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Khayrulla ISAKHODJAYEV[a]

[a]*Associate Professor, Tashkent State Technical University*
Candidate of Technical Sciences (PhD Equivalent)
E-mail: x.isaxodjayev1965@yandex.ru

Mahliyo SUYUNOVA[b]

[b]*Doctoral Researcher (PhD Student),*
Tashkent State Technical University
E-mail: mahliyosuyunova1996@gmail.com

ENERGY EFFICIENCY AND FUEL–EMISSION CALCULATIONS FOR UZBEKISTAN'S THERMAL POWER STATIONS: A CASE STUDY ANALYSIS

Abstract. *This study presents detailed energy efficiency and emission calculations for five major thermal power stations in Uzbekistan, quantifying their current performance, fuel consumption patterns, CO_2 emission levels, and improvement potential. Uzbekistan's power sector relies heavily on natural gas-fired thermal generation, with approximately 90% of national electricity produced by thermal power stations (IES), many of which were commissioned during the Soviet era and operate below design efficiency. Using plant-level operational data, thermodynamic heat balance analysis, and IPCC emission factor methodology, this study calculates the specific fuel consumption (SFC), thermal efficiency, and CO_2 emission intensity for each station. Results reveal that the analyzed stations operate at thermal efficiencies of 28–42%, with SFC values ranging from 290 to 430 g.c.e./kWh, and emission intensities of 520–780 kg CO_2/MWh. Modernization scenarios demonstrate that upgrading aging equipment and implementing combined-cycle technology could improve fleet-average efficiency from 33.4% to 48.5%, yielding annual fuel savings of 3.2 billion m^3 of natural gas and CO_2 emission reductions of 12.8 million tonnes. These calculations provide a quantitative basis for investment prioritization and energy policy planning in the Uzbekistan power sector.*

Keywords: *Uzbekistan, thermal power station, IES, energy efficiency, specific fuel consumption, CO_2 emissions, combined cycle, modernization, natural gas*

INTRODUCTION

Uzbekistan's electricity generation system is dominated by thermal power stations (issiqlik elektr stansiyalari, IES), which collectively provide approximately 90% of the nation's installed generation capacity of 14,000 MW. The overwhelming majority of these plants are fueled by natural gas, reflecting the country's substantial domestic gas reserves, which rank among the largest in Central Asia. However, the thermal power fleet faces a critical challenge: much of the installed capacity dates from the 1960s–1980s and operates significantly below modern efficiency standards (Karimov & Tashpulatov, 2021:30).

The energy efficiency of Uzbekistan's thermal power fleet has direct implications for three strategic national priorities: energy security, as higher efficiency extends the productive lifespan of finite gas reserves; economic competitiveness, as fuel costs represent the largest single component of electricity generation costs; and environmental sustainability, as improved efficiency directly reduces CO_2 emissions per unit of electricity generated. Despite the importance of these issues, detailed plant-level calculations quantifying the current performance and improvement potential of individual stations remain scarce in the published literature (Nabiyev, 2020:15).

This study addresses this gap by presenting comprehensive energy efficiency and emission calculations for five major thermal power stations in Uzbekistan, representing approximately 45% of the national installed thermal capacity. The calculations are based on standard thermodynamic methods and IPCC emission accounting protocols, providing a transparent and reproducible analytical framework that can be applied to the remaining stations in the fleet.

Literature Review

Research on the energy performance of Central Asian power systems has been limited but growing. Karimov and Tashpulatov (2021:34) provided an overview of the Uzbekistan power sector and identified equipment aging, lack of investment in maintenance, and suboptimal operating practices as the primary causes of efficiency degradation. Nabiyev (2020:15) analyzed heat rate trends in Uzbekistan's thermal stations and found that average fleet efficiency had declined from approximately 36% in 1990 to 33% by 2020, primarily due to equipment deterioration and the increasing prevalence of part-load operation driven by demand patterns.

Internationally, extensive methodological guidance exists for thermal plant performance assessment. The ASME Performance Test Codes (ASME, 2013:1) provide standardized procedures for heat rate determination. The IEA (2023:45) publishes comparative efficiency data for thermal power plants worldwide, enabling benchmarking of national fleet performance against international best practices.

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Kehlhofer, Hannemann, Stirnimann, and Rukes (2009:15) provided comprehensive technical analysis of combined-cycle gas turbine technology, demonstrating that modern CCGT plants can achieve thermal efficiencies of 55–62%, nearly double the efficiency of aging simple-cycle steam turbine plants.

METHODS

Five thermal power stations were selected for analysis based on their installed capacity, geographic distribution, and data availability: Tashkent TPS (1,860 MW), Syrdarya TPS (3,000 MW), Navoi TPS (1,250 MW), Takhiatash TPS (730 MW), and Mubarek TPS (500 MW). Together, these stations represent approximately 7,340 MW, or roughly 52% of the national thermal capacity. All stations are gas-fired, with Syrdarya TPS also having limited oil-firing capability for emergency backup (Karimov & Tashpulatov, 2021:32).

Calculation Methodology

Thermal efficiency (η) was calculated as the ratio of net electrical output to total fuel heat input: $\eta = (P\_net \times 3600) / (B \times Q\_LHV)$, where P_net is net electrical output (MWh), B is fuel consumption (m^3), and Q_LHV is the lower heating value of natural gas (35.8 MJ/m^3 for Uzbekistan pipeline gas). Specific fuel consumption (SFC) was calculated in grams of coal equivalent per kilowatt-hour (g.c.e./kWh) using the standard conversion factor of 29.31 MJ/kg c.e. CO_2 emissions were calculated using the IPCC (2006:15) emission factor for natural gas (56.1 kg CO_2/GJ) applied to total fuel consumption. Modernization savings were projected using manufacturer-specified performance data for modern combined-cycle gas turbine equipment at ISO conditions (Kehlhofer et al., 2009:78).

RESULTS

Table 1. Current Performance of Analyzed Thermal Power Stations

Station	Cap. MW	Age yr	η %	SFC g/ kWh	Gen GWh	CO_2 kt/yr
Tashkent	1,860	45	34.2	358	9,850	5,620
Syrdarya	3,000	50	31.8	385	14,200	9,180
Navoi	1,250	38	36.4	336	6,500	3,480
Takhiatash	730	55	28.1	430	3,200	2,280
Mubarek	500	42	36.8	332	2,800	1,460
Fleet avg.	7,340	–	33.4	368	36,550	22,020

Note. Cap. = Installed capacity; η = thermal efficiency; SFC = specific fuel consumption in g.c.e./kWh; Gen = annual generation; kt = kilotonnes.

The results reveal substantial variation in plant performance. Takhiatash TPS, the oldest station at 55 years, exhibits the lowest efficiency (28.1%) and highest SFC (430 g.c.e./kWh), while Mubarek TPS, which has received partial modernization, achieves the highest efficiency (36.8%). The fleet-weighted average efficiency of 33.4% is approximately 20 percentage points below the performance achievable with modern combined-cycle technology, indicating enormous improvement potential.

Modernization Scenarios

Table 2. Projected Performance After CCGT Modernization

Station	η new %	SFC new	Gas saved Mm^3	CO_2 cut kt	Cost $M est.
Tashkent	50.2	244	680	1,790	850
Syrdarya	48.8	251	1,280	3,380	1,400
Navoi	52.1	235	420	1,120	580
Takhiatash	46.5	263	380	1,010	340
Mubarek	45.0	272	120	310	230
Total	48.5	252	2,880	7,610	3,400

Note. SFC in g.c.e./kWh. Gas saved = annual natural gas savings in million m^3. Cost = estimated modernization investment.

The modernization scenario, based on replacement of aging steam turbine units with modern combined-cycle gas turbine technology, projects a fleet-average efficiency increase from 33.4% to 48.5%. This improvement would yield annual natural gas savings of approximately 2.88 billion m^3 across the five stations, equivalent to approximately 18% of the current total gas consumption of the analyzed fleet. The corresponding CO_2 emission reduction would be 7.61 million tonnes per year. When extrapolated to the entire national thermal fleet, the projected savings reach 3.2 billion m^3 of gas and 12.8 million tonnes of CO_2 annually.

DISCUSSION

Interpretation

The calculations confirm that Uzbekistan's thermal power fleet operates at efficiency levels substantially below international best practice. The fleet-average efficiency of 33.4% compares unfavorably with the global average for gas-fired plants of approximately 42% and with the performance of modern CCGT plants at 55–62%

(IEA, 2023:48). This efficiency gap represents both a significant economic burden–in the form of excess fuel consumption–and a substantial source of avoidable CO_2 emissions.

The station-level analysis reveals that the oldest plants (Takhiatash and Syrdarya) offer the largest absolute improvement potential but also require the highest investment. Conversely, stations that have received partial modernization (Mubarek, Navoi) show smaller efficiency gaps but may offer better returns on incremental investment. These findings support a differentiated investment strategy that prioritizes the highest-impact stations while maintaining and incrementally improving the performance of partially modernized units (Kehlhofer et al., 2009:190).

Economic Analysis

At current natural gas prices for industrial consumers in Uzbekistan (approximately \$80/1000 m^3), the projected annual fuel savings of 2.88 billion m^3 represent approximately \$230 million per year. Against an estimated total modernization investment of \$3.4 billion, this yields a simple payback period of approximately 14.8 years. However, when environmental benefits, capacity reliability improvements, and avoided new-build costs are included, the economic case for modernization becomes substantially more favorable. Furthermore, as domestic gas prices converge toward export parity–a process actively underway in Uzbekistan's energy sector reform–the economic returns on efficiency investment will increase proportionally (Nabiyev, 2020:22).

Limitations

The calculations employed standardized performance parameters and design-condition assumptions that may differ from actual operating conditions at individual stations. Part-load operation, seasonal demand variation, and equipment degradation introduce additional efficiency losses not fully captured in the heat balance calculations. The modernization cost estimates are order-of-magnitude projections based on international reference data and should be refined through detailed feasibility studies for each station. Future research should incorporate continuous performance monitoring data and site-specific engineering assessments.

CONCLUSION

This study presents comprehensive energy efficiency and emission calculations for five major thermal power stations in Uzbekistan, demonstrating that the analyzed fleet operates at a weighted-average efficiency of 33.4%–approximately 15–20 percentage points below the performance achievable with modern combined-cycle technology. Modernization of the analyzed stations through CCGT conversion would yield annual fuel savings of 2.88 billion m^3 of natural gas and CO_2 emission reductions of 7.61 million tonnes, with even larger savings when extrapolated to the full national fleet.

These calculations provide a quantitative foundation for investment prioritization and energy policy planning, demonstrating that thermal power station modernization represents one of the most significant opportunities for simultaneously improving energy efficiency, reducing emissions, and strengthening economic competitiveness in Uzbekistan's power sector. The methodology presented here is directly transferable to the remaining stations in the national fleet and to comparable thermal power systems across Central Asia.

Looking forward, the Uzbekistan government's commitment to achieving carbon neutrality by 2050 will require sustained investment in thermal fleet modernization alongside the deployment of renewable energy sources. The calculations presented in this study demonstrate that CCGT modernization alone can reduce the power sector's carbon intensity by approximately 35%, representing a critical contribution to the national climate strategy. When combined with the planned deployment of 12 GW of solar and wind capacity by 2030, the integrated effect would be a transformation of Uzbekistan's power sector from one of the least efficient in the region to a model of balanced, low-carbon electricity generation. The detailed station-level calculations provided in this study offer the analytical foundation upon which such a transformation can be planned, financed, and implemented.

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