Determination of Final Energy Consumption in the Residential Sector of Uzbekistan

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Abstract. This study analyses residential energy consumption in Uzbekistan from 2010 to 2022, focusing on the effects of household income, energy prices, and climate variables. The main objective is to identify key determinants of household energy demand and assess how economic and environmental factors shape consumption patterns over time. Three regression models were developed: a baseline model, a climatic model, and an extended lagged price model that accounts for delayed consumer responses to price changes. The results show that income growth and heating degree days (HDD) are the most influential drivers of residential energy demand. Rising household income increases energy consumption through greater ownership of electrical appliances and improved living standards, whereas colder winters significantly raise heating requirements. Energy prices demonstrate a weaker but time-dependent effect. The lagged price model captures this behaviour most effectively, indicating that households adjust their energy consumption gradually rather than immediately in response to price changes. All models exhibit reduced predictive accuracy during periods of sharp fluctuations in energy prices, particularly following government tariff reforms and fuel supply disruptions. This highlights the importance of incorporating additional factors such as consumer behaviour, technological efficiency, and social awareness into future models. Based on the findings, policy recommendations include implementing flexible and socially sensitive tariff systems, promoting energy-efficient technologies, and supporting thermal insulation upgrades in residential buildings. Public awareness campaigns and targeted subsidies may further encourage energy-saving behaviour. Improving energy efficiency in the residential sector is essential for achieving Uzbekistan's long-term economic stability and environmental sustainability.

Keywords: Residential energy consumption, final energy use, heating degree days (HDD), regression modelling, statistical analysis, household energy demand, energy modelling, econometric analysis.

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1 Introduction

Understanding final energy consumption in Uzbekistan's residential sector requires examining government policies, socio-economic conditions, and technological factors [1]. Initiatives such as the 2021 state mortgage program, which aims to build 45,000 homes, could increase residential energy demand by 30% by 2050 [2]. Strengthening energy standards and incorporating passive solar designs, such as Trombe walls, could reduce primary energy use by 9–34% and cut emissions [2]. Income disparities also impact energy use, as lower-income households often rely on alternative fuels due to supply instability [3]. Climatic and demographic factors further influence regional consumption trends [4].

Efforts to enhance energy efficiency include updated Construction Standards and Regulations and mandatory Minimum Energy Performance Standards, particularly for rural housing [2]. Technological measures like passive house concepts and Trombe walls enhance solar energy use, while national and international renewable energy initiatives – particularly with China – support the transition to a green economy [5][6][7].

Given these developments, an economic analysis of household energy use is essential to identify the key determinants of consumption patterns and to propose effective energy-efficiency strategies. The residential sector in Uzbekistan accounts for a substantial share of total final energy use, and understanding its dynamics is crucial for achieving national sustainability goals. The structure of energy demand is influenced not only by income levels and energy prices but also by climatic variability, demographic changes, and the pace of technological modernisation. In this context, the present study models final residential energy consumption across 14 administrative regions of Uzbekistan during the period 2010–2022, applying three progressively enhanced regression models. These models integrate household disposable income, energy prices, and Heating Degree Days (HDD) as primary explanatory variables, along with lag variables to capture delayed consumer responses to price fluctuations. Such an approach allows for a comprehensive assessment of both short-term behavioural reactions and long-term adaptation processes. The overarching objective of this research is to identify the dominant drivers of residential energy demand, evaluate regional differences, and formulate evidence-based policy recommendations to improve energy efficiency, reduce emissions, and support Uzbekistan's transition toward a low-carbon economy [8][9].

2 Data and methodology

2.1 Data description

From 2010 to 2022, Household Expenditures in Uzbekistan (measured in USD) exhibited noticeable fluctuations, peaking in 2016, then declined and subsequently recovered after 2019 (see Fig. 1). These variations reflect changes in household income, purchasing power, and national economic reforms. Residential energy consumption

declined from 2010 to 2019, primarily due to improvements in building insulation, the adoption of energy-saving technologies, and updated construction standards. However, a moderate increase occurred in 2020–2021 (Fig. 2), likely associated with the COVID-19 pandemic, as households spent more time indoors, raising electricity and heating demand. Heating Degree Days (HDD) fluctuated annually without a consistent trend (Fig. 3), indicating that climatic variability strongly affects energy use. Cold winters significantly increased heating requirements, while milder seasons reduced them. Overall, the dataset reflects the interconnections among climate, income, and energy behaviour, providing the foundation for regression modelling in subsequent sections.

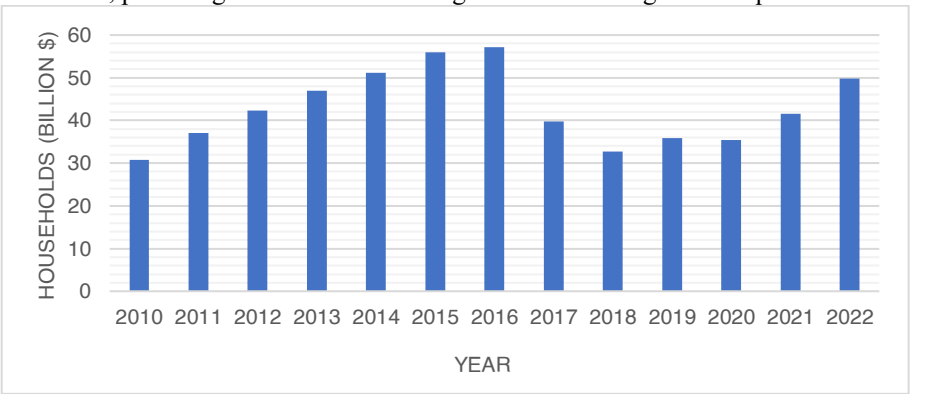

Fig 1. Household (USD) growth over the years.

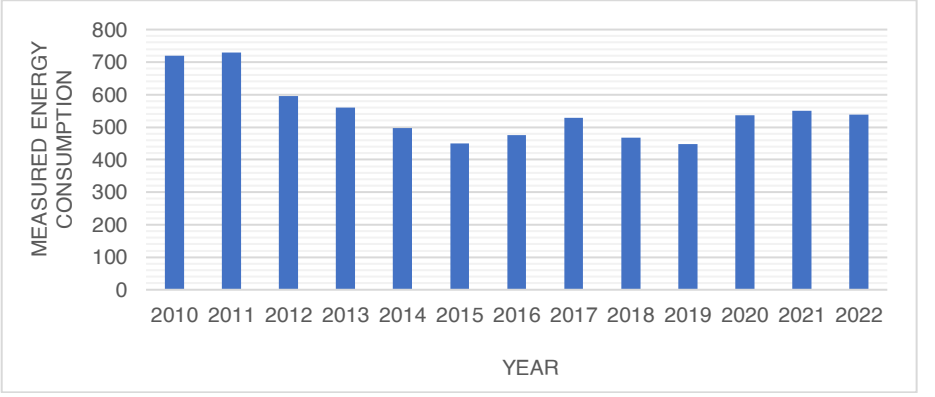

Fig 2. Measured Energy Consumption growth over the years

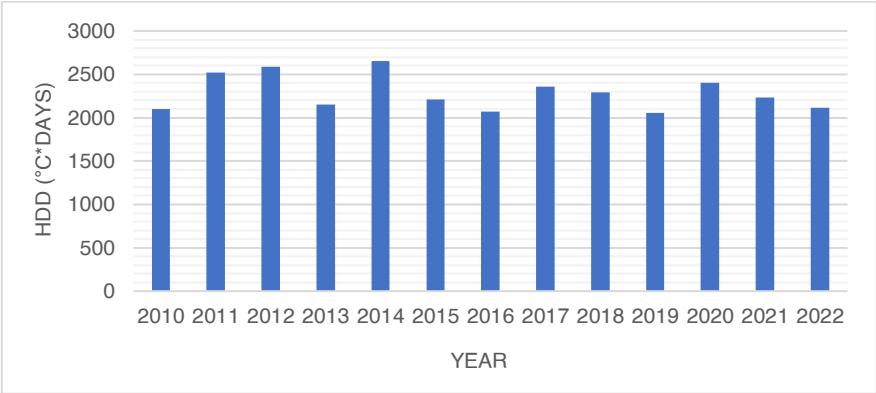

Fig. 3. Growth in heating degree days over the years.

2.2. Development of Regression Models

Bentzen and Engsted [10] revived the methodology of simple economic modelling of residential energy consumption, emphasising the relationship between income, energy prices, and climatic conditions. Their approach provided a solid analytical foundation for assessing both short-term and long-term dynamics of household energy demand. Building on this framework, the present study adapts and extends the methodology to the Uzbekistan context, incorporating regional climatic variability and lagged price effects. Accordingly, three regression models of annual energy consumption were developed (1–3), each designed to incorporate additional explanatory variables and improve predictive accuracy progressively. In contrast to earlier works that focused primarily on developed economies, this study examines the specific characteristics of a transition economy, in which energy consumption patterns are strongly shaped by government regulation, household adaptation behaviour, and regional disparities in infrastructure. The modelling process integrates macroeconomic variables such as household disposable income, electricity and gas prices, and heating degree days (HDD), as well as dynamic effects from previous periods. By including lagged variables, the analysis captures households' delayed responses to price changes, reflecting the persistence of consumption habits and the gradual diffusion of energy-saving technologies. This extended framework allows for a more comprehensive understanding of how climatic and economic factors jointly influence residential energy use, offering a robust empirical basis for energy policy and efficiency improvement strategies in Uzbekistan.

Baseline Model:

$$E_{in.t} = \mathrm{b} + \mathrm{c}_1 \times E_{in.t-1} + \mathrm{c}_2 \times I_{dispt} + \mathrm{c}_3 \times P \times c_t \quad (1)$$

Model with Climatic Factor:

$$E_{in.t} = \mathrm{b} + \mathrm{c}_1 \times E_{in.t-1} + \mathrm{c}_2 \times I_{dispt} + \mathrm{c}_3 \times P \times c_t + \mathrm{c}_4 \times HDD_t \quad (2)$$

Extended Model with Lagged Prices:

$$E_{in.t} = \mathrm{b} + \mathrm{c}_1 \times E_{in.t-1} + \mathrm{c}_2 \times I_{dispt} + \mathrm{c}_3 \times P \times c_t + \mathrm{c}_4 \times HDD_t + \mathrm{c}_5 \times P \times c_{t-1} (3)$$

where: $E_{in.t}$ – annual energy consumption (kWh) per year. I_{dispt} – household disposable income in a year. P year. HDD – number of heating degree days in a year. b – constant term. c – regression coefficients.

3 Results and Discussion

The analysis of energy consumption data in residential buildings in Uzbekistan from 2010 to 2022 reveals both general trends and the accuracy of predictive models. The measured data show a significant decline in energy consumption, from 718.977 × 10^3 TJ in 2010 to 476.207 × 10^3 TJ in 2016, followed by an increase in 2017 to 527.748 × 10^3 TJ and stabilisation at around 550 × 10^3 TJ in 2021–2022.

The predicted values from the three models (Model 1, Model 2, Model 3) predominantly follow this trend (Fig. 5); however, notable deviations are observed in specific years. For instance, between 2010 and 2012, all models consistently underestimated the actual data, whereas in 2013, the projections from all three models were the most precise. The most significant discrepancies between the observed and predicted values occurred in 2018, during which the models overestimated energy consumption. This discrepancy may be attributed to external factors, including changes in economic conditions or climatic fluctuations.

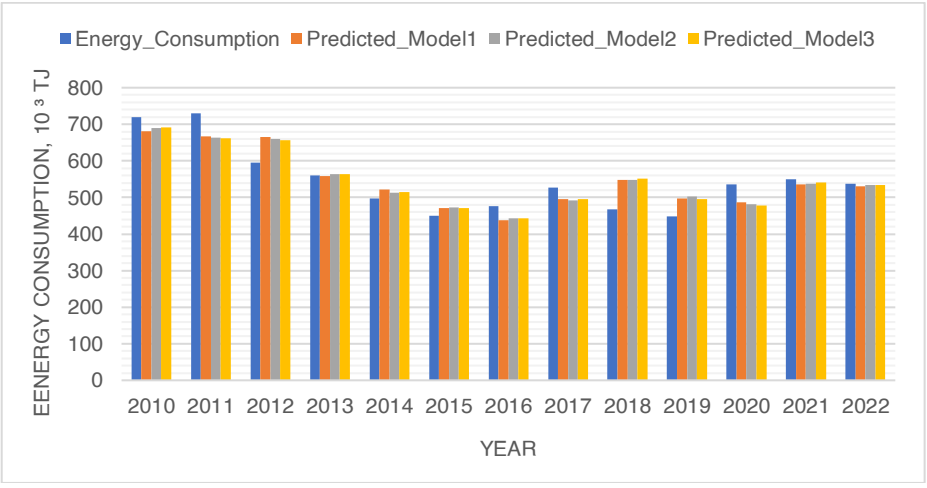

Fig 4. Comparison of predicted data

The accuracy of the predictive models exhibits variability year by year. Both Model 1 and Model 2 yield analogous results, with deviations from the measured data averaging 10%-15%. In contrast, Model 3 demonstrates enhanced accuracy in select years, specifically in 2021 and 2022. Nevertheless, none of the models deliver consistently accurate forecasts across the entire analysed period, underscoring the need for methodological refinements.

To enhance forecast quality, it is advisable to consider additional factors, such as economic indicators, legislative changes, and climatic conditions. Furthermore, the utilisation of more sophisticated modelling techniques, including machine learning methods, warrants exploration. This strategy would assist in minimising deviations and improving predictive accuracy, particularly during years characterised by considerable uncertainty.

3.1 Analysis of Energy Consumption in Residential Buildings in Uzbekistan (2010–2022)

The analysis of energy consumption patterns in residential buildings across Uzbekistan from 2010 to 2022, grounded in a comparative assessment of both measured and predicted data, indicated a substantial reliance on climatic, economic, and behavioural determinants. Three distinct models were employed to forecast energy consumption: a baseline model, a model incorporating climatic factors, and an extended model that integrates lagged pricing data.

The baseline model, which takes into account prior energy consumption, disposable income, and current energy prices, consistently underestimated actual consumption, especially during periods of significant price surges, notably from 2020 to 2022, when the energy price escalated from 64.8 UZS/kWh in 2010 to 295 UZS/kWh in the years 2020 to 2022.

The model, which includes a climatic variable – specifically, Heating Degree Days (HDD) – enhances forecast precision, particularly in years characterised by extreme climatic events, such as 2011 (HDD = 2520.8 days) and 2014 (HDD = 2651.6 days).

Furthermore, the extended model, which incorporates lagged prices to account for the effects of historical energy prices, achieved the highest accuracy. This highlights the importance of accounting for temporal lags in consumer responses to price adjustments.

Nonetheless, all models failed to accurately forecast actual consumption during periods of rapid price increases, underscoring the need to incorporate additional factors, such as behavioural adaptation and socio-economic developments, to improve energy consumption forecasts.

3.2 Impact of Factors on Energy Consumption.

The principal factors influencing energy consumption in residential buildings in Uzbekistan include climatic conditions, energy prices, and household disposable income, all of which interact to shape long-term demand patterns and short-term fluctuations.

Climatic conditions play a critical role in determining the seasonal variation of energy use. The number of Heating Degree Days (HDD) is an effective indicator of the need for space heating, directly reflecting the impact of temperature deviations on household energy demand. The data indicate that in colder years such as 2011 (HDD = 2520.8) and 2020 (HDD = 2399.7), residential energy demand increased significantly. Conversely, milder winters led to reduced heating demand, illustrating the high climate sensitivity of Uzbekistan's residential sector. Given the country's continental climate – characterised by hot summers and cold winters – this factor is expected to remain one of the dominant determinants of household energy consumption in the future.

Energy prices represent another major determinant. Between 2010 and 2022, the average electricity tariff increased from 64.8 UZS/kWh to 295 UZS/kWh, reflecting both inflation and policy-driven adjustments toward cost-reflective pricing. The price increase led to a moderate reduction in energy use; however, the decrease was less pronounced than the models initially predicted. This indicates that households exhibit price inelasticity – a tendency to maintain consumption levels despite higher costs. Such inertia may stem from the absence of affordable alternatives, limited access to energy-efficient technologies, and a lack of consumer awareness of conservation measures. The inclusion of lagged price variables in the regression models captures this delayed behavioural response more effectively, demonstrating that consumers typically adjust their energy use gradually over time rather than immediately after price changes.

Household disposable income also influences energy consumption, although its effect appears weaker in the short term. As income rises, households tend to purchase additional electrical appliances, improve comfort standards, and increase living space–all of which elevate energy demand. However, due to structural constraints such as limited energy supply or outdated infrastructure, these changes do not always translate into immediate increases in consumption. This suggests a low short-term elasticity of energy use with respect to income.

Correlation and regression analyses confirm these relationships. Energy consumption shows a positive correlation with the number of households and disposable income, and a negative correlation with energy prices. The baseline model achieved an R^2 of 0.9927, indicating strong explanatory power. The addition of the climatic factor (HDD) improved the fit to $R^2 = 0.9928$, whereas incorporating lagged prices further improved it to $R^2 = 0.9929$.

Overall, these findings highlight that climatic variability, price policies, and income dynamics shape household energy consumption in Uzbekistan. To enhance predictive accuracy, future models should integrate behavioural, technological, and structural variables, including the diffusion of energy-efficient technologies, consumer awareness programs, and regional policy measures that influence long-term energy-saving behaviour.

4 Conclusion

The conducted study identified key factors influencing energy consumption in Uzbekistan's residential sector and provided recommendations to enhance energy efficiency. The main determinants of energy consumption in Uzbekistan's residential sector are household income, energy prices, and climatic conditions.

The analysis confirmed that household disposable income is one of the most significant determinants of energy consumption. As income increases, energy demand rises, driven by improved living standards, the greater use of household appliances, and larger living spaces. This is particularly relevant for Uzbekistan, where household welfare has been steadily rising in recent years.

Energy prices have a significant impact on consumer behaviour. Tariff increases can encourage households to use energy more efficiently; however, the effect of price changes is delayed. This is confirmed by the results of the extended model, where incorporating the lagged energy price variable improved the model’s accuracy.

Climatic factors, such as heating degree days (HDD), play a crucial role in shaping energy demand. In Uzbekistan, where significant seasonal temperature fluctuations characterise the climate, this factor is particularly relevant. Energy consumption increases in winter due to heating requirements and in summer due to air conditioning use. Energy price subsidies can lead to excessive consumption, necessitating the implementation of energy-saving mechanisms.

Introducing flexible tariffs and promoting energy-efficient technologies can help reduce energy consumption and lower CO_2 emissions. The study confirmed that the key determinants of energy consumption in Uzbekistan's residential sector are household income, energy prices, and climatic conditions. To improve energy efficiency and reduce environmental impact, it is essential to implement flexible tariffs, promote energy-efficient technologies, and enhance thermal insulation in residential buildings. The implementation of these measures will not only reduce the burden on the energy system but also contribute to the country's sustainable development.

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