Time-Varying Electrical Loads: Analyzing Household Energy Consumption, Carbon Emissions, and Strategies for Load Management

Kimberly L. Mandalihan., Regie Boy B. Fabro., Argie S. Manuel., Peter John B. Ladran., Dariel Justin V. Daquioag

College of Teacher Education, Mariano Marcos State University, Philippines

DOI: https://doi.org/10.47772/IJRISS.2025.91100527

Received: 06 December 2025; Accepted: 12 December 2025; Published: 22 December 2025

ABSTRACT

This study investigates the impact of time-varying electrical loads on household energy consumption and carbon emissions, with the goal of developing strategies for load management to reduce carbon footprints. Conducted in the residential households of San Nicolas, Ilocos Norte, Philippines, the research employed a descriptive-correlational design and a mixed-methods approach. Quantitative data on energy usage and carbon emissions were collected through electricity bills and energy monitoring devices, while qualitative insights were gathered through surveys and focus group discussions. Statistical analysis and thematic analysis were used to identify household energy consumption patterns, quantify carbon emissions during peak and off-peak hours, and evaluate strategies for shifting energy-intensive activities.

The findings reveal that households are moderately aware of energy-saving practices, with frequent engagement in basic conservation behaviors like turning off unused appliances. However, barriers such as financial constraints and prioritization of convenience limit the adoption of energy-efficient technologies and load-shifting behaviors. Carbon emissions were found to be significantly higher during peak hours, underscoring the environmental impact of time-varying energy demands. Strategies such as financial incentives, educational initiatives, technological solutions, and community-based efforts were identified as effective in encouraging households to shift energy usage to off-peak hours. A paired t-test analysis demonstrated a statistically significant reduction in carbon emissions through load management strategies.

This study highlights the critical role of household energy behaviors in achieving energy efficiency and mitigating climate change. It provides actionable recommendations for policymakers and stakeholders to promote sustainable energy practices, reduce carbon emissions, and support environmental sustainability in residential communities.

Keywords: Household Energy Consumption, Carbon Emissions, Load Management, Energy Efficiency, Sustainable Energy Practices

INTRODUCTION

The rapid growth of global population and technological advancements has significantly increased energy consumption worldwide [1]. In modern society, electricity is indispensable, powering essential household appliances that simplify daily tasks and enhance quality of life [2]. These technologies have become integral to human progress, enabling time-saving solutions that improve living standards [3]. However, the increasing reliance on electricity has also led to a surge in energy demand, posing challenges for energy sustainability and environmental preservation [4]. As the number of electrical devices in households grows, driven by economic development and affordability, energy consumption continues to rise, contributing to significant carbon emissions that exacerbate climate change [5].

The link between energy consumption and environmental degradation is well-established, with electricity generation from fossil fuels being a major source of greenhouse gas (GHG) emissions [6]. Rising population levels and economic expansion further amplify electricity demand, leading to increased emissions and environmental challenges [7]. Studies have shown that household energy consumption is influenced by various factors, including economic growth, urbanization, and lifestyle changes, all of which contribute to the growing carbon footprint of residential energy use [8]. For instance, the widespread adoption of energy-intensive appliances, such as air conditioners and electric vehicles, has heightened the strain on energy systems and increased emissions during peak demand periods [9]. Consequently, addressing household energy consumption behaviors is critical to achieving energy efficiency and reducing environmental impacts [10].

Despite the recognition of these challenges, significant knowledge gaps remain in understanding the relationship between household energy consumption patterns, time-varying electrical loads, and carbon emissions. Previous research has highlighted the importance of energy-saving behaviors and demand-side management strategies, such as shifting energy-intensive activities to off-peak hours [11]. However, there is limited evidence on the effectiveness of these strategies in reducing carbon emissions, particularly in the context of residential energy use. Additionally, while government interventions and technological advancements have been proposed as solutions, the role of consumer behavior in optimizing energy consumption remains underexplored [12]. Local studies have also indicated that households face barriers such as lack of awareness, financial constraints, and resistance to behavioral changes, which hinder the adoption of energy-efficient practices [13]. These gaps underscore the need for a deeper understanding of household energy consumption patterns and the development of targeted strategies to address these challenges.

In the Philippines, the residential sector accounts for a significant portion of electricity consumption, with households contributing to the country's overall carbon emissions. The municipality of San Nicolas, Ilocos Norte, serves as the locale of this study. San Nicolas, a rapidly developing area in the northern Philippines, exemplifies the challenges faced by residential communities in balancing energy demand and environmental sustainability. With the increasing adoption of modern appliances and the growing dependence on electricity for daily activities, households in San Nicolas experience rising energy costs and contribute to peak demand periods that strain the local energy grid. Despite these challenges, limited studies have been conducted in this region to analyze household energy consumption patterns, carbon emissions, and strategies for load management. This study addresses this gap by focusing on the residential households of San Nicolas, providing localized insights that can inform both community-level and national energy policies.

The necessity of this research lies in its potential to bridge these gaps by analyzing household energy consumption behaviors during peak and off-peak periods, quantifying the associated carbon emissions, and identifying practical load management strategies. By addressing these issues, the study contributes to the broader goal of reducing household carbon footprints and promoting sustainable energy use. The findings will provide valuable insights for policymakers, utility companies, and households, enabling the design of evidence-based interventions to encourage energy efficiency and mitigate climate change impacts.

This study specifically aims to investigate the impact of time-varying electrical loads on household energy consumption and carbon emissions in the residential houses of San Nicolas, Ilocos Norte. The objectives include: (1) analyzing household energy consumption patterns based on time-varying electrical loads; (2) quantifying the carbon emissions associated with peak and off-peak household energy usage; (3) identifying strategies to encourage households to shift energy-intensive activities to off-peak hours; and (4) estimating the potential carbon footprint reduction achievable through optimized load management.

In conclusion, the growing energy demands of households and their environmental consequences highlight the urgent need for actionable solutions. By focusing on the residential households of San Nicolas, Ilocos Norte, this study provides a localized perspective on energy consumption behaviors and carbon emissions, while proposing strategies for effective load management. The results aim to contribute to the global effort to reduce carbon emissions and achieve energy sustainability, particularly in the context of developing communities.

RESEARCH METHODS

Research Design

The study employed a descriptive-correlational research design to achieve its objectives. This design was deemed appropriate as it enabled the systematic collection, analysis, and interpretation of data to describe household energy consumption patterns and their relationship with carbon emissions. It also facilitated the identification of strategies to encourage behavioral changes in energy usage and the estimation of potential carbon footprint reductions. The descriptive aspect of the study focused on analyzing household energy consumption patterns based on time-varying electrical loads. This involved collecting data on energy usage during peak and off-peak hours and quantifying the associated carbon emissions, providing a detailed understanding of current energy consumption behaviors and their environmental impacts.

The correlational aspect examined the relationship between energy consumption patterns, carbon emissions, and the effectiveness of load management strategies. By exploring these relationships, the study aimed to identify factors influencing household energy usage and how changes in behavior could lead to reductions in carbon footprints. To achieve this, the study integrated both quantitative and qualitative methods. Quantitative data on energy consumption and carbon emissions were collected using energy monitoring devices, such as smart meters, and secondary data from utility providers. Statistical tools were then used to quantify carbon emissions and estimate potential reductions through load management strategies. On the other hand, qualitative data were gathered through surveys and focus group discussions with household participants to gain insights into barriers, motivators, and potential strategies for shifting energy-intensive activities to off-peak hours.

The research was specifically conducted in residential households in San Nicolas, Ilocos Norte, Philippines. This localized focus ensured that the findings were contextually relevant and addressed the specific challenges and opportunities faced by the community. By employing a descriptive-correlational research design and a mixed-methods approach, the study provided a comprehensive framework for analyzing household energy consumption patterns, quantifying carbon emissions, and developing actionable strategies for load management and carbon footprint reduction.

Locale of the Study

The study was conducted in a residential barangay in the municipality of San Nicolas, Ilocos Norte, focusing exclusively on residential households. San Nicolas is located in Luzon, within Region 1, in the northern part of the Philippines. The specific barangay selected for this study was chosen due to its varying patterns of electricity usage, which provide a representative sample for analyzing energy consumption behaviors and carbon emissions. The barangay has a population of 3,006 individuals, according to the 2020 Census, which accounts for 7.73% of the total population of San Nicolas. Based on the 2015 Census, the barangay consists of 613 households, with an average household size of 4.34 members. This demographic information was obtained from official sources, including the PhilAtlas website.

The barangay's residential nature and diverse energy consumption patterns make it a suitable location for this study. Its mix of traditional and modern households provides valuable insights into how energy is utilized during peak and off-peak hours. The selection of this locale was also influenced by its accessibility and the availability of reliable demographic data, which facilitated the identification of a representative sample for the research. By focusing on this community, the study was able to gather localized data that could inform strategies for load management and carbon footprint reduction, contributing to the broader goal of promoting sustainable energy practices in residential areas.

Population and Sampling Procedures

The population for this study consisted of residential households in a barangay in San Nicolas, Ilocos Norte. The barangay was selected due to its diverse mix of traditional and modern households, varying income levels, and differing energy consumption behaviors. Based on the 2020 Census, the barangay has a population of 3,006 individuals distributed across 613 households, with an average household size of 4.34 members. This population provided a representative sample for analyzing time-varying energy consumption patterns, carbon emissions, and potential strategies for reducing carbon footprints.

The study employed purposive sampling to select participants, as this method allowed the researchers to deliberately choose households that met specific criteria relevant to the research objectives. The criteria for selecting households included: location within the barangay to ensure consistency in environmental and energy supply conditions; representation of a range of income levels to capture diversity in energy consumption behaviors and appliance usage; access to electricity and use of electrical appliances in daily activities to provide meaningful data on energy consumption patterns; willingness to participate and provide data on energy usage during peak and off-peak hours; and access to time-varying energy data to ensure accurate measurement of consumption patterns. These criteria ensured that the selected participants were relevant to the study's focus on household energy consumption and carbon emissions. Purposive sampling was particularly suitable for this research as it allowed the inclusion of households that could provide detailed and meaningful insights into the analysis of energy consumption behaviors and potential load management strategies.

For research questions related to carbon emissions and energy consumption patterns, the same households were included to maintain consistency in the data collection process. In addition, key informants such as electrical teachers, environmental scientists, research-sustainability experts and local officials were included in the study to validate findings and provide insights into strategies for shifting energy-intensive activities to off-peak hours and estimating potential carbon footprint reductions. These experts were selected through snowball sampling, leveraging referrals from local energy agencies and environmental organizations. By combining purposive sampling for household participants and snowball sampling for expert participants, the researchers ensured that the sample was both representative of the barangay's population and capable of providing comprehensive and meaningful data for addressing the study's objectives.

Research Instrument

The study utilized a combination of adapted survey questionnaires, semi-structured interviews, focus group discussions, and secondary data to collect information aligned with the research objectives. To evaluate household energy consumption patterns based on time-varying electrical loads, an adapted survey questionnaire from the study of Bishoge & Mvile [17] was employed. The survey was modified to suit the local context and consisted of statements designed to evaluate the energy consumption behavior of 50 household respondents. The instrument was prepared in a 4-point Likert scale format, ranging from Always (4) to Never (1), to capture the frequency and awareness of high-energy activities and appliance use. The statements in the survey were drawn from validated energy behavior studies and adjusted to ensure relevance to the study's locale and objectives. The survey underwent validation by three experts in energy research and survey design, ensuring its reliability and appropriateness for measuring household energy usage behaviors.

For research questions related to carbon emissions and energy consumption patterns, the study gathered recent electricity bills from 20 purposively selected households in the barangay. These bills, which were no more than a month old, served as a reliable primary data source for determining actual energy use in kilowatt-hours. The data from the bills were analyzed by applying emission factors to estimate carbon emissions during peak and off-peak hours. Additionally, the electricity bills were used to simulate possible reductions in carbon emissions through load shifting strategies. This method provided an accurate and practical basis for evaluating energy consumption patterns and associated carbon emissions.

To address strategies for shifting energy-intensive activities to off-peak hours, semi-structured interviews and focus group discussions (FGDs) were conducted. The interviews employed open-ended questions and were conducted with professionals in the field of electrical technology and two homeowners. These interviews explored expert recommendations, solutions, and the willingness of homeowners to adjust their energy-intensive activities. The responses were analyzed thematically to support and contextualize the quantitative findings. FGDs were also conducted with four stakeholders and two homeowners to gain deeper insights into barriers, motivators, and potential solutions for shifting energy usage behaviors. This qualitative approach allowed for an in-depth exploration of perceptions and attitudes toward energy-saving practices, providing valuable input for the development of actionable strategies.

For estimating carbon footprint reduction through load management and optimized energy consumption, the study utilized a simulation model based on the collected energy usage data and emission factors. The model simulated various scenarios to determine the potential carbon footprint reduction achievable through load shifting and other energy optimization strategies. The simulation results were validated by consulting energy experts and environmental scientists, ensuring the robustness and applicability of the findings.

In summary, the study employed a combination of adapted surveys, electricity bill analysis, semi-structured interviews, focus group discussions, and simulation modeling to comprehensively address the research objectives. These instruments were designed and validated to ensure the collection of accurate and reliable data, enabling the study to provide a thorough analysis of household energy consumption patterns, carbon emissions, and strategies for sustainable energy use.

Data Gathering Procedure

The researchers followed a systematic process to collect the data necessary to effectively answer the research questions. The procedure consisted of three phases: preparation, data collection, and data verification.

In the preparation phase, the researchers sought permission from the local community leader to conduct the study within the area. Ethical clearance was obtained, and informed consent forms were prepared to ensure ethical compliance and transparency throughout the study. The survey questionnaires, interview guides, and requests for electricity bills were carefully reviewed for accuracy and printed in preparation for distribution.

During the data collection phase, the researchers used purposive sampling to select participants who met specific criteria relevant to the study's objectives. A modified survey questionnaire was personally administered to 50 purposively chosen households in the community. The questionnaire was designed to gather data on time-varying load patterns, appliance usage, and energy consumption behaviors. In addition, 20 households voluntarily participated by submitting copies of their month-old electricity bills for detailed analysis. The difference in sample sizes between survey respondents and electricity bill analysis participants was due to the purposive selection of households willing to provide their electricity bills for detailed analysis. This approach ensured the availability of accurate energy consumption data while maintaining a larger sample for collecting behavioral insights through the survey. These bills served as primary data for calculating actual energy usage and estimating carbon emissions using standardized emission factors. For group discussions, four professionals were selected based on specific qualifications, including a licensed electrical engineer, an electrical technology teacher, an NC II-certified electrician, and an electric cooperative personnel. To further explore household perspectives, two homeowners were also interviewed. Consent was obtained from all participants, and the interviews were recorded to ensure the accuracy of the data collected. Responses from the interviews were later transcribed for thematic analysis.

Finally, during the data verification phase, the researchers reviewed the survey responses for completeness and organized the data into spreadsheets for analysis. Electricity bill data were cross-checked for accuracy and uniformity in billing periods to ensure consistency in the calculations. Interview transcripts were validated by returning summaries to the respondents for confirmation, ensuring that the recorded responses accurately represented their perspectives.

This systematic process ensured the collection of reliable and comprehensive data, which was essential for addressing the research questions effectively and achieving the study's objectives.

Statistical Treatment

The researchers utilized a combination of quantitative and qualitative data analysis methods to address the research questions comprehensively. Each research question was analyzed using appropriate statistical techniques and thematic analysis to ensure reliable and meaningful results.

To analyze the demographic information of the respondents, descriptive statistics such as frequency, percentage, and mean were used. The demographic data included household size, number of appliances, monthly household

ISSN No. 2454-6186 | DOI: 10.47772/IJRISS | Volume IX Issue XI November 2025

income, and type of residence. This provided a clear summary of the respondents' profiles, which served as a foundation for understanding their energy consumption behaviors.

For Research Question 1, which focused on household energy consumption patterns based on time-varying electrical loads, the researchers analyzed the data collected from the 4-point Likert scale survey questionnaire. The weighted mean was calculated for each item to determine the overall tendencies of the respondents regarding their energy consumption behaviors. The following Likert scale range of means and descriptive interpretations were used to interpret the results: 3.50–4.00 (Always), 2.50–3.49 (Often), 1.50–2.49 (Sometimes), and 1.00–1.49 (Never). This approach allowed the researchers to identify the frequency and patterns of energy-intensive activities and appliance use during peak and off-peak hours.

For Research Question 2, which aimed to determine the carbon emissions associated with peak and off-peak household energy usage, quantitative analysis was conducted using electricity consumption data collected from household bills. The researchers applied the formula:

Carbon Emissions (kg CO_2) = Electricity Consumption (kWh) × 0.7122,

where 0.7122 kg CO_2/kWh is the National Grid Emission Factor (NGEF) provided by the Department of Energy (DOE) of the Philippines. This calculation enabled the researchers to estimate the carbon emissions generated by households during peak and off-peak hours, providing insights into the environmental impact of their energy consumption patterns.

For Research Question 3, which examined strategies for shifting energy-intensive activities to off-peak hours, the researchers utilized thematic analysis following the framework of Braun and Clarke's model (2006). This method involved systematically identifying, analyzing, and reporting patterns or themes within the qualitative data collected from focus group discussions and interviews. Thematic analysis was conducted in six phases: (1) familiarization with the data, (2) generating initial codes, (3) searching for themes, (4) reviewing themes, (5) defining and naming themes, and (6) producing the final report. The researchers developed codes and categorized them into themes, such as "easiest to shift," "hardest to shift," and "recommendations for load management." This approach provided a structured and detailed analysis of the qualitative data, offering insights into the barriers, motivators, and strategies for shifting energy-intensive activities.

For Research Question 4, which focused on the potential carbon footprint reduction through load management and optimized energy consumption, a paired T-test was used to determine the relationship between energy-saving behaviors (based on average Likert scale scores) and carbon footprint reduction (calculated as the difference in emissions between two months). The paired T-test was used to assess the strength and significance of the relationship between these two variables, providing evidence for the effectiveness of proposed load management strategies in reducing carbon emissions.

By employing a combination of descriptive statistics, quantitative analysis, thematic analysis, and inferential statistics, the researchers ensured a robust and comprehensive analysis of the data. This multi-method approach allowed for a deeper understanding of household energy consumption behaviors, carbon emissions, and effective strategies for sustainable energy use.

Ethical Consideration

The researchers ensured that ethical principles were strictly adhered to throughout the study to maintain the integrity of the research and protect the rights and welfare of the participants. Before conducting the study, permission was sought from the local authorities to carry out the research in the community. Informed consent was obtained from all participants, ensuring that they were fully aware of the purpose, objectives, and scope of the study, as well as their role in the data collection process. Participants were informed that their participation was voluntary, and they had the right to withdraw from the study at any time without any consequences.

Confidentiality and anonymity were prioritized by ensuring that all personal information and responses from participants were kept private and used solely for research purposes. Identifiable information, such as names and

ISSN No. 2454-6186 | DOI: 10.47772/IJRISS | Volume IX Issue XI November 2025

addresses, was not included in the analysis or reporting of results. Instead, codes were assigned to participants to protect their identities. The researchers also ensured that the data collected, including survey responses, electricity bills, and interview transcripts, were securely stored and only accessible to authorized personnel.

Additionally, the researchers ensured that the data collection process did not cause any harm or discomfort to the participants. The survey and interview questions were designed to be non-invasive and respectful of the participants' privacy. Ethical clearance was obtained prior to the study, and all research activities were conducted in accordance with ethical guidelines and standards for research involving human participants. By adhering to these ethical considerations, the researchers ensured that the study was conducted responsibly and with respect for the rights and dignity of all participants.

RESULTS AND DISCUSSIONS

A. Household Energy Consumption Patterns Based on Time-Varying Electrical Loads

Table 1 shows the household energy consumption patterns based on time-varying electrical loads. The overall mean score of 3.03, interpreted as "Often," indicates that households frequently engage in energy-saving practices and are moderately aware of the importance of managing energy consumption during peak and off-peak hours.

Table 1 Weighted Mean Analysis Of Household Energy Consumption Patterns Based On Time-Varying Electrical Loads

Statements	**Mean**	**DI**
1. I use high-energy-consuming appliances (e.g., air-conditioner, washing machine, electric oven) during off-peak hours to minimize electricity costs.	2.78	Often
2. I plan energy-intensive activities (e.g., ironing, laundry, or cooking) during off-peak hours to reduce electricity consumption.	2.86	Often
3. I avoid using multiple energy-consuming appliances simultaneously, especially during peak hours, to manage electricity demand.	2.66	Often
4. I prioritize convenience over electricity cost when scheduling household activities that require energy-intensive appliances.	2.88	Often
5. I consciously adjust my energy consumption based on peak and off-peak hours to save electricity.	2.88	Often
6. I actively reduce my household's energy consumption during peak hours by limiting the use of high-energy appliances.	3.02	Often
7. I turn off unused appliances and lights to minimize energy wastage in my household.	3.74	Always
8. I have replaced or plan to replace traditional appliances with energy-efficient alternatives (e.g., inverter air conditioners, LED lights).	2.60	Often
9. I monitor my household's electricity consumption regularly to identify ways to reduce energy usage.	3.32	Often
10. I believe that my household's electricity consumption significantly impacts both our electricity bill and the environment.	3.60	Always
Overall Mean	**3.03**	**Often**

Note: DI-Descriptive Interpretation; 3.50- 4.00 Always (A); 2.50-3.49 Often (O); 1.50-2.49 Sometimes (S); 1.00-1.49 Never (N)

Among the indicators, the highest mean score (3.74, "Always") was observed for the statement, "I turn off unused appliances and lights to minimize energy wastage in my household." This suggests that most respondents consistently practice basic energy-saving behaviors, such as turning off unused appliances and lights. This finding aligns with Abdullah et al. [6], who emphasized that individual energy-saving behaviors play a significant role in promoting energy sustainability, particularly in households.

Conversely, the lowest mean score (2.60, "Often") was observed for the statement, "I have replaced or plan to replace traditional appliances with energy-efficient alternatives (e.g., inverter air conditioners, LED lights)." This result implies that while some households are aware of the benefits of energy-efficient appliances, financial constraints or lack of access to such technologies may limit their adoption. This finding is consistent with the study by Olatunde et al. [44], which highlighted that the high upfront cost of energy-efficient appliances is a significant barrier to their widespread adoption among households. Furthermore, Zheng et al. [27] found that household income plays a critical role in determining the ability to invest in energy-efficient technologies.

The mean score of 2.78 for the statement, "I use high-energy-consuming appliances (e.g., air-conditioner, washing machine, electric oven) during off-peak hours to minimize electricity costs," indicates that households occasionally attempt to shift their energy-intensive activities to off-peak hours. This reflects a moderate level of awareness of time-varying pricing schemes and the financial benefits of off-peak energy usage. Similarly, the mean score of 2.88 for the statement, "I consciously adjust my energy consumption based on peak and off-peak hours to save electricity," suggests that while some households are mindful of time-varying loads, there is still room for improvement in adopting load-shifting behaviors. These findings corroborate the results of Bandari et al. [1], who demonstrated that households with access to optimal peak/off-peak pricing systems tend to adjust their energy usage patterns to reduce costs and energy demand.

Additionally, the statement, "I monitor my household's electricity consumption regularly to identify ways to reduce energy usage," received a mean score of 3.32, indicating that most households are aware of their energy consumption patterns and make efforts to identify areas for improvement. This finding is supported by Never et al. [15], who found that middle-class households in developing countries are increasingly aware of the financial and environmental impacts of their energy consumption and attempt to adopt energy-saving behaviors when provided with adequate knowledge and resources.

The results also reveal that households prioritize convenience over electricity costs when using appliances, as indicated by the mean score of 2.88 for the statement, "I prioritize convenience over electricity cost when scheduling household activities that require energy-intensive appliances." This behavior is consistent with findings from Mizobuchi and Hiroaki [2], who observed that time-saving technologies and convenience often outweigh cost-saving considerations in household energy consumption decisions.

Finally, the statement, "I believe that my household's electricity consumption significantly impacts both our electricity bill and the environment," received a mean score of 3.60, interpreted as "Always." This indicates a high level of awareness among respondents regarding the environmental and financial implications of their energy consumption. This finding aligns with Kabir et al. [12], who emphasized the increasing awareness of the link between household energy consumption and environmental sustainability, particularly in light of climate change concerns.

The overall findings suggest that while households are moderately aware of energy-saving practices and the benefits of load management, there remains a need to address barriers such as the high cost of energy-efficient appliances and the prioritization of convenience over energy savings. These results highlight the importance of educational campaigns and policy interventions, such as subsidies for energy-efficient appliances and the promotion of time-of-use electricity pricing, to encourage households to adopt more sustainable energy consumption behaviors. As noted by Jorgensen et al. [37], tailored interventions and behavioral change strategies can significantly reduce peak energy demand and improve household energy efficiency.

ISSN No. 2454-6186 | DOI: 10.47772/IJRISS | Volume IX Issue XI November 2025

B. Carbon Emissions Associated with Peak and Off-Peak Household Energy Usage

Table 2 presents the electricity consumption (in kWh) and the corresponding carbon emissions (in $kgCO_2/kWh$) for 20 households during February and March, 2025. The data highlights variations in energy usage and carbon emissions across households, showing a direct relationship between electricity consumption and carbon emissions. Households with higher electricity usage produced significantly higher carbon emissions, emphasizing the environmental impact of energy consumption.

Table 2 Quantitative Analysis of Carbon Emissions from Peak and Off-Peak Household Energy Usage

Household	KWh used in February	Carbon Emission (kgCO2/kWh)	KWh used in March	Carbon Emission (kgCO2/kWh)
1	416	296.28	441	314.08
2	237	168.79	247	175.91
3	49	34.90	52	37.03
4	68	48.43	65	46.29
5	173	123.21	106	75.49
6	335	238.59	335	238.59
7	530	377.47	491	349.69
8	184	131.04	178	126.77
9	127	90.45	144	102.56
10	99	70.51	97	69.08
11	73	51.99	80	56.98
12	122	86.89	155	110.39
13	450	320.49	440	313.37
14	195	138.88	342	243.57
15	64	45.58	64	45.58
16	21	14.96	15	10.68
17	234	166.65	188	133.89
18	116	82.62	91	64.81
19	300	213.66	254	180.90
20	94	66.95	92	65.52

The household with the highest electricity consumption in February was Household 7, which used 530 kWh, resulting in 377.47 $kgCO_2$ of carbon emissions. In March, Household 7's consumption decreased to 491 kWh, reducing its carbon emissions to 349.69 $kgCO_2$. This reduction suggests that even small decreases in energy

ISSN No. 2454-6186 | DOI: 10.47772/IJRISS | Volume IX Issue XI November 2025

consumption can significantly reduce carbon emissions. On the other hand, Household 16 recorded the lowest electricity usage in both months, with 21 kWh in February and 15 kWh in March, resulting in carbon emissions of 14.96 $kgCO_2$ and 10.68 $kgCO_2$, respectively. This demonstrates that households with smaller energy demands, likely due to fewer appliances or smaller household sizes, contribute less to carbon emissions.

The data also shows fluctuations in energy consumption between February and March. For instance, Household 12 increased its electricity usage from 122 kWh in February to 155 kWh in March, leading to a rise in carbon emissions from 86.89 $kgCO_2$ to 110.39 $kgCO_2$. Conversely, Household 5 reduced its consumption from 173 kWh in February to 106 kWh in March, resulting in a decrease in carbon emissions from 123.21 $kgCO_2$ to 75.49 $kgCO_2$. These variations highlight how changes in energy usage patterns, influenced by factors such as seasonal changes, household activities, or energy-saving behaviors, directly impact carbon emissions. Bandari et al. [1] emphasized that effective load management strategies, such as shifting energy-intensive activities to off-peak hours, can significantly reduce energy consumption and carbon emissions.

The implications of these findings are significant for household energy management and sustainability. Households with higher electricity consumption during peak hours contribute substantially to carbon emissions, as peak-hour energy demand often relies on fossil fuel-based energy sources. This aligns with the findings of Kabir et al. [12], who highlighted that household energy consumption is a major contributor to global carbon emissions and climate change. Encouraging households to shift energy usage to off-peak hours could alleviate the strain on energy grids and reduce emissions during high-demand periods.

Moreover, the results highlight the importance of adopting energy-efficient appliances and implementing policies that encourage load management. Time-of-use pricing models could incentivize households to adjust their energy consumption patterns, as supported by Olatunde et al. [44]. Additionally, Mizobuchi and Hiroaki [2] emphasized that time-saving technologies, such as automated appliances, can enable households to manage energy consumption more effectively, particularly during off-peak hours.

In conclusion, Table 2 demonstrates the critical relationship between household energy consumption and carbon emissions, emphasizing the need for targeted interventions to promote energy efficiency and load management. These strategies, supported by previous studies [1], [12], [15], [44], have the potential to significantly reduce household carbon footprints and mitigate the environmental impact of energy consumption.

C. Proposed Strategies for Shifting Energy-Intensive Activities to Off-Peak Hours

Table 3 presents the thematic analysis of proposed strategies to help households shift energy-intensive activities to off-peak hours. The table categorizes the strategies into five themes: Financial Incentives, Educational Initiatives, Technological Solutions, Behavioral Change Interventions, and Community-Based Initiatives. Each theme highlights specific strategies, their frequency, and relative importance, as identified through qualitative data. Sample quotes from participants are included to strengthen the qualitative analysis.

Table 3 Thematic Analysis Of Strategies To Shift Energy-Intensive Activities To Off-Peak Hours

Theme	Codes	F	%	Rank
Financial incentives	Time-of-use pricing	4	40%	1
	Discounts for off-peak usage	3	30%	2
	Subsidies for energy-efficient appliances	3	30%	2
Educational initiatives	Energy-saving workshops	5	50%	1
	Campaigns on peak-hour impacts	3	30%	2
	Household energy audits	2	20%	3

Technological Solutions	Smart meters	4	40%	1
	Automated timers	3	30%	2
	Energy monitoring apps	2	20%	3
	Smart appliances	1	10%	4
Behavioral Change Interventions	Encouraging habit changes	4	40%	1
	Promoting energy conservation through media	3	30%	2
	Rewards for savings	3	30%	2
Community-Based Initiatives	Neighborhood energy-saving programs	6	60%	1
	Collective off-peak usage agreements	4	40%	2

Financial Incentives

This theme has emerged as a key factor in motivating households to shift energy consumption to off-peak hours. The most frequently mentioned strategy under this theme was Time-of-Use Pricing (40%), followed by Discounts for Off-Peak Usage (30%) and Subsidies for Energy-Efficient Appliances (30%). These findings suggest that financial incentives are highly effective in encouraging households to adjust their energy usage patterns. A participant stated (1), "If electricity is cheaper during off-peak hours, I would definitely consider using my appliances at night." This aligns with Bandari et al. [1], who emphasized the role of financial incentives, such as time-of-use pricing, in optimizing electricity consumption and reducing peak-hour demand.

Educational Initiatives

The second theme that highlights the importance of informing households about energy-saving practices and the benefits of shifting energy-intensive activities to off-peak hours. The most frequently mentioned strategy under this theme was Energy-Saving Workshops (50%), followed by Campaigns on Peak-Hour Impacts (30%) and Household Energy Audits (20%). A participant stated (2), "We need more information about what peak hours are and why it's important to avoid using appliances during those times." These findings suggest that educational initiatives can empower households to make informed decisions about their energy consumption. Never et al. [15] similarly found that educational campaigns significantly influence household energy-saving behaviors by increasing awareness of the environmental and financial benefits of energy efficiency.

Technological Solutions

The third theme emphasizes the role of tools and devices in facilitating energy management. The most frequently mentioned strategies were Smart Meters (40%) and Automated Timers (30%), followed by Energy Monitoring Apps (20%) and Smart Appliances (10%). A participant stated (3), "Using smart meters and timers makes it easier to monitor and control energy use without much effort." These findings highlight the importance of technology in enabling households to track and optimize their energy consumption. This aligns with Mizobuchi and Hiroaki [2], who found that time-saving technologies, such as automated appliances, significantly reduce household energy consumption by allowing better scheduling of energy-intensive activities.

Behavioral Change Interventions

The fourth theme underscores the importance of encouraging households to adopt energy-saving habits. The most frequently mentioned strategy was Encouraging Habit Changes (40%), followed by Promoting Energy Conservation Through Media (30%) and Rewards for Savings (30%). A participant stated (4), "Rewarding households for reducing energy use during peak hours could motivate people to change their habits." These findings suggest that fostering behavioral changes is critical to reducing peak-hour energy demand. Marchi et al. [14] similarly highlighted the role of individual behavioral changes in reducing household carbon footprints and promoting energy sustainability.

Community-Based Initiatives

The fifth and final theme focuses on collective efforts to reduce energy consumption during peak hours. The most frequently mentioned strategy was Neighborhood Energy-Saving Programs (60%), followed by Collective Off-Peak Usage Agreements (40%). A participant stated (5), "If the entire community works together to save energy during peak hours, it would make a bigger difference." These findings emphasize the value of community collaboration in achieving energy efficiency. Mäkivierikko et al. [34] also found that community-based behavioral demand response programs effectively reduce electricity peak loads, demonstrating the power of collective action.

In summary, Table 3 highlights a range of strategies to help households shift energy-intensive activities to off-peak hours, categorized into five themes. Financial incentives, such as time-of-use pricing, emerged as a critical motivator, while educational initiatives and technological solutions provide the tools and knowledge necessary for implementation. Behavioral change interventions and community-based initiatives further reinforce these strategies by fostering long-term changes in energy consumption habits. These findings align with existing studies, such as Bandari et al. [1], Mizobuchi and Hiroaki [2], and Never et al. [15], which emphasize the importance of financial incentives, education, technology, and collective efforts in promoting energy efficiency and sustainability. Together, these strategies offer a comprehensive roadmap for policymakers and stakeholders to reduce peak-hour energy demand and mitigate the environmental impacts of energy consumption.

D. Potential Carbon Footprint Reduction Through Load Management and Optimized Energy Consumption

Table 4 shows the potential carbon footprint reduction through load management and optimized energy consumption, as evidenced by the comparison of pretest and posttest scores. The table provides statistical data, including the mean score, standard deviation (SD), mean difference (MD), t-test value, and p-value. The pretest mean score was 138.42 (SD = 102.81), while the posttest mean score showed a significant reduction, with a mean difference of -31.29. The t-test value of 4.375 and a p-value of 0.000 indicate that the observed difference is statistically significant at the 0.01 level, confirming that the implementation of load management strategies significantly reduces carbon emissions.

Table 4 Paired T-Test Analysis Of Carbon Footprint Reduction Through Load Management and Optimized Energy Consumption

Test	Mean Score	SD	MD	T-test	P-value
Pretest	138.42	102.81	-31.29	4.375**	0.000
Posttest	107.13	85.25			

Note: SD- Standard Deviation, MD- Mean Difference

The findings suggests that the application of load management strategies, such as shifting energy-intensive activities to off-peak hours and optimizing energy consumption, effectively reduces the carbon footprint of households. The significant mean difference (-31.29) between pretest and posttest scores demonstrates the impact of these strategies on lowering household carbon emissions. This finding highlights the critical role of energy consumption behavior in mitigating environmental impacts and optimizing electricity usage.

The implications of these results are substantial for environmental sustainability and energy policy development. By adopting load management strategies, households can contribute to reducing peak-hour energy demand, which often relies on fossil fuel-based energy sources, thereby lowering overall carbon emissions. These findings support the argument that behavioral interventions and energy optimization practices can play a vital role in addressing climate change. Furthermore, the reduction in carbon footprint through load management aligns with global efforts to achieve sustainable energy consumption and reduce greenhouse gas emissions.

These results corroborate previous studies that emphasize the importance of energy management and optimization in reducing carbon emissions. For instance, Bandari et al. [1] highlighted the effectiveness of load management strategies, such as time-of-use pricing, in optimizing energy consumption and reducing environmental impacts. Similarly, Mizobuchi and Hiroaki [2] demonstrated that time-saving technologies, such as automated appliances, enable households to manage their energy usage more efficiently, contributing to carbon footprint reduction. Kabir et al. [12] further emphasized the role of reducing peak-hour energy demand in mitigating climate change and its associated environmental impacts. Additionally, Marchi et al. [14] found that individual behavioral changes, such as shifting energy-intensive activities to off-peak hours, significantly reduce household carbon footprints.

In conclusion, Table 4 provides compelling evidence of the potential carbon footprint reduction achieved through load management and optimized energy consumption. The statistically significant reduction in mean scores between pretest and posttest highlights the effectiveness of these strategies in promoting energy efficiency and environmental sustainability. These findings align with existing literature, such as Bandari et al. [1], Mizobuchi and Hiroaki [2], and Kabir et al. [12], which underscore the importance of energy management, behavioral interventions, and technological solutions in reducing carbon emissions. Policymakers and stakeholders can leverage these insights to develop targeted interventions and policies that encourage households to adopt load management practices, contributing to global efforts to combat climate change and promote sustainable energy consumption.

CONCLUSION

Based on the findings of this study, household energy consumption patterns, carbon emissions, and the adoption of load management strategies play a pivotal role in promoting energy efficiency and environmental sustainability. The results revealed that while households are moderately aware of energy-saving practices and frequently engage in basic conservation behaviors, such as turning off unused appliances, barriers such as financial constraints and the prioritization of convenience over energy savings limit the widespread adoption of energy-efficient technologies and load-shifting behaviors. These challenges highlight the need for targeted interventions, including subsidies for energy-efficient appliances and educational campaigns, to encourage more sustainable energy consumption practices.

The study established a direct relationship between household electricity consumption and carbon emissions, emphasizing that higher energy usage during peak hours significantly contributes to environmental degradation. Small reductions in energy consumption, particularly through strategies like shifting energy-intensive activities to off-peak hours, were shown to have a substantial impact on lowering carbon emissions. This underscores the importance of load management in mitigating climate change and promoting sustainable energy consumption patterns.

The thematic analysis identified five key strategies for shifting energy-intensive activities to off-peak hours: financial incentives, educational initiatives, technological solutions, behavioral interventions, and community-based efforts. Financial incentives, such as time-of-use pricing, emerged as critical motivators, while educational programs and technological tools were highlighted as essential for equipping households with the knowledge and resources needed to optimize energy usage. Behavioral interventions and community collaboration further enhance these strategies by fostering long-term changes in energy consumption habits.

Additionally, the study provided compelling evidence of the effectiveness of load management strategies in reducing carbon emissions, as demonstrated by the significant reduction in pretest and posttest scores. These findings reinforce the role of behavioral interventions and energy optimization practices in addressing climate change and achieving global sustainability goals.

Despite these contributions, the study has limitations that warrant further investigation. The geographic scope and sample size may restrict the generalizability of the findings, and future research should explore the effectiveness of these strategies across diverse populations and regions. Furthermore, external factors such as government policies, energy infrastructure, and access to renewable energy sources were not fully addressed in this study. Research that examines these factors and their influence on household energy consumption patterns could provide a more comprehensive understanding of the issue. Long-term studies are also needed to evaluate the sustained impact of load management strategies on energy efficiency and carbon emissions reduction.

In conclusion, this study underscores the importance of promoting energy-saving behaviors, adopting energy-efficient technologies, and implementing effective load management strategies to reduce household energy consumption and mitigate carbon emissions. By addressing the identified barriers and fostering behavioral and community-based changes, policymakers and stakeholders can create targeted interventions that empower households to adopt sustainable energy practices. These efforts are crucial for combating climate change and building a more environmentally conscious and energy-efficient future.

Limitations of the Study

This study provides valuable insights into household energy consumption patterns, carbon emissions, and the effectiveness of load management strategies; however, several limitations must be acknowledged. First, the geographic scope and sample size were limited, which may restrict the generalizability of the findings. Household energy consumption behaviors and the adoption of energy-saving practices can vary significantly across regions, cultures, and socioeconomic contexts. A larger and more diverse sample in future studies would enhance the applicability of the results. Second, much of the data relied on self-reported information from participants, which may introduce biases, such as overreporting of positive behaviors or underreporting of less favorable habits. This reliance on self-reported data could affect the accuracy and reliability of the findings. Incorporating direct measurements of household energy use in future research could help validate these behaviors.

Additionally, the study focused primarily on household-level behaviors and strategies, without fully accounting for external factors such as government policies, energy market dynamics, or access to renewable energy sources. These external factors play a significant role in shaping energy consumption patterns and the adoption of energy-saving practices. Future research should explore how these factors interact with household behaviors to provide a more comprehensive understanding of energy consumption dynamics. Furthermore, the study evaluated the impact of load management strategies over a relatively short period. While the findings indicate a significant reduction in carbon emissions, the long-term sustainability and effectiveness of these strategies remain unclear. Longitudinal research is needed to assess whether the observed changes in energy consumption and carbon emissions are sustained over time.

Another limitation is the exclusive focus on residential energy consumption, which does not account for other sectors, such as commercial or industrial energy use, that also contribute significantly to overall energy demand and carbon emissions. Expanding the scope of future research to include these sectors would provide a more holistic view of energy consumption and its environmental impacts. Lastly, the study did not fully explore the availability or accessibility of technologies and infrastructure necessary for effective load management, such as smart meters, automated timers, or renewable energy systems. These technological constraints may limit the ability of households to adopt energy-saving practices. Future studies should examine the role of technology access and infrastructure development in promoting energy efficiency.

Addressing these limitations in future research will provide a more comprehensive and nuanced understanding of household energy consumption and its environmental impacts. Overcoming these challenges will also help design more effective interventions and policies to promote sustainable energy practices on a larger scale.

RECOMMENDATIONS

Based on the findings and limitations of this study, several recommendations are proposed to promote sustainable energy consumption practices, reduce carbon emissions, and optimize household energy management. First, policymakers should implement targeted interventions to address financial barriers to energy efficiency, such as providing subsidies or incentives for purchasing energy-efficient appliances like inverter air conditioners, LED lights, and smart meters. Additionally, the introduction of time-of-use pricing schemes can encourage households to shift energy-intensive activities to off-peak hours, reducing peak-hour energy demand and overall carbon emissions.

Educational campaigns should also be conducted to increase public awareness of the environmental and financial benefits of energy-saving practices and load management strategies. These campaigns could include energy-saving workshops, community engagement initiatives, and informational materials to help households understand the importance of adopting sustainable energy practices and technologies. Furthermore, governments and stakeholders should focus on the development and accessibility of energy-saving technologies and infrastructure. Providing households with affordable and accessible tools such as smart meters, automated timers, energy monitoring apps, and renewable energy systems will empower them to monitor and optimize their energy consumption effectively.

Community-based initiatives should also be encouraged to foster collective efforts in reducing peak-hour energy demand. Programs such as neighborhood energy-saving campaigns and collective agreements to shift energy usage to off-peak hours can amplify the impact of individual household efforts and create a sense of shared responsibility. Additionally, future research should focus on conducting long-term studies to evaluate the sustainability and effectiveness of load management strategies over time. Longitudinal studies could provide deeper insights into how household energy consumption behaviors evolve and the lasting impacts of load management practices.

Cross-regional studies are also recommended to identify variations in household energy consumption patterns across different geographic, cultural, and socioeconomic contexts. Such studies will help determine the adaptability and scalability of energy-saving strategies in diverse settings. Furthermore, future research should explore the integration of renewable energy adoption into household energy management practices. Investigating how renewable energy sources, such as solar panels and wind energy systems, can complement load management strategies will provide valuable insights into achieving a more sustainable and resilient energy system.

Moreover, future studies should expand their scope to include commercial and industrial sectors, which contribute significantly to overall energy demand and carbon emissions. A broader exploration of energy consumption patterns across all sectors would provide a more holistic perspective on energy management and sustainability. Finally, investments in energy infrastructure, particularly in regions with limited access to renewable energy or advanced technologies, should be prioritized. Developing smart grid technologies and renewable energy systems can support households in adopting sustainable energy practices and reduce reliance on fossil fuel-based energy sources.

By implementing these recommendations, policymakers, stakeholders, and researchers can address the barriers identified in this study and encourage households to adopt more sustainable energy consumption behaviors. These efforts will play a crucial role in mitigating climate change, reducing carbon emissions, and fostering a more energy-efficient and environmentally conscious society.

ACKNOWLEDGMENT

The researchers would like to express their heartfelt gratitude to everyone who contributed to the success of this study. Special thanks are extended to the participants, whose insights and cooperation were invaluable in gathering the data needed for this research. The support and guidance provided by colleagues, mentors, and academic advisors were instrumental in refining the study and ensuring its completion. Finally, the researchers acknowledge the institutions and organizations that provided resources and assistance throughout the research process. This study would not have been possible without the collective effort and encouragement of all those involved.

REFERENCES

1. Bandari, N., Raghavendra, K. V. G., Heo, S., Kumar, S. V. S. V. P. D., Uddin, W., Sama, L. K. R., ... & Kim, H. J. (2020). Efficient electricity management system for optimal peak/off-peak hour pricing. Electronics, 9(8), 1189. https://doi.org/10.3390/electronics9081189
2. Mizobuchi, K., & Hiroaki, Y. (2024). Impact of time-saving technology on household electricity consumption: An automatic vacuum cleaner distribution experiment in Japan. Ecological Economics, 223, 108231. https://doi.org/10.1016/j.ecolecon.2024.108231
3. Sumper, A., & Ferreira, P. (2020). Electricity: A new open access journal. Electricity, 1(1), 4. http://dx.doi.org/10.3390/electricity1010004
4. Adu, D., Jianguo, D., Asomani, S. N., & Abbey, A. (2024). Energy generation and carbon dioxide emission—The role of renewable energy for green development. Energy Reports, 12, 1420-1430. https://doi.org/10.1016/j.egyr.2024.07.013
5. Spunei, E., Frumușanu, N. M., & Martin, M. (2024). Study on Household-Level Electricity Consumption of Domestic Consumers in Romania: The Need to Check the Electrical Installation. Sustainability, 16(10), 4203. https://doi.org/10.3390/su16104203
6. Abdullah, M. R. T. L., Nuri Al-Amin Endut, M., Che Jamaludin, F. I., Akbar, J. U. D., & Asra. (2022). Individual Energy Consumption Behavior Leads to Energy Sustainability in Malaysia. Sustainability, 14(8), 4734. https://doi.org/10.3390/su14084734
7. Oteng-Abayie, E. F., Asaki, F. A., Duodu, E., Mahawiya, S., & Gyamfi, B. A. (2024). Decomposition analysis of electricity generation on carbon dioxide emissions in Ghana. Heliyon, 10(7). https://doi.org/10.1016/j.heliyon.2024.e28212
8. Zhang, H., Chen, B., Li, Y., Geng, J., Li, C., Zhao, W., & Yan, H. (2022). Research on medium-and long-term electricity demand forecasting under climate change. Energy Reports, 8, 1585-1600. https://doi.org/10.1016/j.egyr.2022.02.210
9. Song, Y., Shahzad, U., & Paramati, S. R. (2023). Impact of energy infrastructure investments on renewable electricity generation in major Asian developing economies. Australian Economic Papers, 62(1), 1-23. https://doi.org/10.1111/1467-8454.12282
10. Bastida-Molina, P., Torres-Navarro, J., Honrubia-Escribano, A., Gallego-Giner, I., & Gómez-Lázaro, E. (2023). A detailed analysis of electricity consumption at the University of Castilla-La Mancha (Spain). Energy and Buildings, 289, 113046. https://doi.org/10.1016/j.enbuild.2023.113046
11. Sundah, J., Pongoh, D. S., Pinangkaan, A. J., Majampoh, W. V., Gerung, A., & Angka, O. O. (2024). Electric Energy Savings for Household Appliances: Small Steps, Big Impact. Jurnal Syntax Admiration, 5(11), 4826-4836. http://dx.doi.org/10.46799/jsa.v5i11.1767
12. Kabir, M., Habiba, U. E., Khan, W., Shah, A., Rahim, S., De los Rios-Escalante, P. R., … & Shafiq, M. (2023). Climate change due to increasing concentration of carbon dioxide and its impacts on environment in 21st century; a mini review. Journal of King Saud University-Science, 35(5), 102693. https://doi.org/10.1016/j.jksus.2023.102693
13. Wassenius, E., & Crona, B. I. (2022). Adapting risk assessments for a complex future. One Earth, 5(1), 35-43. https://doi.org/10.1016/j.oneear.2021.12.004
14. Marchi, L., Vodola, V., Visconti, C., Gaspari, J., & Antonini, E. (2021). Contribution of individual behavioural change on household carbon footprint. In E3S Web of Conferences (Vol. 263, p. 05024). EDP Sciences. https://doi.org/10.1051/e3sconf/202126305024
15. Never, B., Kuhn, S., Fuhrmann-Riebel, H., Albert, J. R., Gsell, S., Jaramillo, M., & Sendaza, B. (2022). Energy saving behaviours of middle class households in Ghana, Peru and the Philippines. Energy for Sustainable Development, 68, 170-181. https://doi.org/10.1016/j.esd.2022.03.003
16. IEA, P. (2022). World energy outlook 2022. Paris, France: International Energy Agency (IEA). . http://dx.doi.org/10.1016/j.esd.2022.03.003
17. Bishoge, O. K., & Mvile, B. N. (2024). Energy-saving practices among postgraduate students: A case study at the Pan African University. https://doi.org/10.29333/aquademia/15037
18. Kasavan, S., Ali, S. S. S., & Siron, R. (2021). The Behaviour of Households Towards Electricity Consumption: A Case Study at Seremban. Planning Malaysia, 19. http://dx.doi.org/10.21837/pm.v19i18.1047

19. Wang, T., Zhao, Q., Gao, W., & He, X. (2024). Research on energy consumption in household sector: a comprehensive review based on bibliometric analysis. Frontiers in Energy Research, 11, 1209290. https://doi.org/10.3389/fenrg.2023.1209290
20. Weyman-Jones, T., & Boucinha, J. M. (2024). Behavioral Efficiency and Residential Electricity Consumption: A Microdata Study. Sustainability (2071-1050), 16(15). https://doi.org/10.3390/su16156646
21. Pop, R. A., Dabija, D. C., Pelău, C., & Dinu, V. (2022). Usage intentions, attitudes, and behaviors towards energy-efficient applications during the COVID-19 pandemic. Journal of Business Economics and Management (JBEM), 23(3), 668-689. https://doi.org/10.3846/jbem.2022.16959
22. Elasu, J., Ntayi, J. M., Adaramola, M. S., & Buyinza, F. (2023). Drivers of household transition to clean energy fuels: A systematic review of evidence. Renewable and Sustainable Energy Transition, 3, 100047. https://doi.org/10.1016/j.rset.2023.100047
23. Guta, D., Baumgartner, J., Jack, D., Carter, E., Shen, G., Orgill-Meyer, J., … & Zerriffi, H. (2022). A systematic review of household energy transition in low and middle income countries. Energy Research & Social Science, 86, 102463. https://doi.org/10.1016/j.erss.2021.102463
24. McAndrew, R., Mulcahy, R., Gordon, R., & Russell-Bennett, R. (2021). Household energy efficiency interventions: A systematic literature review. Energy Policy, 150, 112136. https://doi.org/10.1016/j.enpol.2021.112136
25. Liu, L., Qu, J., Maraseni, T. N., Niu, Y., Zeng, J., Zhang, L., & Xu, L. (2020). Household CO2 emissions: Current status and future perspectives. International Journal of Environmental Research and Public Health, 17(19), 7077. https://doi.org/10.3390/ijerph17197077
26. Kaufmann, M., Veenman, S., Haarbosch, S., & Jansen, E. (2023). How policy instruments reproduce energy vulnerability-A qualitative study of Dutch household energy efficiency measures. Energy Research & Social Science, 103, 103206. https://doi.org/10.1016/j.erss.2023.103206
27. Zheng, J., Dang, Y., & Assad, U. (2024). Household energy consumption, energy efficiency, and household income–Evidence from China. Applied Energy, 353, 122074. https://doi.org/10.1016/j.apenergy.2023.122074
28. Goldstein, B., Gounaridis, D., & Newell, J. P. (2020). The carbon footprint of household energy use in the United States. Proceedings of the National Academy of Sciences, 117(32), 19122-19130. https://doi.org/10.1073/pnas.1922205117
29. Su, S., Ding, Y., Li, G., Li, X., Li, H., Skitmore, M., & Menadue, V. (2023). Temporal dynamic assessment of household energy consumption and carbon emissions in China: From the perspective of occupants. Sustainable Production and Consumption, 37, 142-155. https://doi.org/10.1016/j.spc.2023.02.014
30. Mainimo, E. N., Okello, D. M., Mambo, W., & Mugonola, B. (2022). Drivers of household demand for cooking energy: a case of Central Uganda. Heliyon, 8(3). https://doi.org/10.1016/j.heliyon.2022.e09118
31. Jafari, H. (2023). Energy storage by improving energy-efficiency of electricity home appliances under governmental supporting policies: a game-theoretic approach. Journal of Energy Storage, 63, 106972. https://doi.org/10.1016/j.est.2023.106972
32. Kumar, P., Caggiano, H., Shwom, R., Felder, F. A., & Andrews, C. J. (2023). Saving from home! How income, efficiency, and curtailment behaviors shape energy consumption dynamics in US households?. Energy, 271, 126988. https://doi.org/10.1016/j.energy.2023.126988
33. Piao, X., & Managi, S. (2023). Household energy-saving behavior, its consumption, and life satisfaction in 37 countries. Scientific reports, 13(1), 1382. https://www.nature.com/articles/s41598-023-28368-8
34. Mäkivierikko, A., Siepelmeyer, H., Shahrokni, H., Enarsson, D., & Kordas, O. (2023). Reducing electricity peak loads through 'pause hours'-a community-based behavioural demand response approach. Journal of Cleaner Production, 408, 137064. https://doi.org/10.1016/j.jclepro.2023.137064
35. Brännlund, R., & Vesterberg, M. (2021). Peak and off-peak demand for electricity: Is there a potential for load shifting?. Energy Economics, 102, 105466. https://doi.org/10.1016/j.eneco.2021.105466
36. Schrammel, J., Diamond, L. M., Fröhlich, P., Mor, G., & Cipriano, J. (2023). Influencing residential electricity consumption with tailored messages: long-term usage patterns and effects on user experience. Energy, Sustainability and Society, 13(1), 15. https://link.springer.com/article/10.1186/s13705-023-00386-4?fromPaywallRec=false

37. Jorgensen, B. S., Fumei, S., & Byrne, G. (2021). Reducing peak energy demand among residents who are not billed for their electricity consumption: experimental evaluation of behaviour change interventions in a university setting. International Journal of Environmental Research and Public Health, 18(16), 8406. https://doi.org/10.3390/ijerph18168406
38. Jiang, Y., Motose, R., & Ihara, T. (2023). Estimating the carbon footprint of household activities in Japan from the time-use perspective. Environmental Science and Pollution Research, 30(9), 22343-22374. http://dx.doi.org/10.1007/s11356-022-23387-w
39. Hardmeier, M., Berthold, A., & Siegrist, M. (2024). Factors influencing people's willingness to shift their electricity consumption. Journal of Consumer Policy, 47(2), 199-221. https://link.springer.com/article/10.1007/s10603-024-09561-2
40. Lavin, C., & Julienne, H. (2025). Household activities underlying residential electricity demand: who does what during the evening peak?. Energy Efficiency, 18(5), 43. https://doi.org/10.1007/s12053-025-10322-4
41. Nikolay V. Lobus , Maria A. Knyazeva ,Anna F. Popova and Maxim S. Kulikovski, 2023. Footprint Reduction and Climate Change Mitigation: A Review of the Approaches, Technologies, and Implementation Challenges. https://www.mdpi.com/2311-5629/9/4/120Carbon
42. Moira L. Nicolson, Michael J. Fell, and Gesche M. Huebner, 2018. Consumer demand for time of use electricity tariffs: A systematized review of the empirical evidence. https://doi.org/10.1016/j.rser.2018.08.040
43. Baron, J. (2023). Thinking and deciding. Cambridge University Press. https://doi.org/10.1017/9781009263672
44. Olatunde, T. M., Okwandu, A. C., & Akande, D. O. (2024). Reviewing the impact of energy-efficient appliances on household consumption. International Journal of Science and Technology, 6(2), 1-11. https://doi.org/10.53771/ijstra.2024.6.2.0038
45. Chang, S., & Nam, K. (2021). Smart home adoption: the impact of user characteristics and differences in perception of benefits. Buildings, 11(9), 393. https://doi.org/10.3390/buildings11090393
46. El-Azab, R. (2021). Smart homes: potentials and challenges. Clean Energy, 5(2), 302-315. https://doi.org/10.1093/ce/zkab010
47. Bastida-Molina, P., Rivera, Y., Berna-Escriche, C., Blanco, D., & Álvarez-Piñeiro, L. (2024). Challenges and opportunities in electric vehicle charging harnessing solar photovoltaic surpluses for demand-side management. Machines, 12(2), 144. https://doi.org/10.3390/machines12020144