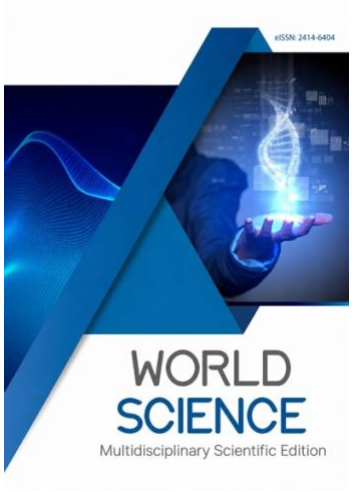


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THE CURRENT STATE AND KEY CHALLENGES OF ENERGY EFFICIENCY IN GEORGIA'S HYDROPOWER SECTOR

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ABSTRACT

This study assesses the current state of energy efficiency in Georgia's hydro power sector and examines the principal technical, hydrological, grid-related, economic, and environmental factors that influence it. The analysis is based on the latest available materials from the Electricity Market Operator of Georgia (ESCO), Georgian State Electrosystem (GSE), the Georgian National Energy and Water Supply Regulatory Commission (GNERC), and the International Renewable Energy Agency (IRENA). Particular attention is given to trends in hydro power generation, the estimation of installed capacity utilization, seasonal variability, aging infrastructure, climate change, sediment accumulation, and grid integration. The analysis indicates that improving energy efficiency does not depend solely on the construction of new hydro power plants. Significant potential also lies in rehabilitating existing facilities, introducing digital monitoring and control, improving water-resource planning, and integrating hydro power with solar and wind generation and energy-storage technologies.

KEYWORDS

Hydropower Plant, Energy Efficiency, Hydropower Generation, Energy Security, Hydrology, Climate Change

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1. Introduction

Hydro power is one of the main pillars of Georgia's electricity system. The country's dense river network and mountainous terrain, characterized by substantial elevation differences, create favorable conditions for the development and use of hydro power resources. Harnessing these resources is important for domestic electricity generation, strengthening energy security, reducing dependence on electricity imports, and increasing the share of renewable energy in the national energy production. [1, 5]

The efficiency of a hydro power plant should not be assessed solely on the basis of its annual electricity output. Its energy efficiency is also influenced by the utilization of installed capacity, the technical condition of hydro turbines and hydro generators, the optimal use of water resources, the frequency of forced outages, electricity transmission losses, and the plant's ability to provide flexible and reliable capacity to the power system. [1, 5]

Seasonality is a defining feature of hydro power in Georgia. Water availability and, consequently, hydro power generation generally increase in spring and summer, whereas electricity demand is high in winter and hydro power output is relatively low. IRENA identifies seasonal variation in hydro power production as one of the factors contributing to Georgia's dependence on energy imports. [5]

2. Research Objective and Methodology

This study aims to systematically assess the energy-efficiency performance of operating hydro power plants in Georgia and to identify the principal challenges affecting their performance. It adopts a descriptive and analytical approach, using comparative analysis of official statistics, electricity balances, and international assessments. [2–6]

The major indicators are: (1) annual hydro power generation; (2) hydro power's share of total domestic electricity generation; (3) the capacity factor of installed capacity; (4) seasonal variability; (5) the technical condition of hydroelectric generating units and hydraulic structures; and (6) opportunities for grid integration and energy storage. [2–6]

The capacity factor (CF) can be calculated using the following formula: **CF** = E/(P_inst × **8,760)**

where E is annual electricity generation (kWh), P_{inst} is installed capacity (kW), and 8,760 is the number of hours in a year. This indicator should be interpreted in conjunction with hydro logical conditions, since a low capacity factor does not necessarily indicate technical inefficiency.

According to official ESCO data, hydropower plants in Georgia generated 8,453.84 million kWh of electricity in 2015. In 2025, annual hydropower generation reached 10,986.6 million kWh. Thus, absolute generation increased by approximately 30% between 2015 and 2025, although substantial year-to-year fluctuations occurred (Figure 1). [2, 3]

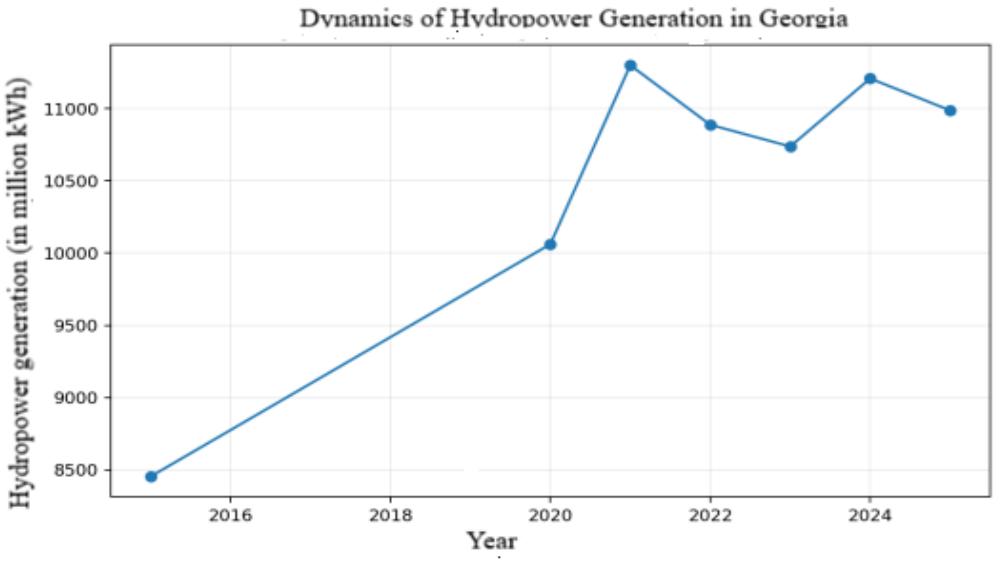


Fig. 1. *Trends in hydropower generation in Georgia.*

According to the 2025 electricity balance, total domestic electricity generation amounted to 13,837.7 million kWh, of which 10,986.6 million kWh was generated by hydropower plants. Hydropower therefore accounted for approximately 79.4% of domestic generation. This figure confirms the systemic importance of hydropower in Georgia while also highlighting the importance of diversifying the energy generation. [3]

Table 1 presents the principal quantitative indicators used to assess hydro power-plant performance. These indicators should be interpreted together rather than in isolation, particularly because hydrological variability can affect generation independently of a plant's technical condition.

Table 1. Key indicators for assessing hydropower-plant performance

Indicator	Definition	Assessment purpose	Significance for Georgia
Annual hydropower generation	Million kWh per year	To assess generation trends	A key measure of hydro power output in the electricity system
Installed-capacity factor	E / (P × 8,760)	To assess the actual utilization of installed capacity	Must be interpreted alongside hydrological conditions
Seasonal variability	Maximum/minimum monthly generation (kWh)	To assess hidrological risk	Important for winter supply deficits
Forced-outage indicator	Duration of unplanned outages (hours) / total operating time (hours)	To assess reliability	Reflects the potential impact of equipment and infrastructure condition
Grid losses	Difference between electricity entering and leaving the grid	To assess transmission efficiency	Relevant to the integration of new hydro power capacity

A significant proportion of Georgia's hydro power plants were built several decades ago. Prolonged operation increases the risk of wear affecting turbines, generators, hydro mechanical equipment, and hydraulic structures. Rehabilitation is therefore important not only for safety but also for energy efficiency. The use of modern turbines and automated operational controls may improve generating-unit performance under different load conditions. [7]

ESCO data for 2025 showed that monthly hydro power generation was 552.2 million kWh in January and 1,327.5 million kWh in June. This difference illustrates the influence of seasonal variations in river flow on electricity generation. Consequently, high output during summer does not, by itself, ensure that electricity demand can be met during winter. [3]

Climate change increases uncertainty about the seasonal distribution of river flows. Longer droughts or shifts in the timing of precipitation may affect hydro power generation. Assessments of both new and existing hydro power plants should therefore draw on multi-year hydro logical records and relevant climate scenarios. [5]

Sediment accumulation can reduce a reservoir's usable storage capacity and contribute to turbine wear. Addressing this issue requires watershed management, erosion control in the mountainous areas surrounding reservoirs, systematic monitoring, and sediment-management measures where necessary. [5]

From a system-wide perspective, the value of hydro power generation depends partly on the ability of the grid to accommodate the electricity produced and deliver it to consumers. The development of new generation facilities should therefore be coordinated with investment in electricity-transmission infrastructure. As variability of solar and wind generation expands, the flexibility of hydro power becomes increasingly important. Coordinated use of hydro power, wind, and solar resources can help balance variations in renewable electricity output, provided that system operation and available hydrological conditions allow this. [4, 6]

The assessment of hydro power projects should take account of river ecosystems, biodiversity, water use, and the interests of local communities. Improvements in energy efficiency should be pursued in a manner that integrates technical modernization with environmental requirements rather than treating them as separate considerations. [5, 6]

The analysis indicates that the main opportunities for improving energy efficiency in Georgia's hydro power sector include rehabilitating existing infrastructure, modernizing generating units, introducing digital monitoring and control, optimizing water and reservoir management, strengthening the electricity grid, and integrating hydro power with other renewable energy sources. Greater attention should be paid not only to constructing new hydro power plants but also to improving the performance of facilities already in operation. [4–6]

IRENA's 2025 assessment of Georgia emphasizes the diversification of renewable energy sources and the more flexible use of existing Regulatory hydroelectric power station. It also points out the need to assess the technical and economic feasibility of integrating existing reservoir hydro power plants with pumped-storage systems. [5]

Therefore the principal measures for improving the performance of Georgia's hydro power plants are:

- Gradual rehabilitation of operating hydro power plants and the use of high-efficiency turbines and generators;
- Introduction of digital condition monitoring for turbines and generators, together with predictive maintenance;
- Optimization of water resource management based on multi-year hydrological forecasts;
- Systematic monitoring of sediment accumulation in reservoirs and management of erosion in watersheds;
- Reinforcement of the transmission grid to facilitate the integration of new hydro power and other renewable generation;
- Combined development of hydro power, wind, and solar energy;
- Assessment of the technical and economic feasibility of energy-storage options, including pumped-storage systems;
- Establishment of a unified national monitoring system for hydro power-plant energy efficiency.

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