the paper is to to investigate the literature on the capacity of artificial intelligence in alleviating energy poverty by providing solutions on almost all the aforementioned levels (socio-cultural, economic, climate and policy). The results can help us understand what needs to be done further to improve the fight against energy poverty, including from the perspective of population energy security. The implications lie in the fact that it can be of assistance to the state, national and international organizations, local administrations, citizens and non-governmental organizations. The value of the study is given by the precariousness of studies on energy poverty (especially at the national level), often being the elephant in the room. In addition, from the perspective of AI possibilities, the approaches in the literature are even more restricted, being able, by their quality, to contribute to the rise from this status.

Keywords: AI, energy, social inequality, energy structure, climate change.

1. Introduction

Energy poverty is increasingly affecting more people globally, and in the European Union (EU27) energy poverty affected no less than 41 million citizens or 9.3% of the population in 2022 [1]. After the outbreak of the COVID-19 pandemic crisis and especially against the backdrop of the outbreak of the war in Ukraine in 2022, the energy problems of the European Union have worsened, and energy poverty has increasingly become a reality in many households in the Member States.

Although with important steps started in the middle of the last century (1940-1950), artificial intelligence took off after the year 2000, when the development of algorithms and natural language continued to improve, and the year 2010 marked, against the backdrop of the assiduous development of computing technologies, the application of deep neural networks and other techniques, which have now led to the ubiquitous use of artificial intelligence (AI) in everyday life. Not only industry and commerce, not only the financial sector, education, health, information technology (IT), but also medicine and sciences, not only the private sector but also state institutions, benefit today from AI assistance, of course with the benefits and risks attached. Thus, against the backdrop of the growing problem of energy poverty, but also of the field of AI, it is extremely clear that beyond the applications already present, the ability to introduce AI in solving systemic, political, economic and social problems is only at the beginning.

The paper is systematized as follows: starting from a brief introduction to the subject, it investigates the relevant literature on energy poverty and the connection with AI, the methodology explains the approach presented in the article, in the following section - results - the practical applications of AI are treated in particular, as well as the strengths and weaknesses of AI implementation in combating energy poverty, the conclusions briefly outline the main findings, but also guidelines that can be retained for future studies.

2. Literature review

Energy poverty is a complex multifaceted concept, it can also be described by other concepts such as "energy deprivation", "energy precariousness", "energy disconnection", etc. Thus, the vast majority of terms used to describe the phenomenon do not necessarily capture problems related to fuel accessibility, but the factors that determine the type of energy services and their quality received in the home [2, 3, 4].

Energy poverty is a phenomenon with various overlapping aspects, under the impact of economic, social, geographical, regional, institutional factors, referring centrally to limited access to modern energy services, and the inability to afford essential energy for heating, cooling, lighting and cooking [5, 6, 7]. Thus, we can say that, against the backdrop of a multitude of factors with multiple influences, such as economic, social, environmental conditions, there are numerous national and regional definitions, but there is still no universally valid definition of energy poverty. However, in the less developed countries of the world, energy poverty is defined based on the accessibility of clean or modern energy, and in developed countries, energy poverty is usually defined based on the accessibility of energy (or fuel) (under the constraint of low incomes, poor energy efficiency and high prices) [8, 4]. Thus, authorities have maintained an increasing interest in recent times against the background of the need to combat the energy crisis and ensure a just transition, supporting social inclusion and reducing disparities [9].

The energy transition must be done in such a way as to preserve a dignified life, without worsening existing social inequalities and even to reduce and improve social and environmental well-being, to facilitate access to clean and efficient energy technologies [10, 11, 12, 13].

Artificial intelligence, through its explosive advance in recent decades, has created the possibility of using prediction models based on machine learning and big data that offer understanding and managing unconventional relationships between variables in a flexible mannerand. AI presents also an increased predictive capacity, being increasingly used both in the theory and practice of energy poverty management, including on distinct aspects such as energy consumption [14, 15, 16, 17].

Against the benefits brought by AI are also the arguments that AI brings about digital disruptions to the demand side of the energy sector, increases the financial fragility of households and can reduce consumption, worsening energy poverty, especially in disadvantaged households [13].

Artificial intelligence focused on artificial neural networks (ANN) started from the attempt to understand the functioning of the human brain and its capabilities, especially in the sphere of uncertainty and a limited amount of previous information. More precisely, it is based on mathematical models consisting of processing nodes connected to each other on certain predefined layers, generally based on a serial process of logical and mathematical functions, having the advantage of not necessarily implying a deterministic causal relationship between the variables involved, identifying existing relationships between cause and effect by using a learning mechanism based on case experiences and training [18, 19].

Clasical statistical models (e.g. regession models) is usually lacking effectiveness in tackling atypical relationships and has certain limits in systematization and prediction the dependent variables [20], but prediction models based on machine learning may offer more flexibility in handling such relationships and display enhanced predictive capability for variables and especially for the field of energy poverty mitigation [15, 21, 22, 23].

Thus, we can say that the result is not necessarily positive or negative, therefore the article attempts, based on the relevant literature, to systematize the strengths, but also aspects that still require remediation, regarding the adequate implementation of AI in combating energy poverty.

3. Methodology

The main objective of this article is to critically examine, by studying the available literature, the role of Artificial Intelligence in addressing the problem of energy poverty. The results are obtained by vetting papers posted on various professional scientific platforms such as Elsevier, ScienceDirect, MDPI, Springer, IEEE and WIT Press etc. A systematization of knowledge is desirable because it is necessary to group the problems, discover strengths, outline limits, identify opportunities and discover threats. Although there may be numerous enabling or repelling factors between Artificial Intelligence and energy poverty, the study only considers the relationship between these two concepts. Although the main focus was intended to be at the European Union level, other regional or global studies had been also investigated. The aim is to expand as much as possible the knowledge gaps and equally discover opportunities for investigating AI in the field of energy poverty.

4. Results

The literature abounds in explaining the various aspects (through individual indicators) of energy poverty or by treating the problem through a composite index that would systematize the problem quite relevantly. Also, the application of artificial intelligence is carried out on an amalgam of domains, through extremely varied techniques, technologies and methods, thus the literature review regarding the interaction between the two domains is investigated in this study through the first graphical systematization below.

Thus, the systematization of the literature takes into account the theory part, the large mass of theoretical studies, the applied aspects of AI in the field of energy poverty (sometimes on specific levels, see Fig. 1), but also the studies that deal with the policy part, social impact and ethical elements.

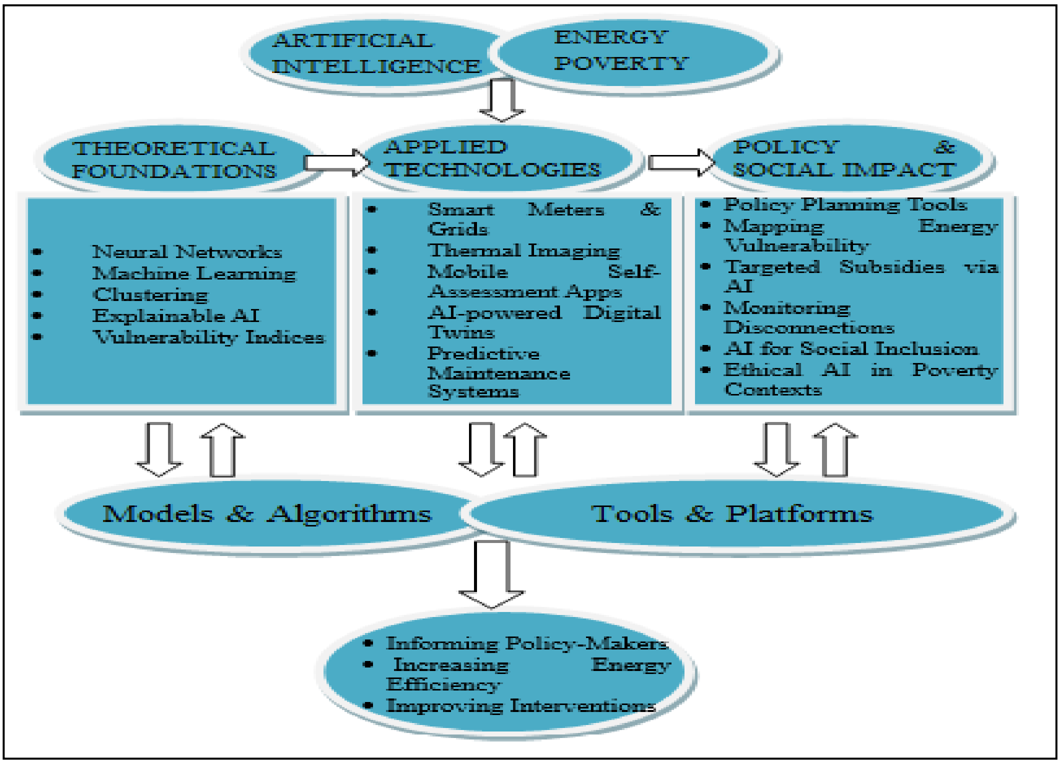

Fig. 1. Graphic diagram of the possible use of AI in combating energy poverty
Source: Author's conception based on informational assistance from ChatGPT

It should be noted that the phenomenon of energy poverty is multifaceted, the discussion about it can be endless. One part of the terminology of energy poverty clearly refers to access to clean, affordable, sustainable energy, and another to the part of social equity, legislation, state regulation, price regulation, subsidies and other means of financial management of the problem. There is a clear, measurable, identifiable energy poverty, but also a hidden form of energy poverty, difficult to identify and therefore difficult to manage. AI can help not only in the already measurable sphere, but can find ways (e.g. through big data) through which it can also bring to light ways of energy poverty that have so far been less captured by literature, specialists, organizations and authorities. Therefore, some of the studies presented below present some of these facets of energy poverty, also touching on a number of aspects of the central scheme presented at the beginning.

Thus, in the paper of Abarca-Alvarez et al.(2019) [24] it was aimed to assess the connection between certain dimensions of social vulnerability and its urban and dwelling context as a fundamental framework in which it occurs using a decision model useful for the planning of social and urban actions. Thus, based on Artificial Neural Networks (Self-Organizing Map), a predictive model and Geographic Information Systems it has been design to predict social vulnerability based on housing information.

In Savage et al. (2021) [25], it is investigated how using heat pumps for domestic heating would impact fuel poverty and social inequality. The analysis integrates a geospatial description of climate observations, gas and electricity infrastructure, energy consumption and fuel poverty from the base world of a Universal Digital Twin based on the World Avatar knowledge graph. The geospatial impact of the heat pumps was assessed in terms of savings, and their effect on fuel cost and fuel poverty, finding an increased potential for fuel cost growth, especially for areas affected by energy poverty. This may lead to the conclusion that the green transition exacerbates social inequality, suggesting in the article the need for a choice between environmental targets and social tensions.

In the study of Al-Obaidi and al. (2022) [26], the Internet of Things (IoT) applications on smart buildings and smart cities are analyzed, through a review, in order to reduce energy consumption. The study highlighted the existence of limitations in developing IoT strategies in buildings and cities due to insufficient comprehension of methods and technologies, and presented a series of improvements in the implementation of IoT for improving energy efficiency.

Savarimuthu and Corbett (2024) [27] explore the potential for using artificial intelligence to model energy patterns that reflect situations of poverty in New Zealand, by using simulated energy consumption data, reaching the conclusion that machine learning models can achieve high predictive accuracy.

In the work of López-Vargas et al. (2024) [28], the problem of energy poverty in Europe, aggravated by the COVID-19 crisis and the global energy crisis, is addressed through the use of Artificial Intelligence of Things (IoT), while also highlighting the benefits but also the societal problems, infrastructure gaps and cybersecurity.

Ding et al. (2024) [29] examine the impact of AI on energy poverty, using panel data for 64 countries, for the period 2000-2019, discovering the contributions of AI applications in ameliorating the effects of energy poverty, especially in high-income countries and lower-middle-income countries, but not in upper-middle-income countries. It is interesting that the authors of effects find a prominence of effects in countries that do not participate in cooperative organizations. This may lead us to the idea that the rules within cooperative organizations may be quite restrictive regarding the deep transfer of benefits from the sphere of artificial intelligence into the technological, political, social and economic area of energy poverty, thus requiring a possible relaxation and flexibility of the rules.

Lampropoulos et al. (2024) [30], through a bibliometric analysis and scientific mapping analysis, explored and provided a review regarding the role of artificial intelligence (AI), the Internet of Things (IoT), and artificial intelligence of things (AIoT) in realizing sustainable development and achieving SDGs. They analyzed 9182 documents from Scopus and Web of Science (WoS) from 1989 to 2022, and they found that AIoT emerged as an important contributor in ensuring sustainability and in achieving SDGs.

As we could see from the above diagram, but also from some of the studies briefly presented above, the possibilities of using energy poverty are countless. Below, a table is presented that rather reflects the application side of the possibility and potential of using AI in combating energy poverty (Table 1).

Table 1. Identifying some AI applications in the field of combating energy poverty by analyzing the relevant literature

AI application to limit or combat energy poverty	Description of potential impact of AI on energy poverty	Studies with possible relevance in the field
Artificial Intelligence (especially Artificial Neural Networks) to predict households likely to face energy poverty	Artificial Neural Networks (ANNs), Big Data, IoT, smart grids, ML etc. based on certain (socioeconomic) factors, identifies vulnerable households, underlying patterns of energy poverty estimates and predict consumption, thermal comfort etc.	Moon and Kim (2010) [31], Pino-Mejías et al., (2018) [15], Hassani et al., (2019) [21], Abarca-Alvarez et al.(2019) [24], Hong and Park, (2021) [22], Gupta et al. (2022) [32], Papada and Kaliampakos (2024) [23]
Smart grid optimization	The aim is to identify adaptive electricity networks that prioritize delivery to critical areas and serve disadvantaged populations better.	Kumar et al. (2020) [33]; Liu et al. (2023) [34], Rajaperumal and Columbus (2025) [35]
Energy inefficiency detection and energy diagnostics of buildings by Computer vision and Thermal imaging	Image recognition based on AI tools to detect poorly insulated homes by taking account of heat loss.	Ham and Golparvar-Fard (2014) [36], Sabato et al. (2020) [37], Amarkhil (2023) [38], Waqas and Araji (2024) [39]
AI analysis to reduce network losses, fraud and lower costs	Detection of non-technical losses (NTL) and their impact on economies, which includes revenue and profit losses of electricity suppliers and decreased stability and reliability of electricity networks.	Shaw et al. (2009) [40], Glauner et al. (2017) [41], Nwafor et al. (2024) [42]
Participatory energy planning	AI systems for community engagement and policy improvement	Bouzarovski (2018) [43], Hagerty and Rubinov (2019) [44], Doukas and Marinakis (2020) [45], Arsenopoulos et al. (2021) [46], Delina and Tung (2024) [47]

Source: investigation of profile platforms, author analysis and systematization, Chat GPT assistance.

From the analysis of price issues, the identification of poor households affected by energy poverty and the energy efficiency of buildings, to optimizations in energy consumption, substantial waste reductions (including hazardous waste) to the management of energy distribution and the constant improvement of the reliability of electricity networks, all make the implementation of AI in reducing energy poverty prove its capacity. Based on the literature studied and previous systematizations, we can outline a series of observations regarding the strengths, weaknesses, challenges and opportunities in combating energy poverty through AI assistance (see Table 2).

Table 2. Recapturing the strengths, weaknesses, challenges and opportunities in using AI in combating energy poverty

Strengths	Description	Weaknesses	Description
Improving efficiency	By optimizing energy consumption, finding alternative solutions, searching for the best means to reduce consumption but also to ensure comfort, AI can reduce energy costs especially for low-income households.	Outdated, oversized, unintegrated energy systems, etc. and high technological threshold	Artificial Intelligence solutions require a reliable infrastructure, including internet access and smart sensors, which is difficult to implement in legacy systems. The solution to this problem is likely to require a grace period, readjustment of the infrastructure, and only then integration of AI solutions.
Increasing access	Solutions based on artificial intelligence can help manage energy distribution in areas with limited access to energy by better understanding infrastructure problems, losses, grid outages and decouplings, regional infrastructure problems, etc.	Poor building infrastructure	The same applies to building infrastructure, the solution would be for all new buildings in cities and villages to be designed from the ground up to have a structural level that allows for the implementation of AI for energy efficiency.
Promoting sustainable practices	Artificial intelligence can be used to monitor and manage renewable energy sources, further reducing energy costs, can design a better integration between conventional and unconventional energy sources, a use of renewable resources where access to conventional energy sources is difficult or simply inapplicable.	Huge energy consumption	The intensive computational processes to collect, process, analyze data and predict, as well as the complexity of the algorithms used, make AI energy-intensive.
Opportunities	**Description**	**Threats and challenges**	**Description**
Major change in human society and Modern Human Capital	Social changes are major in terms of the use of AI in industry, economy, social relations, infrastructure, institutional organization, etc. All of this will make technological implementations bring AI closer to the inhabitants of a household.	Ethical risks	Algorithms that can indirectly exclude or discriminate, algorithms that can select information beyond the limits of privacy, therefore with a potentially invasive and unethical impact on the social sphere of households. Therefore, it may raise ethical issues that require discussion.

Technological progress	AI technology can lead to an individualized relationship, a customized understanding of household needs and therefore an integration of AI for specific needs, with an individualized fight against energy poverty (e.g. for learning - children, flexible work from home - adults, relaxation and comfort - the elderly).	Lack of data	The numerous forms of energy poverty can lead to the invisibility of statistical information, the inability or poor capacity to identify households in energy poverty.
Large-scale social development of both fields	Through the development of artificial intelligence, against the backdrop of successive accumulations of information and knowledge, increasingly versatile practical applications and attached technological solutions, and the substantial reduction of energy poverty by understanding its characteristics, increasingly in depth and from multiple angles.	Lack of technical capacity and societal concenrs	Poor collaboration between authorities, NGOs and citizens, lack of information, lack of digital education, lack of understanding of forms of energy poverty, etc. can lead to a reduced capacity to identify and solve the problem. They are also concerns about data privacy and fears that Artificial Intelligence will exacerbate existing social inequalities.
		Implementation costs	Where communities are isolated either geographically, socially, financially or educationally, against the backdrop of poor overall infrastructure (both energy and IT), implementing AI in assisting energy poverty can be difficult.
		Cybersecurity	Systems based on artificial intelligence may be vulnerable to cyber attacks, affecting energy distribution and compromise security, which requires special care through both legislation and technological adaptation to minimize this risk.

Source: author's conception based on the investigation of the selected literature.

5. Conclusions

Although the application of AI can have an ambiguous effect, on the one hand implying the existence of a relatively high technological level and high energy consumption, and on the other hand AI can contribute to the reduction of energy poverty through successive social optimizations including by shifting attention increasingly towards the smart city or village, in general the idea of potentiality is preferred, selecting the rather positive effects of AI.

At the same time, it is clear that some areas are more advanced, others are lagging behind, in general physical infrastructure (e.g. energy and the condition of buildings) generally holding back the improvement of energy poverty parameters. In this sense, we can consider that the literature captures quite correctly the heterogeneous, and still disaggregated impact of AI on energy poverty, but also the potentialities. In general, Artificial Intelligence has the potential to support the identification, monitoring and combating of energy poverty, but its applicability depends on institutional capacity and access to data, energy infrastructure, buildings and technology, as well as on legislation and ethical governance.

The long-term potential, however, may prove huge as scientific discoveries advance, and private society, the state, NGOs and citizens increasingly understand their involvement in the common well-being, civic spirit and social solidarity. Optimizing solutions to overcome energy poverty should focus on democratizing access to AI technologies and developing open-source solutions.

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