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Combatting energy poverty in eastern Turkey: innovative debt solutions and the power-cut index

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Abstract
Energy poverty (EP), a pressing global concern, is uniquely manifested in regions like eastern Turkey due to intertwined socio-economic conditions and intricate energy consumption patterns. This study critically examines the electricity market dynamics, highlighting the direct impact on end-users, from households to entire communities facing challenges such as unauthorized consumption and waste. Our findings over 2 years period of 6 million customer invoices through 17 cities of 5 distribution companies underscore the limitations of traditional income-based measures in capturing the nuances of EP. In response, we introduce a novel metric—the power-cut index per consumer (PCPC)—spotlighting the prevalence of power interruptions due to non-payment as an actionable intervention metric. To address EP's challenges, we present a mechanism encouraging consumers to reduce consumption, offering debt discounts as incentives. Our methodological approach, harnessing both the Monte Carlo simulation and optimization, promises flexible, actionable strategies tailored to diverse EP situations. Drawing parallels with the European Union's energy transition efforts, this study proposes the adaptation of European frameworks to cater to Turkey's unique landscape. By anchoring our insights in real stories of those affected by EP, we highlight the human dimension, emphasizing the urgency of stakeholder collaboration to ensure a future where energy facilitates prosperity rather than hindrance. The collective endeavors of infrastructure companies, governmental agencies, NGOs, and the public are pivotal in sculpting a brighter, equitable energy future.

Highlights

1. Electricity prices surge due to Covid-19 and natural disasters, impacting consumers' bills and leading to energy poverty (EP).
2. Conventional data analysis methods overlook unique circumstances contributing to EP, necessitating a comprehensive, context-specific approach.
3. Power-cut job orders provide more accurate indicators of EP than income-based formulas, highlighting the need for tailored solutions.
4. EP affects both developed and developing regions, leading to unauthorized consumption and emphasizing the importance of energy efficiency.
5. The power-cut index per consumer (PCPC) offers insights into EP prevalence and its correlation with lower socio-economic development.

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6. Effective support mechanisms require clear funding, objectives, and stakeholder engagement for long-term sustainability.
7. Collaboration between energy companies, government, and NGOs is essential to design impactful support programs addressing EP.
8. Debt collection optimization involves tailored solutions for varying debt levels, maximizing collection rates while avoiding financial risks.
9. Monte Carlo simulations validate effective discount scenarios that reduce debt and support vulnerable households.
10. Social responsibility projects, combining infrastructure development and job creation, have shown promise in mitigating payment disruptions and improving welfare.
11. Data privacy is crucial, and rigorous processing protects sensitive information from being revealed.
12. The Electricity Market Consumer Services Regulation (EMRA) in Turkey prioritizes consumer rights and equitable practices to create a consumer-friendly electricity market.
13. Consumers committing to reduce consumption after power-cut job orders can receive discounted debt payments, fostering responsible energy use.
14. Optimal discount and participation rates can be determined through iterative algorithms, ensuring the program's financial viability.
15. Addressing EP requires a nuanced approach, incentivizing energy conservation, and fostering a sustainable energy landscape for vulnerable communities.

Keywords Energy poverty, Power-cut job orders, Sustainable support mechanisms, Energy efficiency measures, Collaborative approach

Introduction

The recent surge in electricity prices, triggered by the Covid-19 pandemic and further exacerbated by natural disasters like earthquakes and floods, along with the increasing costs of power plant resources, has had a profound impact on consumers' electricity bills. The dynamics of the electricity market, where producers and consumers set prices, directly influence the market clearing price, which in turn affects the tariff price for end consumers through changes in system costs. In the Turkish Day-Ahead Electricity Market, as shown in Fig. 1, market prices skyrocketed from approximately 350 TL/MWh to 4000 TL/MWh due to various factors (EXIST, 2022), representing an 11.5-fold increase. The rise in residential tariff from 578 TL/MWh on May 1st, 2020 to 1445.5 TL/MWh on August 17th, 2022 (EMRA, 2022), a 2.5-fold increase, indicates that not all energy costs are passed on to end consumers, but it still significantly affects energy consumption and may lead to energy poverty (EP). EP, defined as the inability to afford energy services necessary for maintaining a standard lifestyle, is a critical consideration when adjusting energy prices. While tariff prices were increased, support packages were introduced for low-income citizens and vulnerable consumers to mitigate the impact (Emre, 2019).

In the process that started with the energy crisis, the problem was identified as the effects of climate change, and the EU gave great importance to the energy transition to mitigate the effects of climate change. Within the scope of the energy transition, the EU has introduced many legal regulations supporting the transition to a low-carbon system and the use of clean energy. The aim of the low-carbon transition is defined as to create a sustainable energy sector which stimulates growth, innovation, and jobs while improving quality of life, increasing choice, reinforcing consumer rights, and ultimately providing savings in household bills (EU, 2023a, 2023b, 2023c, 2023d). These objectives base themselves on the energy union strategy (2015) which, together with Regulation (EU) 2018/1999 on the governance of the energy union, define the dimensions of the EU's energy policy. Energy transition in EU legislative work identification means:

- Diversifying the EU's sources of energy, ranging from fossil fuels, through nuclear power, to renewables (solar, wind, biomass, geothermal, hydro-electric and tidal) to ensure energy security.
- Realizing a fully integrated, efficient internal energy market without technical or regulatory barriers.
- Improving energy efficiency and the interconnection of energy networks, and cutting emissions.
- Moving towards a low-carbon economy in line with the commitments set out in the Paris Agreement.
- Promoting research in low-carbon and clean energy technologies, and prioritizing research and innova-

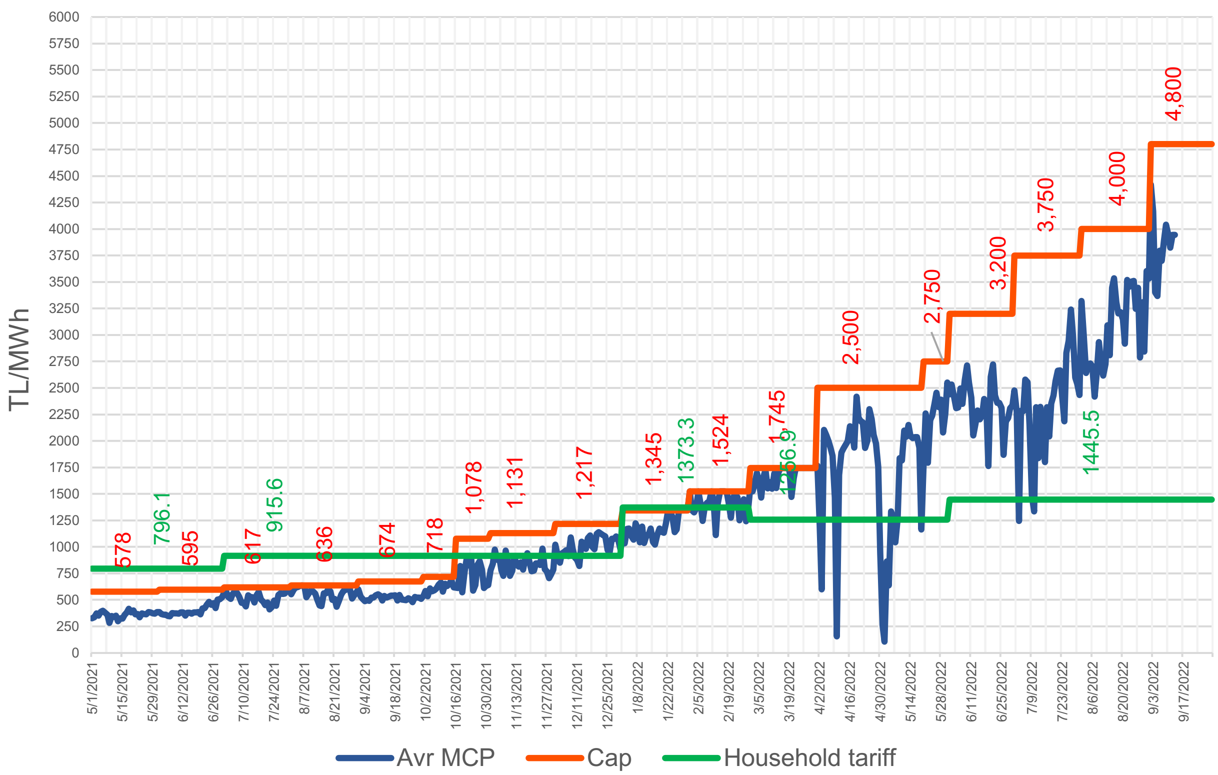

Fig. 1 Market clearing prices (MCP) for Turkish Day-Ahead Electricity Market (EXIST, 2022)

tion to drive the energy transition and improve competitiveness (EU, 2023a, 2023b, 2023c, 2023d)

Totally transformed energy infrastructure will be costly but transition itself is costly for the energy-poor set on the other hand. Although there are steps on renewable energy, energy label and eco-design, some funding's for low-carbon transitions, addressing energy poverty (EP). All the policy change has the priority for the citizens as the affordable energy which means all transition should be design on the strong financial models for the household consumers. Europe defines EP is a situation in which households are unable to access essential energy services and products. Over the past decade, it has increased its efforts and made energy poverty a key concept in the Clean energy for all Europeans package, adopted in 2019. As part of their obligation to assess energy poverty in their National Energy and Climate Plans (NECPs), several EU countries have integrated targeted measures in their national strategies and are developing their own definitions, measurement and monitoring methods and solutions to tackle energy poverty (EU, 2023a, 2023b, 2023c, 2023d).

The Fit for 55 package includes a proposal for a revision of the Energy Efficiency Directive to put a stronger focus on alleviating energy poverty and empowering consumers (Cornelis, 2022).

In autumn 2021, the Commission published the Communication "Tackling rising energy prices: a toolbox for action and support", where it lists a range of short and medium-term initiatives that can be taken at national level to support and help the most vulnerable consumers. The proposal for a recast of the Energy Performance of Buildings Directive and the hydrogen and decarbonized gas market package are expected to further stress the importance of the mitigation of energy poverty in EU policies (EU, 2023a, 2023b, 2023c, 2023d).

The Commission Decision 2022/589 established in April 2022 the Commission Energy Poverty and Vulnerable Consumers Coordination Group, which aims to provide EU countries with a space to exchange best practices and increase coordination of policy measures to support vulnerable and energy-poor households (EU, 2023a, 2023b, 2023c, 2023d).

Today we have many different energy poverty advisory hubs on internet provide updated documentation, advise, best practices and major number of documentation is on diagnostic of the problem but unfortunately not the sustainable financial solution possibilities (Energy Poverty Hub, 2023).

ENPOR, SomAct, STEP, PowerPoor, SocialWatt, EmpowerMed, Renoverty, Reverter, Energy Poverty Zero (EP-0) and JUSTEM projects are some of the Horizon 2020 and LIFE Clean Energy Transition Programme examples. These projects have site works on Bulgaria, Makedonia, Ukraine, Lithuania, Hungary, Czech Republic, Poland, Portugal, Slovakia, Spain, Greece, Latvia, Croatia, Italy, and UK. The projects offer some publications, interactive databases, courses and technical assistance works on site for mitigating energy poverty (EU, 2023a, 2023b, 2023c, 2023d).

Within the European Union (EU), there exists a profound dedication to sustainable growth paired with equitable benefits distribution. The linchpin of the EU's energy strategy rests on ensuring universal access to reliable, cost-effective, and green energy. Recognizing the multifaceted nature of the energy sector, the EU has taken significant measures to combat energy poverty. Their rigorous legislative infrastructure, fiscal tools, and strategic policies underline a balanced focus on both environmental sustainability and social equity. However, Europe's journey is not an isolated tale. The specter of energy poverty casts its shadow globally, revealing diverse challenges shaped by distinct socio-economic and political landscapes. This directs our attention towards Turkey, especially its eastern territories. Deviating from the general European trajectory, Turkey's engagement with energy transformation and energy impoverishment unveils distinct intricacies, shedding light on the ways regional nuances shape global issues.

Situated at the crossroads of Europe and Asia, Turkey's distinct geographical positioning allows it to assimilate influences from both continents. While its eastern territories are a reservoir of profound cultural legacy and abundant natural resources, they have historically grappled with economic constraints. This financial imbalance has given rise to several challenges, notably energy poverty. This research delves into the energy consumption behaviors, debt trajectories, and the comprehensive energy framework of these provinces. Our objective is to illuminate the specificities of energy poverty in these domains and propose viable strategies for redressal.

A critical aspect that bolsters this research is its data-driven approach. Harnessing information from five major electricity distribution companies, spanning 21 regions and affecting over six million customers, the study provides an in-depth analysis of energy consumption, debt patterns, and their implications. The chosen timeframe of 2 years is significant as it captures the immediate effects of some of Turkey's policy decisions on energy and offers a snapshot of the energy landscape in these pivotal years.

One of the major challenges lies in accurately diagnosing the problem using conventional data analysis metrics, like income-based formulas commonly employed by different regions and countries. Unfortunately, existing methods often overlook the unique circumstances and socio-economic factors that contribute to EP within individual contexts. To add to the complexity, there is a lack of sufficient data and information at the household level, which is a common reality, further hindering the development of effective policies and programs.

To tackle this issue effectively, we need to take a more detailed and context-specific approach. This means integrating both quantitative and qualitative data and considering the perspectives of those affected in a comprehensive manner. By doing so, we can gain a deeper understanding of the challenges faced by individuals experiencing energy poverty and devise better solutions that truly address their specific needs. It is crucial that we bridge the gap between different data sources and engage in meaningful dialogue to arrive at a common language that enables us to implement impactful strategies and alleviate energy poverty effectively. An improved indicator of EP is the occurrence of power-cuts resulting from the inability to pay. Studies focusing on power-cut job orders offer more consistent and accurate results than relying solely on socio-economic development indices. EP is not confined to developed countries; regions with weaker socio-economic conditions, including Southeast Europe and Turkey, also grapple with this issue, particularly non-technical losses. Energy-poor households that cannot pay their bills may resort to unauthorized consumption, leading to increased waste and illegal practices. This underscores the importance of energy efficiency measures to reduce costs and alleviate the negative impacts of EP on individuals and communities.

Figures 2 and 3 illustrate the number of power-cut job orders and the loss rates of various provinces, respectively, revealing the complexity of the EP issue, not tied to specific regions or demographics. To accurately assess and address EP and non-technical losses, effective measures, such as meter reading and advanced metering infrastructure, must be implemented to prevent unregistered consumption.

The Fig. 4 introduces the power-cut index per consumer (PCPC), a valuable tool that offers deeper insights into the prevalence of energy poverty (EP) across various regions and demographic groups. What sets the PCPC index apart is its unique approach, considering both power-cut job orders and repetitive status information per subscriber. This comprehensive perspective allows us to gain a better understanding of the extent of energy poverty in different areas.

Shifting our attention to Fig. 5, we explore the relationship between the PCPC index and the development index (Acar, 2019). The findings from this analysis reveal

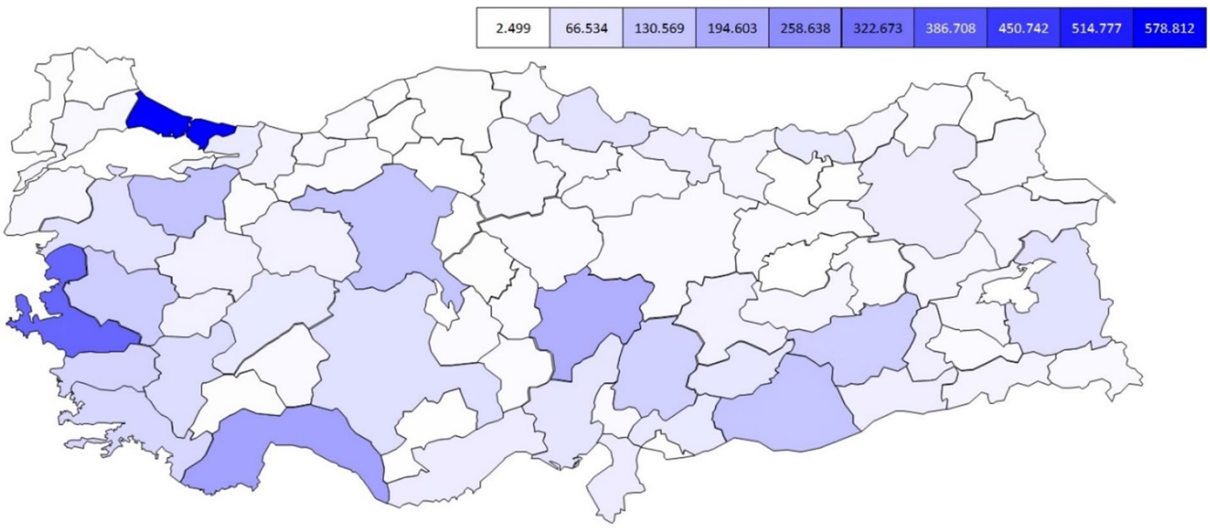

Fig. 2 Power-cut job orders (in numbers) (2019, 20, 21, 22)

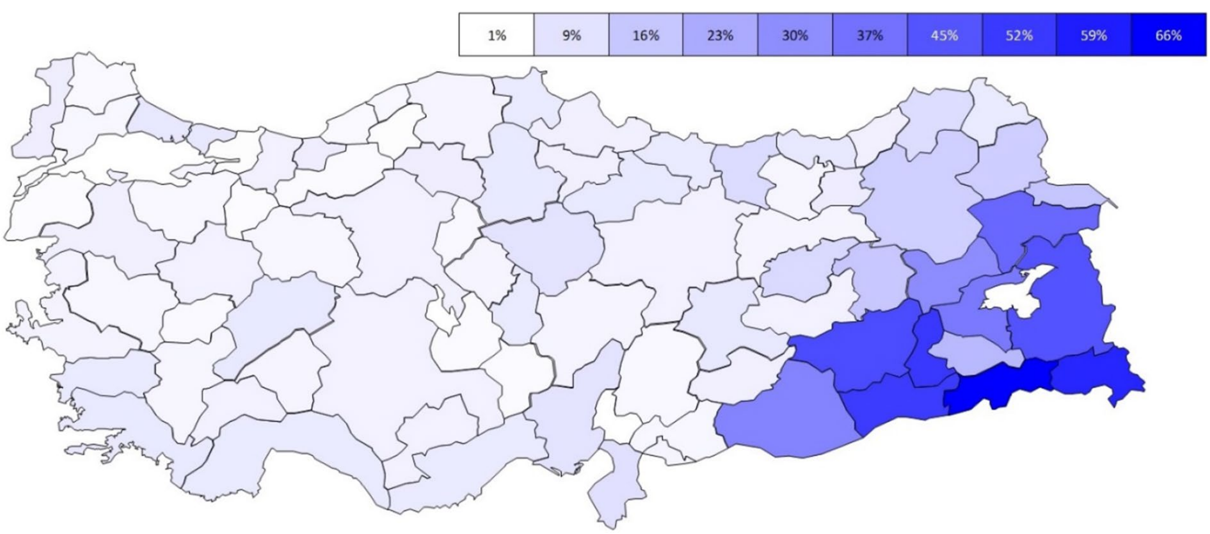

Fig. 3 Loss rates of distribution companies (DisCo's') provinces (in percentages) (EMRA, 2021a, 2021b)

a significant correlation, indicating that regions with higher PCPC index scores generally experience lower socio-economic development levels. This finding underscores the importance of implementing targeted policies and programs, specifically tailored to address energy poverty in regions facing weaker socio-economic conditions. By focusing our efforts on these areas, we can effectively work towards reducing energy poverty and enhancing the well-being of vulnerable communities.

To effectively tackle energy poverty (EP), we need to establish sustainable support mechanisms. However, ensuring the sustainability of these support models may come with its own set of challenges, such as budget limitations and the need for greater accountability. To overcome these obstacles, it is imperative to implement clear and consistent funding mechanisms, define well-defined objectives, and conduct regular monitoring and evaluation.

Moreover, active engagement of stakeholders, including affected communities and utility companies, in the design and implementation of support programs can significantly enhance their success and ensure their long-term sustainability.

By adopting these thoughtful approaches and integrating valuable insights, we can make substantial

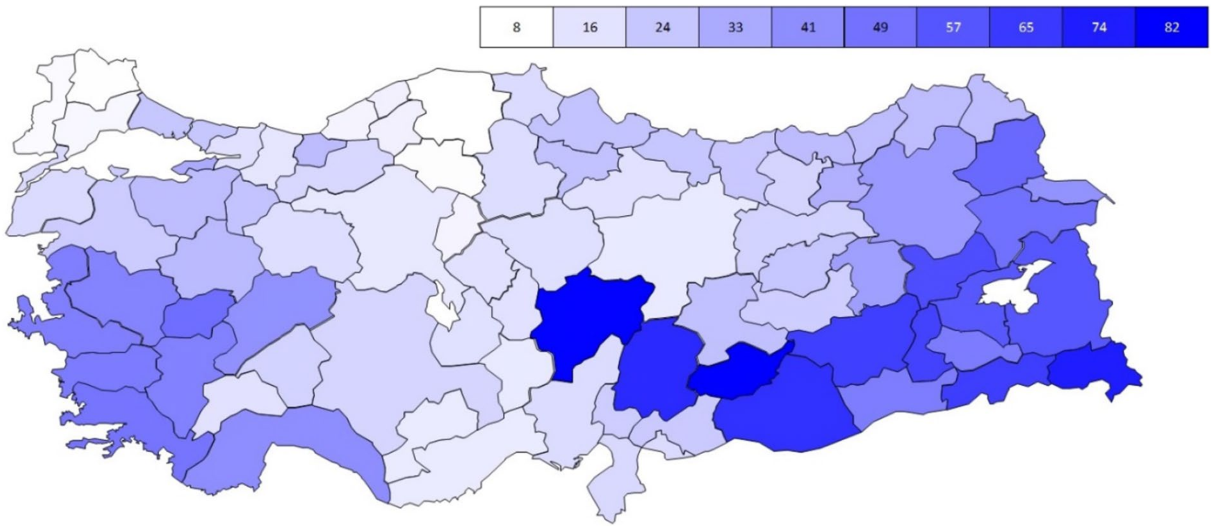

Fig. 4 PCPC index for the cities in units

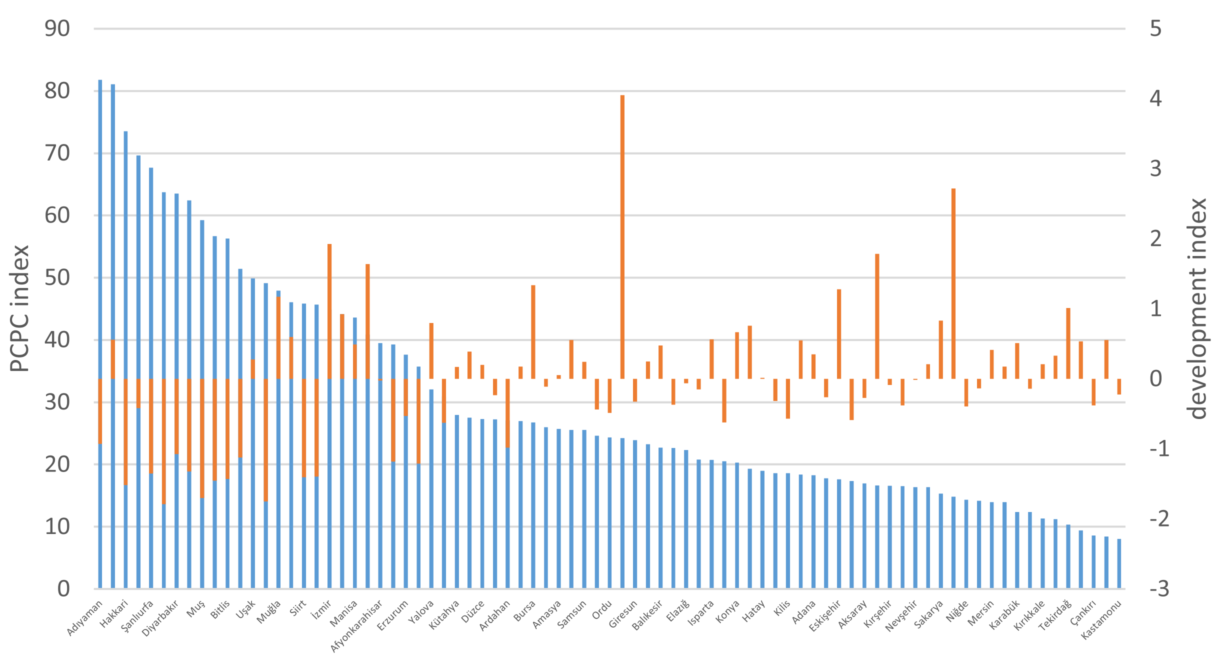

Fig. 5 Relationship between PCPC index and development index

progress in addressing energy poverty and promoting a more resilient and sustainable energy system that benefits everyone involved.

Literature review

The concept of energy poverty is intricate, defined not just by the affordability of energy but by the implications it carries for households, communities, and nations at large. While energy is a basic necessity, its inequitable access can lead to significant socio-economic and health consequences. It is thus imperative to understand its dimensions and the strides made globally to combat this issue.

European Union's addressal of energy poverty

The European Union (EU) has been exemplary in its proactive approach towards both the energy transition and energy poverty. With its cohesive policies, the EU seeks to ensure that while the member nations move towards sustainable energy sources, no citizen is left behind without access to affordable energy (EU, Fit for 55 Package, 2021).

At the core of the EU's efforts is the creation of a robust legal and institutional framework. The commitment to eliminate energy poverty is embedded in several EU directives and regulations. The significant involvement of public authorities in policy crafting, execution, and financing of activities to tackle energy poverty is noteworthy. The EU, recognizing that energy poverty is not just about providing energy but ensuring it is affordable, has initiated programs to increase energy efficiency in homes, especially in low-income households, thereby reducing energy bills and enhancing living conditions (EU, 2023a, 2023b, 2023c, 2023d).

Furthermore, EU member states have been mandated to identify energy-poor households and provide them with benefits like energy checks, financial support, and advice on how to reduce energy consumption. The results have been positive, with a measurable reduction in energy poverty levels in several member states. This serves as an inspiration for other nations looking to address similar challenges in their energy transition journey (EU, 2023a, 2023b, 2023c, 2023d).

Scientific work on EP

Over the last three decades (or more), significant research has been devoted to understanding and even defining EP, a complex and multidimensional issue affecting vulnerable populations globally. While Boardman's 10% criterion, which identifies households spending more than 10% of their income on energy expenditures as energy poor (Boardman, 1991), has been widely referenced, the well-known names like Bradshaw, Moore, Hills, Bouzarovski, Mould, Thomson, and Erdoğdu argue for a more nuanced approach (Boardman, 2012; Bouzarovski, 2014, 2015; Bradshaw, 2008; Erdoğdu, 2020; Moore, 2012; Mould, 2017; Pye, 2017; Thomson, 2017). They highlight the variability of EP thresholds and emphasize the importance of considering factors like thermal comfort, affordability, inefficiency in energy use, access to adequate energy services, and other primary and secondary indicators to comprehensively define EP for different individuals and contexts especially common for all the geographies (Simcock, 2016).

Moreover, studies by ERRA-Inogate and the EU Energy Poverty Observatory (EPOV) have recognized challenges in collecting and evaluating data using various indicators (ERRA-Inogate, 2011; Thema, 2020). Emre's work emphasizes the central role of affordability in EP and underscores the need to assess EP through indicators related to the inability to pay debts leading to power-cuts (Emre, 2022a, 2022b). This finding aligns with previous studies by Bağdadioğlu and Özcan, who used different data but arrived at similar conclusions on the importance of non-payment-related indicators (Özcan, 2013).

The consequences of non-payment in energy services must be understood to design effective support programs. Clear and accurate definitions of debt and power-cut job orders are crucial in this regard (Uludağ EPSAŞ, 2022). "Electricity debt" refers to unpaid receivables resulting from invoiced and consumed electricity recorded through metering devices. As energy consumption is a fundamental human need, this debt data proves to be a robust indicator of inadequacy and EP (Case name, 2018). A noteworthy approach, the bill arrears method, takes unpaid electricity bills into account, helping identify households at risk of electricity disconnection due to financial constraints.

While progress in digitalization has improved data accuracy, accurately quantifying the number of households in poverty or EP remains challenging at the global level (Emre, 2018). Nevertheless, data from public and private infrastructure companies regarding subscribers and invoices provide reliable information on household energy expenditure. Heating (and cooling) represents the primary energy expense, with electricity being the second-highest cost for most households. However, in certain seasons, such as winter for heating or summer in hot regions, electricity expenses may surpass other energy costs. Given that electricity debt often constitutes the largest or second-largest expenditure for many households, those unable to pay their bills risk being deprived of their basic needs, making electricity debt and subsequent cut-offs robust indicators of absolute poverty.

In Turkey, the Electricity Market Consumer Services Regulation (EMRA) of 2021 plays a crucial role in overseeing the entire process of electricity provision for subscribers. It goes beyond technicalities, aiming to ensure that consumers and service providers understand their rights and responsibilities.

The EMRA not only outlines guidelines for measuring, billing, and collecting electricity, but also emphasizes the protection of vulnerable consumers. It provides clear procedures for handling non-payment and service disconnection cases, ensuring fairness and efficiency in billing and collection practices.

When it comes to handling non-payment of electricity bills, Turkey follows a multi-stage process. It begins with metering and billing, followed by last-day payment notifications and energy-cut notifications. If necessary, the actual energy disconnection occurs by sealing the meter. For non-paying subscribers, power-cut job orders are created, and in some cases, legal execution for unpaid debts is pursued.

It is important for distribution companies to strictly adhere to EMRA regulations to safeguard consumer rights and maintain equitable practices. Tampering with the meter's seal during disconnection is considered illegal energy use and theft, which further highlights the significance of following the EMRA guidelines.

In summary, the Electricity Market Consumer Services Regulation (EMRA) in Turkey strives to establish a consumer-friendly electricity market. By prioritizing consumer rights and fair practices, this regulation contributes to a more reliable and transparent energy sector in the country (EMRA, 2021a, 2021b).

The execution of legal proceedings in cases of non-payment can be an unpleasant process for energy and infrastructure companies. The debt repayment rate is typically around 50%, and the average debt repayment period is 2 years (Çoruh EPSAŞ, 2021). Legal proceedings not only lead to customer dissatisfaction, but also incur additional costs in terms of employment and labor force. Therefore, it is essential to address the underlying issues of EP to reduce the frequency of non-payment and its consequences.

According to site experience of the responsible utility companies (Çoruh EPSAŞ i.e.), bill debt is a strong standalone indicator to identify the EP cluster. On average, 15% of energy bills are overdue, and analyzing debts leading to electricity cut-offs reveals that 63% of the total amount is owed by 18% of consumers, in line with national and international literature. Consequently, defining the EP cluster using only bill debt, without additional indicators, can accurately identify vulnerable households. This approach is reinforced by its reliance on real data sources, enabling the identification of absolute and elastic levels of vulnerability through power-cut job orders. Support mechanisms based on these findings hold promise in increasing welfare and reducing EP.

To effectively reduce EP, addressing payment disruptions in energy infrastructure companies is critical, encompassing non-payment and electricity theft. Social responsibility projects have shown promise in mitigating these challenges. In Hungary, a collaboration between the Red Cross, Electricity Distribution Company, and Local Municipalities provided part-time environmental cleaning jobs for individuals facing payment difficulties due to unemployment and poverty, leading to the use of prepaid meter mechanisms and improved payment collection (Emre, 2015). Similarly, Brazil's efforts in building facilities such as sports fields and investing in capacity increase in "favelas" improved living conditions, ensured bill payments, and reconciled problematic social groups (Emre, 2015). Combining infrastructure development with social responsibility projects addresses underlying issues like poverty and unemployment, benefiting both energy companies and vulnerable populations.

Establishing a sustainable support mechanism is not only a duty, but also an act of social awareness and responsibility. Collaboration between energy infrastructure companies, government, and non-government organizations is essential in designing and implementing effective support programs addressing EP's root causes. By emphasizing energy conservation commitments and setting specific objectives, new mechanisms can incentivize consumers facing disconnection due to debt with discounted rates, contingent on their compliance with conservation pledges. Regular assessments will determine the program's continuation, while discount scenarios will be based on power-cut job orders, aiming to effect changes in payment habits and reduce prolonged legal proceedings.

In conclusion, addressing EP requires a comprehensive approach that considers various indicators and acknowledges the complexities across different contexts. The literature highlights the significance of electricity debt and subsequent cut-offs as strong indicators of absolute poverty. Effective support programs must be designed to protect consumer rights, improve payment collection, and tackle the underlying issues of EP, such as unemployment and inadequate living conditions. Social responsibility projects that combine infrastructure development with job creation and improved living conditions have shown promise in reducing payment disruptions and improving welfare. By establishing collaborative support mechanisms and incentivizing conservation commitments, energy infrastructure companies and stakeholders can work towards reducing EP and ensuring a more equitable energy landscape for vulnerable populations.

Shahzad et al. (2022) in their paper delve deep into the interplay between energy poverty and social change. They underscore the need for multifaceted interventions, encompassing technological, socio-economic, and policy domains, to bring about lasting positive change in society.

Zhao et al. (2022) explore the impacts of bilateral trade on energy affordability and accessibility across Europe. Their research suggests that economic globalization, specifically bilateral trade, can play a pivotal role in reducing energy poverty. They posit that increased trade relations, coupled with targeted policies, can enhance energy accessibility for marginalized communities, setting a template for other regions to follow.

A captivating study by Druică et al. (2019) throws light on the relationship between energy poverty and life satisfaction. The authors, through a comprehensive analysis, demonstrate that the absence of energy or its inaccessibility significantly deters the quality of life. Their research calls for immediate interventions, suggesting that addressing energy poverty can directly elevate societal well-being. Qin et al. (2022) stated the same result by using panel data of Chinese household survey.

These works, among others, provide a rich tapestry of knowledge on energy poverty. They underscore its importance, the underlying challenges, and the potential pathways to address it.

Dong et al. (2022a) worked on 2004–2017 dataset for searching the energy efficiency and energy poverty relation. According to their work, improved energy efficiency can simultaneously alleviate income inequality and energy poverty. Another study on technological development and energy poverty relation has been searched by Dong et al. And improving the development of China's inclusive finance can help eradicate energy poverty, and the interaction of inclusive finance and technical innovation can strengthen this effect (Dong et al., 2022b).

Mohsin et al. (2022) worked energy poverty data in Latin America and stated findings imply that no global policy can manage the problem of energy poverty, but individual solutions should be developed.

Stojilovska et al. (2022) evaluates policy documents in six European countries (Spain, France, Portugal, the UK, North Macedonia, and Slovenia) link energy poverty to other related policy areas. Their exploratory study suggests that the most explicit links to energy poverty are made in energy efficiency policies rather than in energy price and income policies, due to the dominant techno-economic approach to addressing energy poverty.

Methodology

The proposed mechanism is based on the principle that consumers who have experienced power-cut job orders should enter into an agreement to reduce their consumption levels for a specified duration, such as a month, quarter, or year. Upon fulfilling this commitment, the consumer may pay their current debt with a predetermined discount rate. This commitment period is renewed regularly. The study analyzes different scenarios, considering the ratio of the discount to the achieved efficiency commitment, as well as the participation rate. The goal is to achieve an efficiency-discount-participation scenario that does not exceed 50% of the debt, as discounts above 50% would lead to financial losses for the utility. To address various possibilities, three scenarios were considered in this study: a discount equal to, double, and triple the committed efficiency, as well as a random participation rate, discount rate, and efficiency using Monte Carlo simulation. The analytical formulas were solved using Visual Basic coding, and MS-Excel's Solver feature was employed.

Data

The data for this study originate from a doctoral thesis entitled "kWh consumption methodology for energy poverty diagnosis" by Emre (2022a, 2022b). The dataset utilized shares similarities with the one mentioned in the aforementioned thesis and is sourced from the work orders of specific Distribution Companies (DisCos) in various provinces.

Our analysis is founded on data collected over a span of 2 years from the eastern regions of Turkey. We meticulously examined invoices from five electricity distribution companies, which collectively serve a staggering 21 regions. This extensive dataset, which encompasses over 6 million customers (out of a total number of approximately 40 million at that time), offers a comprehensive insight into energy consumption patterns and the financial burdens associated with it.

It is essential to emphasize that these data are not derived from simulated scenarios; rather, they represent authentic records, directly reflecting real-life economic constraints. The adoption of such empirical data presents a valuable opportunity to explore customer profiles and discern behavioral patterns, thereby contributing to a comprehensive understanding of consumer dynamics. Moreover, the significance of the power-cut records extends beyond the scope of this study, as they also serve as a crucial basis for the regulatory authority to formulate an effective tariff structure. The data employed in this research are derived from a licensed meter reading institution, subject to rigorous financial scrutiny, thereby instilling confidence in their accuracy and integrity. Consequently, the credibility of the data remains beyond doubt, ensuring a robust foundation for the ensuing analyses. To safeguard the privacy and confidentiality of individuals, the research approach adopted a meticulous data processing procedure. Specifically, the data underwent a transformation to eliminate any identifying information, mitigating the risk of sensitive debt-related details being deemed as personal information. To further preserve data privacy, no attempt was made to replicate the data based on consumption and payment status. Instead, only the pertinent and verified payment information was utilized, maintaining a balance between data utility and privacy protection. In summary, this study underscores the imperative of relying on trustworthy and genuine data sources, illuminating the complexities of real-world economic constraints and enabling profound insights into customer behavior. The ethical handling and meticulous processing of the data underscore the commitment to uphold privacy standards while facilitating valuable research outcomes in the domain of energy distribution and consumer dynamics.

The 2-year period was specifically chosen to gauge the impacts of recent energy transition initiatives and their resultant effects on energy poverty. Given the rapid evolution of energy policies, both at national and global levels, a time frame shorter than this would not have sufficed in capturing the nuanced changes, while a longer duration might have introduced other confounding factors.

The eastern regions of Turkey were chosen due to their distinctive socio-economic backdrop. Historically, these areas have faced numerous challenges, from infrastructural deficiencies to socio-political dynamics, which have collectively shaped the energy consumption behaviors of its inhabitants. Furthermore, by zeroing in on these regions, we aimed to bring to the fore the disparities and challenges that often remain overshadowed in national discourses.

Data analysis

For the data processing and analysis, we employed both qualitative and quantitative approaches:

Quantitative analysis: Utilizing statistical tools, we dissected the raw data to ascertain patterns in energy consumption. This involved a rigorous segmentation of the data based on various parameters such as household size, income brackets, and payment regularity. Regression models were also employed to determine the factors influencing the high incidence of energy debts.

Qualitative analysis: To complement the numerical insights, we conducted interviews with key stakeholders—from policymakers to community leaders and consumers. These interviews enriched our understanding by shedding light on the lived experiences of those grappling with energy poverty.

Drawing parallels with the European energy transition

To enrich our findings and derive actionable insights, we incorporated a comparative dimension with Europe's energy transition experience. By exploring the European Union's multifaceted strategies, we sought to extract lessons, opportunities, and potential roadmap considerations for Turkey.

This comparison revolved around:

Studying the EU's regulatory and institutional mechanisms crafted to counteract energy poverty.

Delving into the variety of interventions, both monetary and advisory, introduced by the EU to better the conditions for households facing energy poverty.

Engaging with European energy experts to grasp the depth of policy strategies and their real-world implications.

Our methodological design, combining primary data, external sources, and expert engagements, aspires to present a comprehensive understanding of energy poverty in eastern Turkey, while also benefiting from insights from the European framework.

Data availability

To ensure the confidentiality and protection of sensitive information, the data used in this study are not publicly accessible. Revealing such information could potentially impact the commercial standing of the operating companies. To maintain the privacy of all parties involved, we have deliberately concealed the names of the electricity distribution companies throughout the study and its results.

Analysis results

The analytical problem focuses on determining a discount rate tied to the productivity rate. The goal is to ensure a collected debt above 50% of the total. The "participation rate" indicates the percentage of consumers joining the program, agreeing to reduce consumption in return for a discounted debt rate. By analyzing different scenarios using mathematical models and simulations, this study aims to strike an optimal efficiency–discount–participation balance, ensuring a high participation rate without financial losses for the utility company. The data are sourced from a doctoral thesis, with company names obscured for confidentiality.

Monte Carlo simulation for debt collection rate

The Monte Carlo method is used to simulate various scenarios and assess the debt collection rate. The total debt is divided into 10 categories for clear understanding, and 5000 simulations are run for each debt category, considering different combinations of discount and participation rates. The success of each scenario is determined by whether the collection rate is above 50%, which is considered a risk-free threshold.

Scenario-1: Discount rate equal to the efficiency ratio

The study findings demonstrated that, on average, the collection rate reached an impressive 88% of the total debt (see Fig. 6). This surpasses the critical 50% threshold, indicating that a discount rate equal to the efficiency ratio proves to be a successful scenario, with no losses incurred. The proposed mechanism exhibits its effectiveness in reducing consumers' debt while ensuring the utility company's financial stability.

Scenario-2: Discount rate twice the efficiency ratio

In this more assertive scenario, the average collection rate amounted to 74% of the debt (see Fig. 7). Encouragingly, only a marginal 0.42% of scenarios fell below the 50% threshold, highlighting the relatively low risk involved. While Scenario-2 carries slightly higher risk compared to Scenario-1, it remains a feasible option categorized as a "Slight Risk Scenario". By adopting this approach, there is still significant potential to effectively reduce debt while prudently managing the financial risk for the utility company.

Scenario-3: Discount rate three times the efficiency ratio

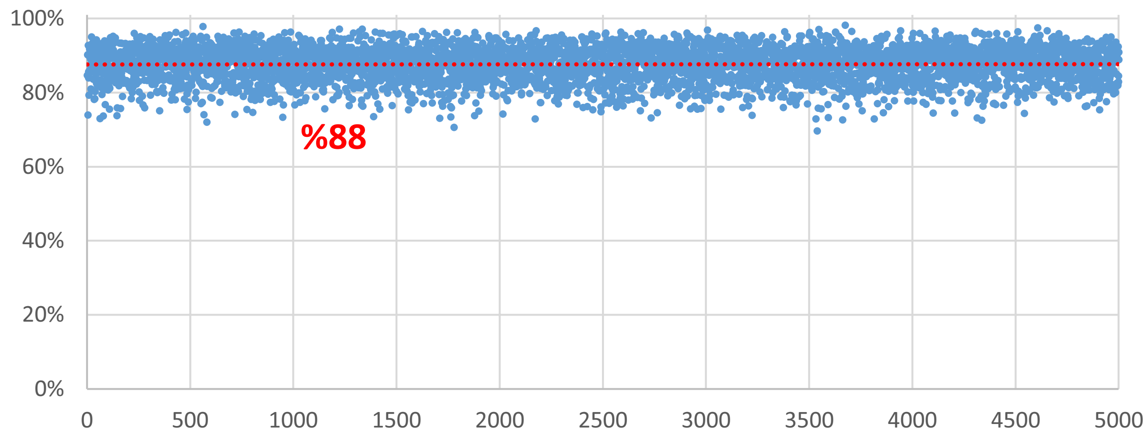

Fig. 6 Distribution of the collection in Monte Carlo simulation

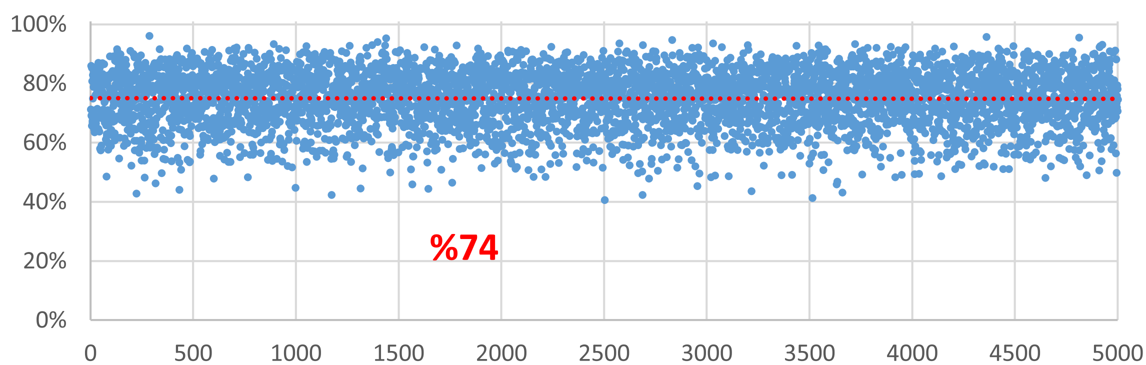

Fig. 7 Distribution of the collection in Monte Carlo simulation

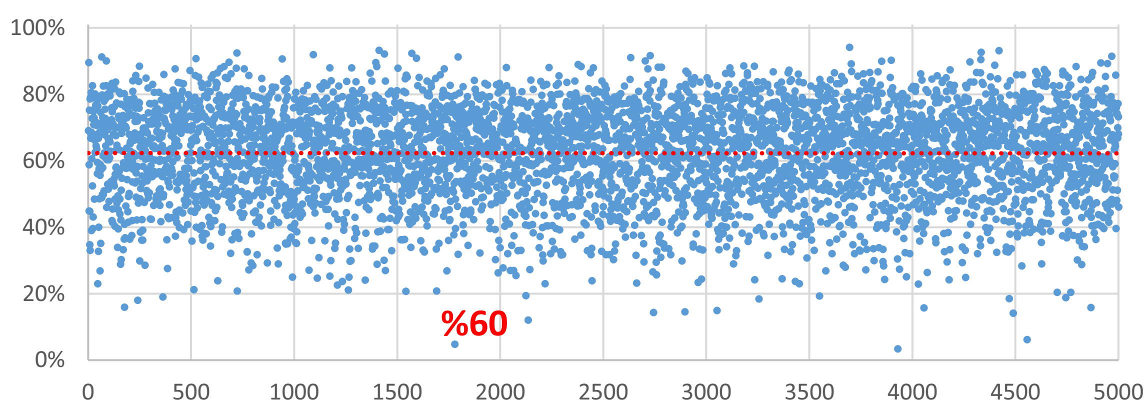

Fig. 8 Distribution of the collection in Monte Carlo simulation

Scenario-3 aims to explore the limits of the program by using a discount rate three times the efficiency ratio. The average collection rate in this scenario is 60% of the debt (see Fig. 8). Approximately one-third of the scenarios have collection rates below 50%. While the average collection rate is still above 50%, the high tolerance of 20% suggests that this scenario is a "Risky Scenario" with less viability compared to the previous scenarios.

In summary, the results obtained from the Monte Carlo simulations present compelling evidence in favor of Scenario-1, where the discount rate equals the efficiency ratio. This approach proves to be successful and effective in achieving the desired objectives. Moving on to Scenario-2, which involves a double discount rate, it remains a feasible option, though slightly riskier compared to the first scenario. However, we need to exercise caution with Scenario-3, as the triple discount rate appears to be an extreme and less viable choice due to the increased risk of collection rates falling below the desired threshold.

These valuable insights shed light on the potential outcomes of the proposed mechanism for reducing debt while ensuring the financial stability of the utility company. By carefully considering the different scenarios, we can make informed decisions to enhance the overall effectiveness and sustainability of the proposed approach.

Optimization approach for debt collection

In this study, we take a pragmatic approach to effectively address energy poverty (EP) by incorporating different debt levels. The segmentation of data based on debt amounts has proven to be a powerful strategy. We have classified the data into ten distinct categories, ranging from debts less than 100 TL to those between 900 and 1000 TL.

Our primary goal is to optimize the money collected through the discount program while ensuring a collection rate above the crucial 50% threshold to avoid any risk of bankruptcy. To achieve this, we have introduced a variable known as the participation rate, which enables us to tailor solutions to cater to varying EP levels.

In formulating the optimization problem, we have considered essential constraints. For instance, we have carefully ensured that the discount rate for higher debt categories must not be lower than that of lower debt categories. Additionally, we have put a cap on the sum of discount rates for all categories, preventing it from exceeding half of the total debt sum, thus safeguarding financial stability.

Practical considerations were also taken into account, such as the participation rate being confined to a real number between 0 and 1, and the efficiency lying within the range of 0 to 0.5.

By diligently respecting these constraints, we have crafted a tailored solution that aligns with the specific requirements of different EP levels. This bespoke approach optimizes debt collection while effectively mitigating any potential losses.

Our analysis of Scenario-1 and Scenario-2, where the discount rate is twice the efficiency ratio, has yielded encouraging results. Notably, all households in each category participate with a 100% rate, resulting in an average collection rate exceeding 50%. This positive outcome signifies that these scenarios are not loss-making and bodes well for the efficacy of our approach.

With these promising findings as a starting point, we are committed to pursuing further optimization and fine-tuning of the discount program. Our dedication to iterative improvement will enable us to craft even more effective measures in combating energy poverty and providing vital support to vulnerable households.

In Scenario-2, the MS Excel-Solver platform was used to find the optimal combination of discount rate and participation rate that satisfies the constraints and maximizes collection rate. With 22% efficiency, the program achieved 100% participation and maintained a collection rate above 50%. The optimization approach effectively tailored the discount and participation rates for different debt categories, leading to a more efficient solution for EP.

In Scenario-3, where the discount is three times the efficiency ratio, the MS Excel-Solver platform found an optimal solution that maximizes the collection rate. With 14% efficiency, 100% participation was achieved while adhering to optimization constraints. These constraints consider efficiency not exceeding 50% and applying different discounts to each debt category.

Overall, the results from all three scenarios demonstrate the feasibility of finding effective solutions through optimization while considering various levels of EP. This approach offers valuable insights for addressing EP and improving debt collection rates. Further optimization and fine-tuning of the discount program can lead to even better outcomes.

Solution with Descent Algorithm

The Descent Algorithm is a powerful iterative method employed to find the optimal solution for the given optimization problem, characterized by the objective function and constraints. Unlike traditional mathematical approaches like the Solver platform, the Descent Algorithm dynamically adjusts the discount rate and participation rate based on the gradient of the objective function and constraints. This iterative process leads to the convergence of the algorithm towards the most suitable solution that maximizes the collection rate while respecting the specified conditions.

The results derived from the implementation of the Descent Algorithm align consistently with those obtained from the Solver platform (because of speed of detailed solution and of course accuracy), validating its efficacy and reliability as a solution approach for this specific problem. Notably, the relationship between the participation rate and the discount rate follows a fascinating parabolic pattern. As the discount rate increases, the participation rate initially rises until it reaches a saturation point. Conversely, lower participation rates are observed at lower discount rates.

To optimize the discount program while safeguarding against potential bankruptcy, a function representing the intricate relationship between the participation rate and the discount rate was formulated. This function serves as the cornerstone for an algorithm that skillfully optimizes both rates, while adhering to the specified constraints, ultimately maximizing the collection rate.

Based on the available data, a precise representation of this relationship is found in the function: participation = some root of discount. The derivation of this function is supported by the findings of Emre T.'s doctoral thesis, titled "kWh consumption methodology for energy poverty diagnosis" (Ph.D. Thesis, 2022b).

The algorithm operates through iterative calculations to determine the optimal discount rate and participation rate, continually adjusting their values and validating if they satisfy the constraints. The final outcome is a combination of the discount rate and participation rate that maximizes the collection rate while ensuring it remains above the pivotal 50% threshold, thereby ensuring the financial viability of the discount program.

Connection between the earlier analyses and trends

Over the past 2 years, energy consumption has notably increased in Turkey's eastern regions. This growth has been more pronounced in urban areas, attributed to factors like urbanization, technological adoption, and intensified industrial activities. Recognizing these trends is vital as they set the context for our analysis and findings, highlighting the pressing need for efficient energy solutions and policies.

Financial challenges and energy debts

Financial challenges linked to energy consumption are at the forefront. A significant percentage of the populace faced difficulties in settling their energy bills promptly, leading to accruing debts. The regression models underscored that lower income levels, coupled with a lack of energy-efficient appliances, were primary factors driving these debts.

Stakeholder perspectives on energy poverty

The qualitative inputs provided a more layered understanding. Policymakers often cited the challenging balancing act between promoting sustainable energy transitions and ensuring affordability. Regional leaders stressed the need for more decentralized energy solutions, while consumers shared their daily struggles, often having to make hard choices between basic needs due to escalating energy costs.

The European experience: a comparative analysis

The European Union, with its progressive approach to energy transition, offers valuable lessons. Several member states have successfully integrated renewable energy sources, championed energy-efficient solutions, and implemented policies that balance both environmental and economic imperatives. Their robust legal frameworks and financial initiatives serve as an inspiration. Literature tells us eastern-south eastern European countries have similarities with Turkey's eastern parts.

Regulatory and institutional mechanisms: the EU's emphasis on a cohesive regulatory framework has been pivotal. Institutional support, in the form of advisory bodies and collaborative platforms, aids member states in navigating the complex terrain of energy transition while keeping affordability in focus.

Interventions against energy poverty: across the EU, myriad interventions are in place to aid households grappling with energy costs. From subsidized energy-efficient appliances to financial incentives for adopting renewable energy solutions, there's a strong push to alleviate the strain on economically vulnerable households.

When juxtaposed with Turkey's eastern regions, the EU's successes underscore the potential gains of a more integrated and strategic approach.

Results are parallel with the European Projects such as ComAct which applied to Bulgaria, Ukraine, Hungary, Lithuania, Makedonia and optimal saving calculation as per condition of the house, heating system, etc., by offering a clear methodology for efficiency and EP mitigation (ComACT, 2023).

Poorpower Project on the other side defines "energy poverty", urges countries to set more ambitious energy efficiency goals (Poorpower, 2023). SocialWatt Project confirmed the energy-poor population live mainly at the eastern European countries (SocialWatt, 2023).

Insights from supplementary references

Shahzad et al. (2022) emphasize the interplay between resolving energy poverty and instigating social change. The paper pinpoints areas where energy affordability can drive larger societal benefits.

Zhao et al. (2022) delve into the impacts of bilateral trade on energy affordability, highlighting the crucial role economic globalization plays. Their insights resonate with Turkey's own trade dynamics and potential levers to enhance energy affordability.

Druică et al. (2019) provide an interesting vantage point, linking energy poverty with life satisfaction. Their findings, suggesting a direct correlation between energy accessibility and well-being, accentuate the human dimension of our study.

Conclusion and policy implications

Energy poverty (EP) is a central challenge in the contemporary global energy scenario. In areas like eastern Turkey, intertwined socio-economic factors and energy consumption intricacies make addressing EP imperative for social justice, economic stability, and sustainable development.

Fluctuating electricity market dynamics, impacted by rising prices and natural disasters, deeply influence end consumers. These high-level dynamics have tangible implications at the grassroots level, leading to households facing energy bill pressures, communities dealing with inconsistent power access, and regions confronting unauthorized consumption and wastage.

Our research highlighted the challenges of defining and gauging EP. While conventional income-based methods provide insights, they may miss granular realities. In contrast, the power-cut index per consumer (PCPC) offers an actionable metric, emphasizing areas requiring immediate attention in economically vulnerable regions.

Recognizing EP's magnitude is just the beginning. Tackling its repercussions requires innovative solutions, cooperative endeavors, and unwavering commitment. Our proposed strategy encourages post power-cut consumption reduction, coupling it with incentives like discounted debt rates. This approach fosters financial prudence and endorses energy conservation.

Utilizing the Monte Carlo simulation and optimization techniques, we propose adaptable strategies for diverse EP scenarios. These methods translate theories into feasible, data-backed solutions, balancing the fiscal health of energy providers with consumers' essential needs.

Our findings suggest that resolving energy poverty is not solely dependent on new regulations or additional funds. Energy poverty relief can be funded by revisiting the legal strategies for unresolved utility bills. Numerous opportunities exist to enhance utility firms' financial efficiency. Operational efficiency, reflected in tariffs, presents a viable strategy to fund EP alleviation efforts. Furthermore, this study accentuates the potential of boosting resources for EP through improved public awareness.

Europe's approach to energy transition offers a blueprint for Turkey. The EU's structured frameworks, prioritizing environmental sustainability and economic objectives, can guide Turkish policymakers. Merging localized insights from eastern Turkey with European strategies creates a comprehensive plan addressing regional specifics and global standards.

However, policies are most potent when anchored in real-life narratives. Our exploration delved into stories of individuals and communities impacted by EP. These accounts, from households making tough decisions to communities brainstorming solutions, underscore the human side of EP. They remind us that statistics represent human tales of aspiration, adversity, and tenacity.

The references added to our study widen our analytical spectrum. Exploring the nexus between EP and societal shifts, understanding trade dynamics' effects on energy costs, and connecting energy access to holistic well-being metrics enrich our conclusions and open avenues for subsequent research.

In summary, as global energy challenges loom, EP solutions hinge on our innovative, cooperative, and determined efforts. It's more than just providing affordable energy access; it's about envisioning energy as a conduit to prosperity. By bolstering public cognizance, fostering multi-stakeholder cooperation, and emphasizing the energy sector's societal role, we can aspire for a future devoid of energy poverty.

Tackling EP is a collaborative obligation—involving energy infrastructure firms, governmental entities, NGOs, and the public at large. United, we can brighten homes, ignite aspirations, and pave a more inclusive future for everyone.

Author contributions

TE: Conceived and design the analysis, collected the data, contributed data and analysis tools, performed the analysis, wrote the paper. AS: Conceived and design the analysis, contributed data analysis, contributed the paper writing.

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Declarations

Competing interests

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