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Article

Regional Distribution and Optimization Methods of Electricity Consumption by Sectors

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Abstract: The sectoral distribution of regional electricity consumption and its optimization play a crucial role in ensuring economic stability and efficiency. This article analyzes the dynamics of distribution and losses of net electricity generated in the Republic of Uzbekistan from 1992 to 2020 across various economic sectors. The research results indicate a decrease in energy consumption in the industrial and construction sectors, an increase in the share of household consumers, and a reduction in energy demand in the agricultural sector. The rise in power grid losses confirms the need to modernize the electricity distribution system. The use of strategic and operational management models is proposed to optimize regional electricity supply. Optimization can be implemented at the strategic level using the Multiverse algorithm, and at the operational level using the Gurobi solver. The research findings provide scientifically grounded recommendations for effective planning of electricity distribution, minimizing energy losses, and enhancing economic efficiency. This article has significant theoretical and practical importance for exploring opportunities to optimize electricity supply strategies and apply econometric models.

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1. Introduction

Electricity is a critical strategic resource for the economic development and social well-being of every region. The sectoral distribution and optimization of regional electricity consumption plays a key role in ensuring the uninterrupted operation of industry, agriculture, and households. However, the challenges observed in electricity supply, including energy shortages, imbalances in distribution, seasonal fluctuations in demand, and network losses, can negatively impact regional economic efficiency [1]. Therefore, an in-depth analysis of electricity distribution across sectors and the development of optimal management mechanisms is an urgent issue [2] .

The distribution and optimization of electricity across regional sectors is one of the important research areas for economists and developers. Studies show that the efficient distribution of electricity among industry, agriculture, and households plays a crucial role in optimizing production processes, ensuring economic stability, and the rational use of resources. Disruptions in electricity supply or misallocation of resources can lead to a decrease in regional economic efficiency, reduced production, and imbalances in energy consumption [3]. Therefore, analyzing the optimal distribution and consumption of electricity is essential for ensuring sustainable economic growth. Examining the sectoral distribution of electricity is a pressing matter. This study aims to analyze the sectoral distribution and losses of regional electricity consumption between 1992-2020 and serves to identify existing trends and optimization opportunities [4].

Literature Rreview

The sectoral distribution and optimization of regional electricity consumption are examined through microeconomic and macroeconomic approaches. Various studies have analyzed models for improving the efficiency and distribution of electricity in industry, agriculture, households, and other sectors [5].

Gujarati in his book "Basic Econometrics" notes that multiple regression analysis models can be used to determine the relationship between electricity prices, production volume, and consumer demand elasticity [6]. This approach can be used to assess the relationship between the sectoral distribution of electricity and price elasticity [7].

Al-Fattah et al. compared electricity consumption in different regions using a panel data regression model. The results of the study showed that urbanization, industrial development, and population growth are the main factors influencing electricity consumption [8]. These findings can serve as a basis for assessing the balance of energy consumption between industry and agriculture.

Research conducted in the industrial sector shows that the optimal distribution of electricity has a positive impact on production efficiency and economic growth. Stock and Watson analyzed the effectiveness of energy consumption forecasting using the ARIMA (Autoregressive Integrated Moving Average) model. This model allows for accounting for seasonal fluctuations and long-term trends in electricity supply [9].

Optimal distribution of electricity for the agricultural sector is important for ensuring production efficiency and uninterrupted operation of infrastructure, such as water pumps. In a study conducted by Joskow, the Stochastic Frontier Analysis (SFA) model was used to increase efficiency in the generation and distribution of electricity. Using this model, the efficiency levels of various power plants were compared, and the impact of modernization projects on economic outcomes was studied [10].

Paterakis et al. proposed the use of multi-objective optimization models to optimize demand-based management of electricity by consumers [11]. These models contribute to the efficient distribution of electricity among the population, industry, and agriculture, as well as the optimal use of energy resources. In particular, the importance of risk minimization models for managing energy reserves and ensuring the stable operation of networks is emphasized [12].

Research on reducing electricity losses and increasing the efficiency of electrical networks is also of current relevance. A study conducted by Chattopadhyay analyzes the role of artificial intelligence (AI) and machine learning algorithms in increasing the efficiency of electricity distribution optimization [13]. The study examined the application of AI technologies in the processes of energy production, forecasting, monitoring, and network management in renewable energy systems [14]. This approach is important for stabilizing regional electricity supply, reducing losses, and increasing energy efficiency [15].

2. Materials and Methods

This study aims to analyze the distribution of electricity across regional sectors in the Republic of Uzbekistan and explore optimization possibilities from 1992 to 2020. The primary data were compiled from statistical reports of national energy agencies and government organizations . Additionally, collected data on electricity generation, distribution, and losses were analyzed. Supplementary economic and demographic data were used to identify factors influencing electricity consumption trends.

The research was conducted using a two-stage optimization model aimed at optimizing regional power supply based on strategic planning and operational management.

1. Strategic optimization - serves to formulate a long-term electricity planning strategy. In this case, the decision variables relate to determining the optimal power configuration for each energy source, while constraints define the permissible power range for electricity generation facilities. The objective function aims to increase the economic benefits and ensure the stability of regional power supply. The Multiverse Algorithm (MVA) was employed as the optimization method to determine the most efficient electricity distribution.

2. Operational optimization - ensures real-time monitoring of the balance between energy production and distribution. Constraints account for the production-consumption balance, technical capabilities, and energy reserve limitations. The objective function focuses on maximizing operational revenue and maintaining system stability. The Gurobi Solver was used as the optimization method, achieving efficient energy distribution and optimization of the power supply system.

3. Results and Discussion

As The production of electricity and its distribution across various sectors play an important role in ensuring economic development and energy supply stability[16]. Between 1990 and 2020, net electricity production increased significantly. In 1990, this figure was 47,964 million kWh, and by 2020 it reached 64,259 million kWh. This represents an increase of 33.97% [17]. This growth is associated with reforms in the energy sector, technological modernization, and increased industrial needs. This represents an increase of 33.97% [18].

Along with the production of electricity, its distribution among consumers is also an important factor. Different sectors of the economy use energy resources to varying degrees, which also affects their growth rates. The share of net electricity generated is divided among the following sectors: industry and construction consumption (%), agriculture, forestry, and fisheries consumption (%), household consumers (%), construction sector (%), and losses in the grid (%). These are illustrated in Figure 1.

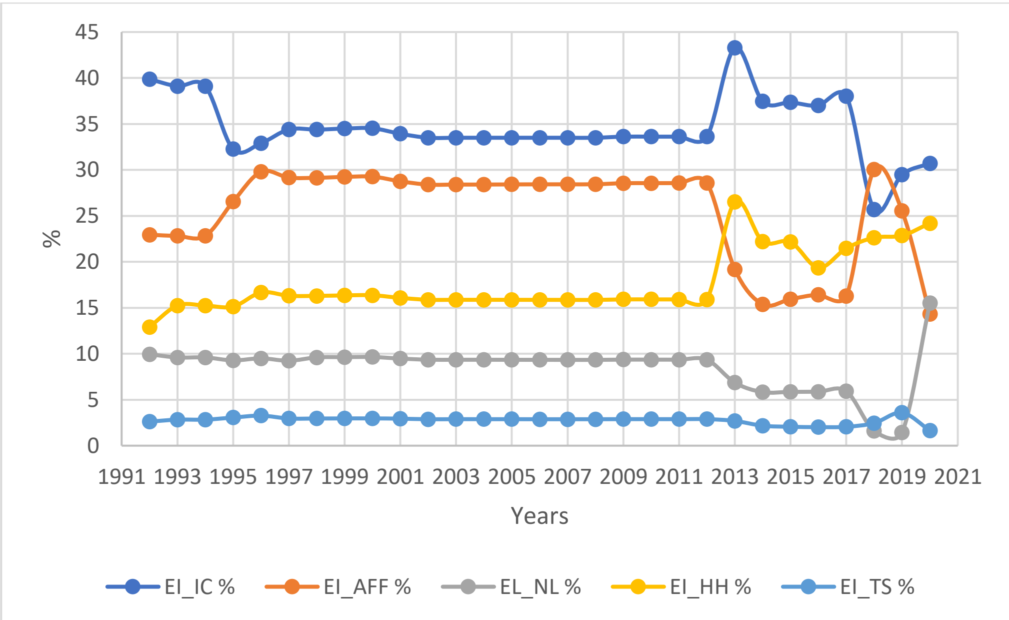

Figure 1. Sectoral distribution of regionally produced net electricity consumption in the Republic of Uzbekistan and the dynamics of network losses (1992-2020)

EI_IC-Share of net generated electricity consumption in industry and construction (%), EI_AFF-Share of net generated electricity consumption in agriculture, forestry, and fishing (%), *EL_NL-Share of net generated electricity losses in networks (%), EI_HH-Share of net generated electricity consumption in households (%), EI_TS-Share of net electricity production consumed by the transport sector (%).*

The production and distribution of electricity depend on changes in demand across economic sectors, technological advancements, and energy efficiency. In the Republic of Uzbekistan, significant dynamics were observed in the distribution of net electricity production across various sectors from 1992 to 2020. Below is a detailed analysis of the main sectors [19].

1. Share of electricity consumption in the industrial and construction sectors. In 1992, the industrial and construction sector consumed 35.87% of electricity, but by 2020 this figure had decreased to 30.71%. The main reasons for this decline may be:

Technological modernization to improve energy efficiency in industry. Increased use of alternative energy sources. Transition of some large industrial enterprises to other energy sources (for example, gas or renewable energy). In 2013, this share increased to 43.28%, which is likely due to an increase in industrial production volumes or changes in power supply systems.

2. Electricity consumption in agriculture, forestry, and fisheries. The share of electricity consumption in agriculture and related industries was 22.95% in 1992, and by 2020 this figure had decreased to 14.32%. The main reasons for this decline may be:Innovations aimed at automation and energy efficiency in agriculture. Implementation of hybrid energy systems, such as the use of solar panels and wind energy. Replacement of water pumps and irrigation systems with energy-saving technologies.Consumption in the agricultural sector remained stable throughout the 2000s but declined after 2015 [20].

3. Share of losses in networks. Losses of electricity in the networks increased from 9.94% in 1992 to 15.52% by 2020. This increase may be due to the following reasons: Deterioration of power transmission and distribution systems. Insufficient effective management measures for network losses. Increase in technical losses associated with the transmission of electricity over long distances. Also, after 2013, a decrease in the share of losses was observed [21].

4. Share of household consumers. The share of household electricity consumption increased from 12.91% in 1992 to 24.19% in 2020.

Increased demand for electricity in households, particularly due to the widespread use of modern electrical appliances and technologies. Improved access to electricity for the population. Rise in household electricity consumption as a result of urbanization processes. The most significant growth was observed after 2013, indicating an expansion of the domestic sector at the expense of reduced consumption in industry and agriculture.

5. Share of electricity consumption in the transport sector. The share of electricity use in the transport sector was 2.61% in 1992 and decreased to 1.64% by 2020.

This decrease may be attributed to: Limited use of electricity in transport. The prevalence of internal combustion engines and insufficient adoption of electric vehicles. However, by the 2030s, the popularization of electric vehicles is expected to reverse this trend.

Analyses on optimizing regional electricity supply show that significant changes occurred in the distribution of net electricity production across various sectors during 1992-2020. Specifically, the share of electricity consumption in the industrial and construction sectors decreased, while the share of household consumers increased considerably. This further confirms the relevance of optimization issues, considering the regional variability of power supply.

Analyses indicate that econometric models are crucial for effective management and forecasting of regional electricity supply. In particular:

The decrease in energy consumption in industrial areas suggests that production processes are striving for energy efficiency and highlights the need to optimize industrial electrical loads.

The decline in electricity use in agriculture, forestry, and fisheries sectors underscores the importance of accurately forecasting energy demand in these sectors and increasing the role of alternative energy sources in regional electricity supply.

The increase in electricity losses in the networks necessitates the modernization of power distribution systems and the development of strategic measures to reduce transmission losses.

The growth in domestic consumers' demand for electricity confirms the increased significance of urbanization processes in electricity supply and the need to develop strategic plans that take into account regional characteristics of electricity supply.

These results demonstrate the necessity of developing econometric models for optimizing regional electricity supply and strategies for network optimization, considering the specific energy consumption trends of various sectors.

The above analysis of regional electricity supply optimization demonstrates that changes in the sectoral distribution of electricity and dynamics of energy consumption necessitate the development of effective management strategies. To successfully implement this process, a two-stage optimization model based on the integration of strategic planning and operational management should be applied. At the strategic level, it is crucial to develop long-term energy supply plans, while at the operational level, efficient real-time management of electricity must be ensured. Therefore, it is possible to create a sustainable energy system by formulating optimal models of energy distribution in various regions and minimizing sectoral losses.

Optimization of regional electricity supply is a complex process that encompasses aspects of strategic planning and operational management. This analysis was conducted based on a two-stage optimization model, examining the integration of high-level strategic planning and lower-level operational management, see Table 1.

Table 1. Regional Electricity Supply Optimization: Strategic and Operational Approaches.

Model level	Optimization direction
Strategic level	Improving the efficiency of regional electricity supply
Operational level	Daily energy production and distribution management

1. High-Level Planning Model (Strategic Optimization)

This level serves to formulate a long-term electricity supply strategy. Decision variables: Optimal configuration capacity for each energy source. Constraints: Permissible capacity range for each electrical power facility. Objective function: Ensuring maximum economic benefits of regional electricity supply and enhancing energy sustainability. Optimization method: Multiverse algorithm, which helps to find the best configuration for efficient electricity distribution.

2. Lower-Level Operational Model (Daily Energy Management)

This stage controls the real-time balancing of electricity generation and distribution processes. Constraints: Energy input and output balance - ensuring equilibrium between production and consumption. Generation constraints of units - taking into account technical limits for each energy unit. Energy storage device constraints - optimizing the procedure for working with energy reserves. Energy distribution ratio constraints - effectively managing the distribution of electricity to the population and industry. Objective function: Supporting the stable operation of the energy system by ensuring maximum operational revenue. Optimization method: Gurobi solver, which is used to optimally solve the lower-level operational model.

Between 1992 and 2020, significant changes were observed in the sectoral distribution of electricity consumption in the Republic of Uzbekistan. The share of industrial and agricultural sectors decreased, while the share of household consumers increased. Concurrently, electricity losses in the networks rose from 9.94% to 15.52%, indicating the need for measures to improve the efficiency of the power distribution system and minimize losses. Based on these results, a two-stage model (strategic and operational optimization) was applied to optimize regional power supply. The Multiverse algorithm was used to determine the optimal distribution of electricity, while the Gurobi Solver was employed to ensure system stability at the operational level.

4. Conclusion

This study aimed to analyze the distribution of electricity across regional sectors in the Republic of Uzbekistan and explore optimization possibilities. The research results indicate that the share of industrial and agricultural sectors in the sectoral distribution of electricity has decreased, while the share of household consumers has increased. This confirms the need to revise regional energy strategies and develop effective distribution models. Additionally, electricity losses in the networks have increased, which may be associated with the obsolescence of power transmission systems and inadequate management measures.

Furthermore, a two-stage model of strategic planning and operational management for optimizing regional electricity supply was analyzed. Specifically, at the strategic optimization stage, long-term electricity distribution was analyzed using the Multiverse algorithm, and its impact on economic efficiency was studied. At the operational optimization stage, energy production and distribution balance was monitored in real-time through the Gurobi Solver, and the possibilities for stable system operation and loss reduction were assessed.

The results demonstrate that to increase the efficiency of regional power supply, it is necessary to introduce new approaches to forecasting energy distribution and increasing the share of sources for minimizing losses. It is particularly important to analyze electricity consumption at the sectoral level, develop forecast models that consider regional characteristics of energy supply, and scientifically substantiate decisions to improve economic efficiency. Consequently, this approach serves to develop strategic decisions on optimal electricity distribution, reducing network losses, and supporting regional economic development based on econometric models for optimizing regional electricity supply.

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