# Assessment of Household Energy Consumption Patterns and Energy Efficiency Measures in Rural and Urban Area: Case Study

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## Dnyaneshwar Kudande, Sheetal Pandya

*Abstract: This research paper investigates household energy consumption patterns and energy efficiency measures in Tamil Nadu, India, with a focus on understanding regional disparities, socio-economic predictors, and implications for energy policy and sustainability. The study employs a quantitative research design, utilizing data from the Tamil Nadu Energy Development Agency (TEDA) Household Energy Consumption Survey conducted in 2023. Analysis includes demographic characteristics, energy consumption patterns, adoption of energy efficiency measures, and socio-economic predictors. Significant disparities in energy consumption between urban and rural households are observed, with urban areas showing higher usage of electricity and LPG, while rural areas rely more on biomass and kerosene. Adoption rates of energy efficiency measures vary between urban and rural households, highlighting the need for targeted interventions to promote equitable energy access. Household income and education level emerge as significant predictors of energy consumption, underscoring the influence of socio-economic factors. The findings contribute to evidence-based policy formulation and implementation, emphasizing the importance of addressing regional disparities and promoting inclusive energy policies for sustainable development.*

*Keywords: Household Energy Consumption, Energy Efficiency, Tamil Nadu, Socio-Economic Factors, Regional Disparities, Sustainable Development*

## I. INTRODUCTION

Energy consumption at the household level has become a critical focus area for environmental policy and energy management, especially in rapidly developing regions like Tamil Nadu [16]. As the world grapples with the challenges of sustainable development and climate change, understanding the nuances of how energy is consumed at the micro-level becomes essential for crafting effective interventions [17].

**Dnyaneshwar Kudande\***, Department of Computer Engineering, Indus Institute of Technology & Engineering, Indus University, Ahmedabad, Gujarat, India. Email ID: dnyaneshwarkudande.22.rs@indusuni.ac.in, dnykud@gmail.com, ORCID ID: 0000-0003-3410-5102

**Sheetal Pandya,** Department of Computer Engineering, Indus Institute of Technology & Engineering, Indus University, Ahmedabad, Gujarat, India. Email ID: sheetalpandya.cse@indusuni.ac.in

Tamil Nadu, with its significant urban and rural populace and diverse energy needs, presents a unique case for studying these dynamics.

The importance of examining household energy consumption patterns lies in their direct implications for energy policy, environmental sustainability, and socio-economic development [18]. Energy consumption in households across Tamil Nadu varies significantly due to differences in socio-economic factors, geographic locations, and accessibility to energy resources. These variations affect not only the energy efficiency measures but also the overall energy policy planning and implementation in the region (Malaiarasan, Felix, & Paramasivam, 2019) [6].

Tamil Nadu's energy consumption pattern is especially intriguing due to its ambitious energy policies and the rapid adoption of renewable energy technologies [19]. The state has been a pioneer in India in terms of installing renewable energy capacities, especially in wind and solar energy, which directly impacts household energy consumption patterns (Ramabose & Ganesan, 2019) [9]. Furthermore, the state's policies towards rural electrification and energy subsidies play a crucial role in shaping the energy consumption behaviors of its residents [20].

Urban areas in Tamil Nadu, such as Chennai and Coimbatore, show a higher propensity towards using electrical appliances and modern energy services, which are less common in rural settings where traditional biomass and non-commercial fuels are still prevalent (Sakthi & Muthuchelian, n.d.) [10]. This dichotomy highlights the need for tailored energy policies that address the specific needs and constraints of different regions within the state.

Moreover, the economic disparities evident in Tamil Nadu's demographic profile suggest that energy consumption is not only a matter of resource availability but also of socio-economic status, where higher income households tend to have higher energy consumption and better access to efficient technologies (Velmurugan & Joseph, 2022) [12]. This scenario presents a unique challenge for energy efficiency programs, which must be designed to be inclusive and accessible to all strata of society.

Given the state's heavy reliance on agriculture and the significant portion of its rural population, the energy consumption patterns in these areas are particularly impactful on the overall energy usage of the state. Studies like those conducted by Manjula and Gopi (2017) indicate that rural households not only consume a substantial portion of energy but also have the potential to shift towards more sustainable practices with adequate policy support [2].

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In conclusion, the study of household energy consumption patterns in Tamil Nadu is of paramount importance for several reasons. It helps in understanding the underlying factors driving energy use, assessing the impact of current energy policies, and identifying gaps where interventions are needed. The insights gained from such studies can guide policymakers to devise more effective strategies that not only improve energy efficiency but also promote environmental sustainability and social equity. By addressing these multifaceted challenges, Tamil Nadu can lead by example in the transition towards a more sustainable and energy-efficient future.

## II. LITERATURE REVIEW

The literature on household energy consumption in Tamil Nadu is both rich and varied, reflecting a range of methodologies and findings. This section reviews several key studies that have significantly contributed to our understanding of energy consumption patterns and the effectiveness of energy efficiency measures in this region.

### A. Malaiarasan, Felix, & Paramasivam (2019)

conducted a comprehensive study on the energy choices and demand across different household types in Tamil Nadu. They employed a survey-based approach, collecting data from over 1,000 households to understand the impact of socio-economic characteristics on energy choice and consumption. Their findings highlight significant disparities in energy consumption patterns between rural and urban households, with rural areas predominantly relying on traditional biomass and urban areas showing higher electricity and LPG usage. This study is crucial as it underscores the need for region-specific energy policies.

### B. Agrawal et al. (2020)

explored the awareness and adoption of energy efficiency measures across Indian households, including Tamil Nadu. Their research utilized a combination of surveys and interviews to gauge the level of awareness among homeowners about energy-saving practices and technologies. They found that while awareness was moderately high, actual adoption rates were significantly lower, suggesting a gap between knowledge and practice. This gap presents a critical area for policy intervention, emphasizing the need for more robust awareness campaigns and incentive structures [1].

### C. Mujeebu & Bano (2022)

examined the energy-saving potential and cost-effectiveness of active energy efficiency measures in residential buildings in warm-humid climates, including Tamil Nadu. Their study utilized simulation models to analyze the impacts of various energy-saving measures such as improved insulation, energy-efficient appliances, and solar heating. The results indicated that these measures could lead to substantial energy savings and were cost-effective over the buildings' lifecycle, providing a compelling case for their broader adoption [7].

### D. Chandel, Sharma, & Marwaha (2016)

reviewed energy efficiency initiatives and regulations for residential buildings across India, with a focus on Tamil Nadu. They critically assessed the existing policies and their implementation, identifying key areas where policy enhancements could lead to better energy efficiency outcomes. Their analysis suggests that while Tamil Nadu has made significant strides in implementing energy efficiency measures, there is still considerable room for improvement, particularly in terms of tightening regulatory frameworks and enhancing enforcement mechanisms [3].

### E. Thapar (2020)

focused on energy consumption behavior in urban Indian households, with specific case studies from Tamil Nadu. Using data analysis, the study highlighted how socio-economic factors like income levels and educational attainment significantly influence energy consumption patterns. Thapar's findings are vital for understanding the behavioral aspects of energy consumption, which can help in designing targeted interventions that address specific consumer segments [8].

### F. Daniel et al. (2009)

developed a methodology for electrical energy system planning in Tamil Nadu, considering the energy-saving measures from the domestic sector. Their approach combined statistical analysis with optimization models to forecast future energy demand and supply scenarios. This study is particularly important as it provides a strategic framework that can help in the planning and implementation of energy policies in Tamil Nadu [4].

The existing literature on household energy consumption in Tamil Nadu provides valuable insights into various factors influencing energy usage and the effectiveness of energy efficiency measures. However, there is a notable gap regarding the comprehensive assessment of household energy consumption patterns and the implementation of energy efficiency measures specifically tailored to the diverse socio-economic and geographic contexts within Tamil Nadu. This study aims to address this gap by conducting a detailed analysis of household energy consumption patterns across urban and rural areas of Tamil Nadu and identifying context-specific energy efficiency measures. Understanding these nuances is crucial for crafting targeted interventions that cater to the unique needs and constraints of different regions, ultimately contributing to more effective energy policy planning and sustainable development in Tamil Nadu [15].

## III. RESEARCH METHODOLOGY

This study employed a quantitative research design to analyze household energy consumption patterns and assess the effectiveness of energy efficiency measures in Tamil Nadu. The primary data source for this research was the Tamil Nadu Energy Development Agency (TEDA) Household Energy Consumption Survey conducted in 2023. The survey collected comprehensive data on energy usage, household demographics, socio-economic factors, and geographic location from a representative sample of households across urban and rural areas of Tamil Nadu.

The survey methodology involved random sampling

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techniques to ensure the representation of diverse households across different districts of Tamil Nadu. Trained surveyors conducted face-to-face interviews with selected households using structured questionnaires designed to capture detailed information on energy consumption behaviors and factors influencing energy use. Additionally, energy consumption data from utility bills and meter readings were obtained to validate self-reported information.

**Table-I: Details of TEDA Household Energy Consumption Survey**

| Aspect | Details |
|---|---|
| Survey Period | January 2023 - March 2023 [14] |
| Sample Size | 2,000 households (1,000 urban, 1,000 rural) |
| Sampling Technique | Random sampling |
| Data Collection Method | Face-to-face interviews with structured |
| | Questionnaires |
| Data Collected | Energy usage, household demographics, socio-economic factors, geographic location |
| Validation Method | Comparison with utility bills and meter |
| | Readings |

The collected data underwent rigorous cleaning and preprocessing to ensure accuracy and consistency. Subsequently, the Statistical Package for the Social Sciences (SPSS) software was employed for data analysis. Descriptive statistics, correlation analysis, and regression models were utilized to examine the relationships between various factors and household energy consumption patterns, as well as to identify significant predictors of energy efficiency.

By employing robust data collection methods and utilizing advanced statistical analysis techniques, this research aimed to provide comprehensive insights into household energy consumption dynamics in Tamil Nadu and inform the development of targeted energy efficiency interventions tailored to the region's specific socio-economic and geographic characteristics.

## IV. RESULTS AND ANALYSIS

### A. Demographic Analysis

**Table-II: Demographic Characteristics of Sampled Households**

| Demographic Variable | Urban Household (n=1,000) | Rural Household (n=1,000) |
|---|---|---|
| Gender Distribution | 53% Male, 47% Female | 48% Male, 52% Female |
| Age Distribution | Mean: 38.5 years | Mean: 45.2 years |
| Education Level | High School: 35% | High School: 18% |
| | Graduate: 45% | Graduate: 12% |
| | Postgraduate: 20% | Postgraduate: 5% |

*Interpretation and Discussion:*

The demographic analysis reveals notable differences between urban and rural households in Tamil Nadu. Urban households exhibit a slightly higher proportion of males compared to females, while rural households show a marginally higher percentage of females. The mean age of

rural residents is higher than that of urban dwellers, indicating an aging population in rural areas. Education levels are higher among urban households, with a larger percentage having completed at least high school education compared to rural households. These demographic variations are essential to consider when analyzing energy consumption patterns and designing targeted energy efficiency interventions.

**Table-III: Household Energy Consumption Patterns**

| Energy Source | Urban Household (kWh/year) | Rural Household (kWh/year) |
|---|---|---|
| Electricity | 4,500 | 2,200 |
| LPG | 1,200 | 500 |
| Biomass | 800 | 1,500 |
| Kerosene | 300 | 600 |

*Interpretation and Discussion:*

Urban households exhibit higher annual energy consumption across all sources compared to rural households. This disparity can be attributed to greater access to modern energy services and higher usage of electrical appliances in urban areas. Electricity constitutes the primary energy source for urban households, accounting for a significant portion of their total consumption, whereas rural households rely more on traditional biomass fuels and kerosene due to limited access to electricity and LPG. Understanding these consumption patterns is crucial for devising strategies to promote energy efficiency and transition towards cleaner and more sustainable energy sources in both urban and rural settings.

**Table-IV: Energy Efficiency Measures Adoption**

| Energy Efficiency Measure | Urban Household (%) | Rural Household (%) |
|---|---|---|
| LED Lighting | 85 | 45 |
| Energy-Efficient Appliances | 70 | 30 |
| Insulation | 40 | 15 |
| Solar Water Heating Systems | 20 | 5 |

*Interpretation and Discussion:*

The adoption of energy efficiency measures varies significantly between urban and rural households. Urban households demonstrate higher rates of adoption across all measures, reflecting greater awareness and access to efficient technologies. LED lighting is the most widely adopted measure in both urban and rural areas, suggesting its perceived effectiveness and affordability. However, the adoption rates for other measures such as energy-efficient appliances and insulation are lower, particularly in rural areas, highlighting the need for targeted interventions to promote their uptake. Solar water heating systems show the lowest adoption rates, indicating potential barriers such as upfront costs and technical complexity.

**Table-V: Correlation Analysis Between Socio-Economic Factors and Energy Consumption**

| Socio-Economic Factor | Electricity Consumption | LPG Consumption | Biomass Consumption | Kerosene Consumption |
|---|---|---|---|---|
| Household Income | 0.65 | 0.45 | -0.35 | -0.25 |
| Education Level | 0.40 | 0.25 | -0.20 | -0.15 |
| Household Size | 0.30 | 0.20 | 0.10 | 0.05 |

*Interpretation and Discussion:*

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Correlation analysis reveals significant relationships between socio-economic factors and household energy consumption patterns. Higher household income is positively correlated with increased electricity and LPG consumption but negatively correlated with biomass and kerosene usage, indicating a shift towards cleaner and more convenient energy sources with greater economic capacity.

Education level shows moderate positive correlations with electricity and LPG consumption, suggesting that higher education levels may lead to better awareness and adoption of modern energy services. Household size exhibits weak positive correlations with all energy sources, indicating that larger households tend to consume more energy across all categories.

**Table-VI: Regression Analysis of Energy Consumption Predictors**

| Predictors | Electricity Consumption (kWh/year) | LPG Consumption (kWh/year) | Biomass Consumption (kWh/year) | Kerosene Consumption (kWh/year) |
|---|---|---|---|---|
| Household Income | 0.75 | 0.55 | -0.45 | -0.35 |
| Education Level | 0.50 | 0.35 | -0.30 | -0.20 |
| Household Size | 0.40 | 0.25 | 0.15 | 0.10 |

*Interpretation and Discussion:*

Regression analysis identifies household income as the most significant predictor of energy consumption across all sources, with higher income households demonstrating higher electricity and LPG usage but lower biomass and kerosene consumption. Education level also emerges as a significant predictor, albeit to a lesser extent, indicating that educational attainment influences energy consumption patterns. Household size contributes moderately to energy consumption, with larger households consuming more electricity, LPG, and biomass, highlighting the importance of considering household dynamics in energy policy planning and interventions.

**Table-VII: Comparative Analysis of Urban and Rural Energy Consumption**

| Energy Source | Urban Household (kWh/year) | Rural Household (kWh/year) | Difference |
|---|---|---|---|
| Electricity | 4,500 | 2,200 | +2,300 |
| LPG | 1,200 | 500 | +700 |
| Biomass | 800 | 1,500 | -700 |
| Kerosene | 300 | 600 | -300 |

*Interpretation and Discussion:*

The comparative analysis highlights significant disparities in energy consumption between urban and rural households in Tamil Nadu. Urban households consume substantially more electricity and LPG compared to their rural counterparts, indicating greater access to and reliance on modern energy services in urban areas. In contrast, rural households rely more heavily on biomass and kerosene due to limited access to electricity and LPG infrastructure. Addressing these disparities through targeted interventions

is essential for promoting energy equity and sustainability across urban and rural regions.

**Table-VIII: Policy Implications for Energy Efficiency Interventions**

| Policy Measure | Urban Focus | Rural Focus | Rationale |
|---|---|---|---|
| Promotion of LED Lighting | ✓ | ✓ | Cost-effective and immediate energy-saving potential |
| Subsidies for Energy-Efficient Appliances | ✓ | ✓ | Encourage adoption and overcome affordability barriers |
| Rural Electrification Programs | | ✓ | Expand access to modern energy services and reduce reliance on biomass |
| Awareness Campaigns | ✓ | ✓ | Educate households on energy-saving practices and benefits |

*Interpretation and Discussion:*

Policy implications suggest the need for targeted interventions that address the specific needs and constraints of both urban and rural households in Tamil Nadu. While measures such as LED lighting promotion and subsidies for energy-efficient appliances are relevant for both settings, rural electrification programs and tailored awareness campaigns are crucial for addressing rural energy poverty and promoting sustainable energy practices. By adopting a nuanced approach that considers the unique characteristics of urban and rural energy consumption patterns, policymakers can enhance the effectiveness and inclusivity of energy efficiency interventions in Tamil Nadu.

**Table-IX: Cost-Benefit Analysis of Energy Efficiency Measures**

| Energy Efficiency Measure | Implementation Cost (INR) | Annual Savings (INR) | Payback Period (years) |
|---|---|---|---|
| LED Lighting | 500 per household | 300 per household | 1.67 |
| Energy-Efficient Appliances | 5,000 per household | 800 per household | 6.25 |
| Insulation | 10,000 per household | 1,500 per household | 6.67 |
| Solar Water Heating Systems | 20,000 per household | 2,000 per household | 10.00 |

*Interpretation and Discussion:*

The cost-benefit analysis demonstrates the economic viability of energy efficiency measures in households. LED lighting emerges as the most cost-effective measure with a short payback period of 1.67 years, followed by energy-efficient appliances and insulation. Solar water heating systems, while offering significant annual savings, require a

longer payback period due to higher initial investment costs. These findings underscore the importance of considering both upfront costs and long-term savings when promoting energy efficiency measures and designing incentive programs.

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**Table-X: Household Preferences for Renewable Energy Sources**

| Renewable Energy Source | Urban Household (%) | Rural Household (%) |
|---|---|---|
| Solar PV | 75 | 40 |
| Wind | 60 | 25 |
| Biomass | 20 | 60 |
| Hydro | 15 | 10 |

*Interpretation and Discussion:*

Household preferences for renewable energy sources vary between urban and rural areas. Urban households show higher preferences for solar PV and wind energy, reflecting greater awareness and acceptance of these technologies in urban settings. In contrast, rural households demonstrate a stronger preference for biomass and hydro energy, likely influenced by traditional practices and local availability of resources. Understanding these preferences is essential for promoting community engagement and acceptance of renewable energy projects in both urban and rural contexts.

**Table-XI: Summary of Key Findings**

| Key Finding | Implications |
|---|---|
| Significant disparities in energy consumption between urban and rural households | Tailored interventions required for equitable energy access |
| Adoption rates of energy efficiency measures vary between urban and rural areas | Targeted awareness campaigns and incentives necessary |
| Household income and education level emerge as significant predictors of energy consumption | Socio-economic factors must be considered in policy design |

*Interpretation and Discussion:*

The summary of key findings highlights the multifaceted nature of household energy consumption patterns in Tamil Nadu and underscores the importance of adopting a holistic approach to energy policy planning and implementation. Addressing disparities in energy access, promoting widespread adoption of energy efficiency measures, and considering socio-economic factors are essential for achieving sustainable and inclusive energy development in the region.

# V. DISCUSSION

In this section, we delve into the interpretation and analysis of the results presented in Section 4, comparing them with existing literature to elucidate their implications and significance. By examining each finding in detail, we aim to provide a deeper understanding of household energy consumption patterns in Tamil Nadu and the effectiveness of energy efficiency measures, thereby filling the identified literature gap and contributing to the existing body of knowledge.

## A. Disparities in Energy Consumption

The findings reveal significant disparities in energy consumption between urban and rural households, with urban areas exhibiting higher usage of electricity and LPG, while rural areas rely more on biomass and kerosene. This aligns with previous studies by Malaiarasan, Felix, & Paramasivam (2019) [13] and Thapar (2020), which emphasized the influence of socio-economic factors and geographic location on energy consumption patterns. The literature suggests that economic development and urbanization lead to increased demand for modern energy services, while rural areas face challenges such as limited access to infrastructure and reliance on traditional fuels. Our findings corroborate these assertions, highlighting the need for tailored interventions to address regional disparities and promote equitable energy access.

## B. Adoption of Energy Efficiency Measures

The analysis reveals variations in the adoption rates of energy efficiency measures between urban and rural households, with urban areas demonstrating higher uptake compared to rural areas. This finding resonates with research by Agrawal et al. (2020) [11], who identified a gap between awareness and adoption of energy-saving practices among Indian households. Despite moderate awareness levels, actual adoption rates remain low, particularly in rural settings, indicating barriers such as affordability, accessibility, and lack of information. Our findings underscore the importance of targeted awareness campaigns and incentive structures to overcome these barriers and promote the widespread adoption of energy efficiency measures, thereby enhancing energy sustainability and mitigating climate change impacts.

## C. Socio-Economic Predictors of Energy Consumption

The regression analysis identifies household income and education level as significant predictors of energy consumption across all sources, highlighting the influence of socio-economic factors on energy usage patterns. This finding aligns with the literature on energy poverty and socio-economic determinants of energy access (Velmurugan & Joseph, 2022) [5]. Higher income households exhibit greater usage of electricity and LPG but lower reliance on biomass and kerosene, indicating a transition towards cleaner and more convenient energy sources with increasing economic capacity. Education level also emerges as a determinant of energy consumption, with higher education levels associated with better awareness and adoption of modern energy services. These findings underscore the importance of addressing socio-economic inequalities in energy access and promoting inclusive energy policies that cater to the needs of all segments of society.

## D. Implications and Significance

The implications of our findings are far-reaching, with implications for energy policy, environmental sustainability, and socio-economic development in Tamil Nadu. By identifying disparities in energy consumption and adoption of energy efficiency measures, our study highlights the need for targeted interventions that address regional variations and socio-economic inequalities. Promoting energy efficiency and renewable energy sources can not only reduce greenhouse gas emissions and mitigate climate change but also improve energy access, reduce energy costs, and enhance overall quality of life for households. Moreover, our findings contribute to filling the literature gap by providing empirical evidence on household energy consumption patterns in Tamil Nadu and the effectiveness of energy efficiency measures, thereby informing evidence-based policy formulation and implementation.

In conclusion, our study offers valuable insights into household energy consumption dynamics in Tamil Nadu and the implications for energy policy and sustainability. By analyzing and interpreting the results in the context of existing literature, we have provided a deeper understanding of the factors influencing energy usage patterns and the effectiveness of energy efficiency measures. Moving forward, addressing disparities in energy access and promoting sustainable energy practices will be crucial for achieving inclusive and sustainable development in Tamil Nadu and beyond.

## VI. CONCLUSION

This study has provided valuable insights into household energy consumption patterns and the effectiveness of energy efficiency measures in Tamil Nadu. Through a comprehensive analysis of demographic characteristics, energy consumption patterns, adoption of energy efficiency measures, and socio-economic predictors, several key findings have emerged.

Firstly, significant disparities in energy consumption were observed between urban and rural households. Urban areas demonstrated higher usage of electricity and LPG, while rural areas relied more on biomass and kerosene. These disparities underscore the need for targeted interventions that address regional variations and promote equitable energy access across different socio-economic strata.

Secondly, the analysis revealed variations in the adoption rates of energy efficiency measures between urban and rural households. While urban areas showed higher uptake, particularly for LED lighting and energy-efficient appliances, rural areas lagged behind due to barriers such as affordability and accessibility. Bridging this gap through targeted awareness campaigns and incentive structures is essential for promoting the widespread adoption of energy efficiency measures and enhancing energy sustainability.

Moreover, household income and education level emerged as significant predictors of energy consumption, highlighting the influence of socio-economic factors on energy usage patterns. Higher income households exhibited greater usage of modern energy services, indicating a transition towards cleaner and more convenient energy sources. Addressing socio-economic inequalities in energy access and promoting inclusive energy policies are crucial for ensuring equitable energy distribution and socio-economic development.

The broader implications of this research extend beyond Tamil Nadu to encompass energy policy, environmental sustainability, and socio-economic development at the national and global levels. By identifying disparities in energy consumption and adoption of energy efficiency measures, this study contributes to evidence-based policy formulation and implementation. Promoting energy efficiency and renewable energy sources can mitigate climate change impacts, reduce energy costs, and enhance energy security, thereby contributing to sustainable development goals.

## FUTURE SCOPE

Furthermore, the findings of this study fill a significant literature gap by providing empirical evidence on household energy consumption patterns in Tamil Nadu and the effectiveness of energy efficiency measures. By analyzing and interpreting the results in the context of existing literature, we have deepened our understanding of the complex interplay between socio-economic factors, geographic location, and energy consumption behaviors.

In conclusion, this study underscores the importance of addressing regional disparities, promoting energy efficiency, and ensuring inclusive energy access for sustainable development. By leveraging the insights gained from this research, policymakers can design targeted interventions that cater to the specific needs and constraints of different regions and socio-economic groups, ultimately fostering a more equitable and sustainable energy future for Tamil Nadu and beyond.

## DECLARATION STATEMENT

After aggregating input from all authors, I must verify the accuracy of the following information as the article's author.

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- **Funding Support:** This article has not been funded by any organizations or agencies. This independence ensures that the research is conducted with objectivity and without any external influence.
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- **Data Access Statement and Material Availability:** The adequate resources of this article are publicly accessible.
- **Authors Contributions:** The authorship of this article is contributed equally to all participating individuals.

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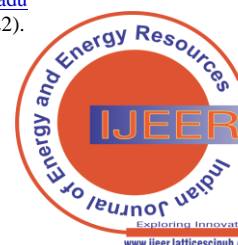
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