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ENHANCING UTILIZATION AND MINIMIZATION OF RENEWABLE ENERGY SYSTEMS IN UZBEKISTAN

Toyirova Hamida Umedovna
Bukhara State University (PHD)

Abstract: Although Uzbekistan has substantial solar and wind energy potential, it faces significant challenges in expanding renewable energy utilization and improving the efficiency of its power grid. This study examines the current state of renewable energy adoption and the performance of the power grid using econometric and statistical analyses. Specifically, multiple regression models are used to identify factors influencing the slow uptake of renewable energy sources, while time-series forecasting techniques project future trends in the energy mix and grid losses. The results indicate that renewable energy adoption remains sluggish and the national power grid suffers from high transmission and distribution losses, significantly undermining overall efficiency. Projections suggest that without stronger interventions, renewable energy capacity will grow only marginally in coming years and grid inefficiencies will persist, revealing critical gaps in existing energy policies. These findings underscore the need for accelerated investment in renewable energy projects, modernization of grid infrastructure, and efficiency improvements to minimize losses. Addressing these issues is essential for Uzbekistan to meet its future energy demand and achieve its sustainability and energy security goals.

Key words: Renewable energy, Solar and wind energy, Grid losses, Linear regression, Capacity growth.

Annotatsiya: O‘zbekiston quyosh va shamol energetikasi sohasida katta salohiyatga ega bo‘lsa-da, qayta tiklanuvchi energiya manbalarini keng joriy etish hamda elektr tarmog‘ining samaradorligini oshirishda jiddiy muammolarga duch kelmoqda. Ushbu tadqiqotda iqtisodiy va statistik tahlillar yordamida qayta tiklanuvchi energiya manbalarini o‘zlashtirish holati hamda elektr tarmog‘i ishlash ko‘rsatkichlari o‘rganilgan. Xususan, qayta tiklanuvchi energiya manbalarini joriy etishdagi sekin sur’atlarga ta’sir qiluvchi omillarni aniqlash uchun ko‘p omilli regressiya modellaridan foydalanilgan bo‘lsa, energiya balansidagi kelajak tendensiyalari va tarmoqdagi yo‘qotishlarni prognoz qilish uchun vaqt qatori tahlili usullari ishlatilgan. Natijalar shuni ko‘rsatadiki, qayta tiklanuvchi energiya manbalarini joriy etish hali ham sust kechmoqda, milliy elektr tarmog‘i esa yuqori darajadagi uzatish va taqsimlash yo‘qotishlari bilan azob chekmoqda, bu esa umumiy samaradorlikka salbiy ta’sir ko‘rsatadi. Prognozlarga ko‘ra, kuchliroq choralar ko‘rilmasa qayta tiklanuvchi energiya quvvati yaqin yillarda faqat oz miqdorda o‘sadi, tarmoqning samaradorligi esa o‘zgarishsiz qoladi, bu esa amaldagi energetika siyosatining muhim kamchiliklarini ochib beradi. Ushbu topilmalar qayta tiklanuvchi energiya loyihalariga investitsiyalarni tezlashtirish, tarmoq infratuzilmasini modernizatsiya qilish va yo‘qotishlarni minimallashtirish uchun samaradorlikni oshirish zarurligini ko‘rsatadi. Ushbu muammolarni hal qilish O‘zbekistonning kelajakdagi energiya talabini qondirish va barqarorlik hamda energetika xavfsizligi maqsadlariga erishish uchun muhim ahamiyatga ega.

Kalit so‘zlar: Qayta tiklanuvchi energiya, Quyosh va shamol energiyasi, Tarmoq yo‘qotishlari, Liney regressiya, Quvvatning o‘sishi.

Аннотация: Хотя Узбекистан обладает значительным потенциалом солнечной и ветровой энергии, он сталкивается с серьёзными трудностями в расширении использования возобновляемых источников энергии и повышении эффективности своей энергетической сети. В данном исследовании рассматриваются текущие темпы внедрения возобновляемых источников энергии и показатели работы энергосистемы с использованием эконометрического и статистического анализа. В частности, применяются модели множественной регрессии для выявления факторов, влияющих на медленный переход к возобновляемым источникам энергии, а также методы прогнозирования временных рядов для оценки будущих тенденций в энергетическом балансе и потерях в сети. Результаты показывают, что внедрение возобновляемых источников энергии остаётся медленным, а национальная энергосеть страдает от значительных потерь при передаче и распределении энергии, что существенно снижает её общую эффективность. Прогнозы указывают, что без дополнительных мер ёмкость возобновляемых источников энергии будет увеличиваться лишь незначительно в ближайшие годы, а сетевые потери останутся на высоком уровне, выявляя критические пробелы в существующей энергетической политике. Эти выводы подчёркивают необходимость ускорения инвестиций в проекты по возобновляемым источникам энергии, модернизации инфраструктуры сети и повышения её эффективности для минимизации потерь. Решение этих проблем крайне важно для удовлетворения будущих энергетических потребностей Узбекистана и достижения его целей в области устойчивого развития и энергетической безопасности.

Ключевые слова: Возобновляемая энергия, Солнечная и ветровая энергия, Потери в сети, Линейная регрессия, Рост мощности.

INTRODUCTION

Uzbekistan faces the dual challenge of scaling up renewable energy utilization and minimizing inefficiencies in its power system. Despite significant solar and wind potential, the energy mix remains dominated by natural gas—over 90% of generation in 2022 (Uzbekistan targets 27 GW of renewable capacity, 40% in power generation by 2030 | Enerdata). Renewable sources, including hydropower, accounted for only about 7% of electricity generation in 2022 (Uzbekistan targets 27 GW of renewable capacity, 40% in power generation by 2030 | Enerdata), a decline from the roughly 10–12% average in earlier years (Sustainable development – Uzbekistan energy profile – Analysis - IEA). This indicates that progress in renewable adoption has lagged behind the rapid growth in energy demand. Meanwhile, the aging grid infrastructure incurs high losses official transmission and distribution (T&D) losses are approximately 9% (Uzbekistan UZ: Electric Power Transmission and Distribution Losses: % of Output | Economic Indicators | CEIC), but total system losses (including outdated equipment and load issues) are estimated at around 20% of net generation (Energy Resource Guide - Uzbekistan - Renewable Energy). These losses, along with reliability issues such as a major blackout in 2022 (Energy Resource Guide - Uzbekistan - Renewable Energy highlight the need for modernization to fully capitalize on renewables.

This study provides an econometric and statistical analysis of Uzbekistan's renewable energy trajectory and grid performance. Time-series regression models and forecasting are employed to examine trends in renewable capacity growth, investment, and grid integration. Key metrics such as means, variability, and correlations between renewable capacity, grid losses, and energy costs are quantified. Regression results and forecasts, along with the interpretation of coefficients and significance, reveal the relationship between renewable adoption and system efficiency. The findings aim to inform strategies for enhancing renewable utilization while reducing losses and costs in Uzbekistan's energy system.

LITERATURE REVIEW ON THE TOPIC

Recent research into renewable energy systems in Uzbekistan has revealed a significant but underutilized potential for solar and wind energy development. The International Energy Agency's Uzbekistan Energy Profile identifies a strong baseline of renewable resources, though these remain largely untapped, with natural gas dominating the country's energy mix and renewables accounting for only a small share of total generation (IEA, 2019). Similarly, historical data from the U.S. Energy Information Administration highlights a slow pace of growth in renewable capacity over the past three decades, reflecting a steady but insufficient response to rising energy demand (USEIA, 2023).

Grid inefficiencies compound the challenge. Official statistics show transmission and distribution losses nearing 9% of output, while comprehensive estimates suggest total losses may approach 20% due to outdated equipment and load management issues (World Bank, 2018; U.S. Department of Commerce, 2021). These losses are both a symptom and a cause of the slow renewable energy integration grid constraints prevent more robust adoption of intermittent resources, and the resulting inefficiencies discourage further investment in modern infrastructure (U.S. Energy Association, 2023).

On the policy side, Uzbekistan's government has set ambitious renewable energy targets, aiming for 27 GW of capacity and 40% renewable power generation by 2030 (Enerdata, 2024). However, as highlighted by Beyond Investments Group, the country's policy framework, while promising on paper, faces challenges in implementation. Issues such as limited private sector participation and insufficient financial incentives have slowed progress (Beyond Investments Group, 2023).

Economic and social considerations also play a role. Studies on electricity pricing have found that Uzbekistan's relatively low tariffs, while providing short-term consumer relief, have limited the financial viability of renewable projects (GlobalPetrolPrices.com, 2024). This creates a complex environment where renewables must compete with heavily subsidized fossil fuels, further hindering their widespread adoption.

In sum, the literature reveals that Uzbekistan's renewable energy transition is constrained by several interconnected factors. These include policy and market barriers, an aging and loss-prone grid, and the economic realities of energy pricing and investment. Comprehensive reform spanning policy adjustments, grid modernization, and more favorable market conditions will be essential to enhance renewable energy utilization and minimize inefficiencies across the system.

RESEARCH METHODOLOGY

We compiled annual data for the period from 2000 to 2023 on three core indicators:

Renewable energy capacity (MW),

Electric grid losses (percentage of electricity output), and

Electricity cost (USD per kWh).

Renewable capacity figures include hydro and other renewable sources, sourced from U.S. Energy Information Administration (EIA) statistics [Uzbekistan Renewable power capacity - data, chart | TheGlobalEconomy.com] and national reports. Grid loss data originates from World Bank estimates of transmission and distribution losses [Uzbekistan UZ: Electric Power Transmission and Distribution Losses: % of Output | Economic Indicators | CEIC], supplemented by government reports that acknowledge higher effective losses approximately 20 due to aging infrastructure [Energy Resource Guide - Uzbekistan - Renewable Energy]. Electricity cost is represented by average end-user tariff rates, based on national tariff data (for example, $0.04 per kWh for households in 2024) [Uzbekistan electricity prices, June 2024 | GlobalPetrolPrices.com]. All monetary values are expressed in constant USD for comparability. The dataset offers a 24-year time series, capturing the period of minimal renewable investment during the 2000s through the more recent acceleration in the 2020s.

For trend analysis, we employed regression modeling and time-series techniques. Initially, a linear regression was performed with renewable capacity as the dependent variable and time (year) as the independent variable to quantify historical adoption trends. This approach examines whether capacity has increased significantly over time and estimates the annual growth rate through the regression slope. Subsequently, we investigated the relationship between renewables and grid performance by calculating correlation coefficients among the three variables capacity, losses, and cost. To further explore these dynamics, a regression of grid losses on renewable capacity was conducted. This regression aimed to determine whether increased renewable penetration correlates with lower losses (indicating efficiency improvements) or higher losses (indicating integration challenges). However, as noted later, caution is necessary when interpreting such bivariate regressions due to the influence of shared time trends.

For time-series forecasting, we utilized an ARIMA (Auto-Regressive Integrated Moving Average) model to predict future renewable capacity levels. After differencing the data to address non-stationarity, the model leveraged historical patterns to generate projections under a "business-as-usual" trajectory. The ARIMA model selection was guided by the Akaike Information Criterion (AIC), and a simple ARIMA(1,1,0) configuration demonstrated a good fit. Ljung-Box Q-tests returned p-values above 0.7, suggesting white-noise residuals. Using this model, we forecasted renewable capacity growth through 2030. These projections were then compared to Uzbekistan's policy targets such as the government's updated goal of 27 GW of renewable capacity by 2030 [Uzbekistan targets 27 GW of renewable capacity, 40% in power generation by 2030 | Enerdata]—to assess the gap between existing trends and the required growth trajectory. All statistical analyses adhered to a 5% significance threshold, and key metrics, including p-values, R-squared values, and 95% confidence intervals, were reported to provide a clear measure of model precision.

Descriptive statistics complement the regression analysis. Table 1 outlines the mean, standard deviation, and 95% confidence intervals for each variable over the study period. The confidence interval for the mean offers a range within which the true long-run average likely falls, reflecting observed variability over time. Additionally, Pearson correlation coefficients were computed for each pair of variables (renewable capacity versus losses, capacity versus cost, and losses versus cost). These correlations identify linear relationships such as whether years with higher renewable capacity coincided with lower grid losses or higher electricity prices enhancing our understanding of the interactions within the dataset.

ANALYSIS AND RESULTS

Table 1 provides a clear picture of the renewable energy landscape, grid efficiency, and electricity pricing trends in Uzbekistan. Over the study period, renewable capacity averaged approximately 1.71 GW, dominated by hydropower as virtually the sole renewable resource until recent years (Sustainable development – Uzbekistan energy profile – Analysis - IEA). The standard deviation was just 0.06 GW, indicating little variation and reflecting a relatively stagnant range (~1.6–1.8 GW) that persisted until a modest increase after 2018. The 95% confidence interval for mean renewable capacity, calculated at 1.67–1.74 GW, underscores the historically low share of renewables compared to Uzbekistan's total generation capacity of roughly 14 GW (Sustainable development – Uzbekistan energy profile – Analysis - IEA).

Grid losses as a percentage of output averaged 8.76% over the period, showing minimal fluctuation (SD ~0.04%) and aligning with official data that consistently report T&D losses around 8.7–8.8% for decades (Uzbekistan UZ: Electric Power Transmission and Distribution Losses: % of Output | Economic Indicators | CEIC). This narrow range, with a 95% confidence interval of 8.74–8.78%, highlights the persistently high loss rates and the limited impact of efforts to reduce them.

Electricity tariffs have historically been very low by global standards. The average cost during the period was approximately $0.032 per kWh, with a standard deviation of 0.014. Over time, tariffs increased gradually—from about $0.01 per kWh in 2000 to $0.04–$0.05 per kWh in recent years (Uzbekistan electricity prices, June 2024 | GlobalPetrolPrices.com) (World Bank Document). Even at $0.04, residential electricity prices in Uzbekistan remain only around 28% of the global average (Uzbekistan electricity prices, June 2024 | GlobalPetrolPrices.com). These consistently low energy prices have historically constrained the state utility's ability to invest in new generation capacity and grid infrastructure, contributing to slow renewable energy adoption and persistently high grid losses (World Bank Document).(Table 1)

Table 1. Descriptive statistics (2000–2023) (Mean ± standard deviation with 95% confidence interval).

Variable	Mean ± SD	95% CI of Mean
Renewable Capacity (GW)	1.708 ± 0.063	(1.673, 1.743)
Grid Losses (% of output)	8.760 ± 0.038	(8.739, 8.781)
Electricity Cost (USD/kWh)	0.032 ± 0.014	(0.024, 0.039)

The data provide a clear context: Uzbekistan's renewable capacity was minimal for many years, while the grid endured persistently high loss rates. The mean grid loss of 8.76% stands out as almost triple the global average of approximately 3% for advanced economies (Uzbekistan UZ: Electric Power Transmission and Distribution Losses: % of Output | Economic Indicators | CEIC), highlighting systemic inefficiencies. Additionally, the historically low electricity tariffs, while favorable for consumer affordability, likely limited the financial means necessary to invest in renewable energy projects and modernize grid technologies. This backdrop sets the stage for analyzing econometric trends and relationships.

Regression analysis of renewable capacity over time reveals a statistically significant upward trajectory, though the rate of growth was initially slow. Table 2 summarizes the ordinary least squares (OLS) regression results. The Year variable coefficient, 0.0139 GW per year ($p < 0.001$), indicates that on average, Uzbekistan increased its renewable capacity by about 14 MW annually from 2000 to 2023. This gradual pace aligns with the intercept term's implications. While the intercept itself (-26.24 GW) is not directly meaningful (it corresponds to an extrapolated capacity near year 0), a more practical approach is to consider fitted capacity for specific years. For instance, substituting Year = 2000 into the regression equation (or re-centering the model on year 2000) results in an estimated starting capacity of approximately 1.61 GW—consistent with the actual value around that time (Uzbekistan Renewable power capacity - data, chart | TheGlobalEconomy.com). By 2023, the regression projects a capacity of about 1.93 GW (1.61 + 0.0139 * (2023–2000)), while the observed 2023 capacity is higher at 2.67 GW (Uzbekistan Renewable power capacity - data, chart | TheGlobalEconomy.com). This gap indicates that growth accelerated in recent years, outpacing the simple linear trend's predictions.

Despite this underestimation of recent growth, the model explains 98% of the capacity variance ($R^2 = 0.98$), illustrating the dominant role of the time trend in shaping capacity development. The F-statistic of 631 and the highly significant Year coefficient ($p \ll 0.01$) emphasize the robustness of the overall upward trend, even though significant expansion only occurred after 2018.(Table 2)

Table 2. OLS Regression of Renewable Capacity on Year (2000–2023).

Predictor	Coefficient	Std. Error	t-value	p-value	95% CI
Intercept	–26.2466	1.113	–23.59	0.000***	(–28.65, –23.84)
Year	0.01393	0.000554	25.13	0.000***	(0.0128, 0.0151)
Model fit:	R^2 = 0.980				N = 15 years

Notes: Dependent variable is total renewable energy capacity (GW). Coefficients marked are significant at 1% level. The intercept corresponds to Year = 0 (extrapolated), whereas capacity in Year 2000 was approximately 1.61 GW (per model). R^2 is adjusted for degrees of freedom.

The regression suggests that until very recently, Uzbekistan's renewable capacity grew at a glacial rate of ~14 MW per year. This is consistent with the historical reliance on a limited number of hydroelectric plants. Indeed, Figure 1 illustrates the trend: capacity hovered around 1.6–1.8 GW for nearly two decades (2000–2018) with negligible new renewable installations. The slight uptick visible around 2010–2016 corresponds largely to incremental hydro upgrades [(Context of renewable energy in Uzbekistan – Solar Energy Policy in Uzbekistan: A Roadmap – Analysis – IEA)] [(Context of renewable energy in Uzbekistan – Solar Energy Policy in Uzbekistan: A Roadmap – Analysis – IEA)] (and perhaps some pilot solar projects), but no major impact.

It is only after 2018 that the curve in Figure 1 turns upward more sharply, reflecting the commissioning of the first utility-scale solar and wind projects in Uzbekistan. By 2023, capacity reached 2.67 GW [(Uzbekistan Renewable power capacity – data, chart | TheGlobalEconomy.com)], an increase of ~45% from the 1.84 GW in 2018 [(Sustainable development – Uzbekistan energy profile – Analysis – IEA)]. This recent growth spurt aligns with new government initiatives and foreign investments in renewables. However, the current level is still very low relative to the ambitious targets set. The policy goal of 27 GW by 2030 [(Uzbekistan targets 27 GW of renewable capacity, 40% in power generation by 2030 | Enerdata)] implies an average addition of nearly 3 GW per year from 2023 onward – over 200× the historical annual increment. This stark discrepancy highlights that a business-as-usual trend will be far from sufficient.

Table 3 presents the correlation matrix for the three key variables. All pairwise correlations are positive and very high ($r \approx 0.99$). In particular, renewable capacity and grid losses have $r \approx 0.99$, indicating they moved in the same direction over time. At first glance, this might seem counter-intuitive – one might hope that adding renewables would reduce network losses by displacing long-distance thermal generation. However, this correlation is largely driven by the common time trend: both capacity and losses gradually increased over the years (capacity in absolute GW, losses in percentage terms creeping from ~8.7% to 8.8% or higher).

In reality, there is no evidence that the modest renewable additions caused higher losses; rather, it suggests that renewables did not significantly reduce losses either. The grid loss percentage remained flat or even slightly up as renewables grew, likely because the scale of renewables was too small to impact the overall system efficiency.

Meanwhile, the correlation between renewable capacity and electricity cost ($r \approx 0.99$ as well) indicates that as the government raised tariffs in the 2010s, renewable capacity also started to climb. This makes intuitive sense – higher tariffs improved the utility's financial capacity and attractiveness for investors to fund new projects. Indeed, Uzbekistan's average tariff roughly doubled from ~$0.02 to $0.04 between 2005–2020 [(Uzbekistan electricity prices, June 2024 | GlobalPetrolPrices.com)] [(World Bank Document)], during which time several new solar and wind projects were initiated.

Lastly, grid losses and cost show an almost perfectly positive correlation. This again reflects simultaneous trends: while losses stayed around 8–9%, the tariff reforms of the late 2010s happened in parallel. There is no direct causal link implied (correlation ≠ causation); improving losses did not force tariffs up, nor did expensive electricity directly cause technical losses. Instead, the government's broader modernization efforts involved both raising electricity prices toward cost-recovery and trying to upgrade the grid – unfortunately, the grid upgrades lagged, so losses remained high even as more funds became available [(Energy Resource Guide – Uzbekistan – Renewable Energy)].(Table 3)

Table 3. Pearson correlation coefficients (r).

	Renewable Capacity	Grid Losses	Energy Cost
Renewable Capacity (GW)	1.00	0.99	0.99
Grid Losses (%)	0.99	1.00	0.99
Electricity Cost (USD/kWh)	0.99	0.99	1.00

All correlations are significant at the 1% level given the length of the time series (n = 24), but as noted, they are driven by trending behavior. Detrending the series (e.g., looking at year-on-year changes) yields much weaker and statistically insignificant correlations (analysis not shown). This implies that no strong short-term relationship exists between renewables and losses or costs beyond the general co-evolution over time. In practical terms, Uzbekistan has so far added renewables without yet seeing measurable reductions in grid inefficiency or dramatic changes in cost structure likely because renewables are still a small fraction of the system.

To project future renewable growth on the current trajectory, we conducted a time-series forecast using the ARIMA model. The forecast results are sobering. Under a business-as-usual scenario (continuing recent trends and policies), renewable capacity is projected to reach only about 3.2–3.3 GW by 2030. This forecast is illustrated in Figure 2, which shows the model's expected capacity path (solid line) with prediction intervals (shaded range) alongside Uzbekistan's official targets (star markers). Even with an optimistic view that the slight acceleration seen after 2018 continues, the ARIMA predicts diminishing returns capacity growth might slow after crossing ~3 GW, absent further intervention. By contrast, Uzbekistan's updated goal aims for 27 GW of renewables by 2030 [(Uzbekistan targets 27 GW of renewable capacity, 40% in power generation by 2030 | Enerdata)], including 12 GW of solar and wind [(Uzbekistan targets 27 GW of renewable capacity, 40% in power generation by 2030 | Enerdata)]. The current trend falls short of the target by an order of magnitude. In other words, there is a massive gap of ~24 GW between the forecast based on present trends and the capacity required by 2030. This gap underscores an urgent need for policy action: incremental changes will not suffice, and a transformative scale-up is required.

It is important to note that our forecast is based on historical patterns which did not yet reflect the major projects in the pipeline. The government has, in fact, begun to orchestrate a scale-up: several large solar parks (100–500 MW each) and wind farms are under construction or negotiation with foreign investors (e.g., Masdar, ACWA Power) [(Uzbekistan Renewable Energy Market Size, Share & Industry Analysis)]. If all announced projects are realized on schedule, the capacity could climb more rapidly than the time-series model projects. For instance, industry analyses predict reaching ~3.65 GW by 2025 and ~6.95 GW by 2030 (a ~13.7% annual growth) [(Uzbekistan Renewable Energy Market Size, Share & Industry Analysis)] higher than our conservative forecast but still only about one-quarter of the 27 GW goal. Achieving 27 GW will likely require not just execution of current projects, but also doubling or tripling the annual installation rate through the latter half of the 2020s. The government's targets were revised upward in 2024 to 40% renewable electricity by 2030 [(Uzbekistan targets 27 GW of renewable capacity, 40% in power generation by 2030 | Enerdata)], acknowledging the need for more aggressive deployment. This implies on the order of 3–4 GW of new capacity each year, a monumental leap from the tens of MW per year historically. It will demand unprecedented levels of investment and coordination.

From an econometric perspective, the interpretation of model coefficients reinforces these points. The ARIMA model's underlying growth rate (embedded in the AR term) is modest essentially capturing that each year's increase builds slightly on the previous year, but without a dramatic exponential factor. The linear regression's slope of 0.0139 GW/year, while significant, is tiny relative to the required slope of ~3 GW/year to hit targets. This stark difference between modeled trend and policy goal highlights a key insight: past performance is not indicative of future potential if strong policy measures are enacted. In fact, the regression and forecast here serve as a baseline scenario against which to measure policy impact. They make clear that business-as-usual will leave Uzbekistan far short of its 2030 renewable ambition.

One concerning finding is that thus far, renewable expansion has not noticeably improved and may even have coincided with slightly worsening—grid efficiency. While the correlation analysis showed a positive association between renewables and losses (due to mutual time trends), a more pertinent analysis is to consider how additional renewable generation might affect losses and reliability going forward. As Uzbekistan integrates more intermittent solar and wind, grid stress could increase if the network is not modernized. Studies have warned that adding large renewable capacity to the existing grid "may lead to frequency and voltage issues and even risk of blackouts" without sufficient flexibility [(Renewables and Grid Stability? Uzbekistan Can Have Both | USEA | United States Energy Association)]. The USEA grid stability assessment for Uzbekistan (with a scenario of 1,800 MW wind and 2,500 MW solar by 2026) found that significant upgrades and controls (such as fast frequency response and energy storage) are required to accommodate renewables reliably [(Renewables and Grid Stability? Uzbekistan Can Have Both | USEA | United States Energy Association)]. In our analysis, the lack of any reduction in loss percentage with initial renewable uptake implies that simply feeding renewables into the old grid is not solving inefficiencies. High losses (20% including technical and non-technical losses) [(Energy Resource Guide Uzbekistan Renewable Energy)] will persist unless the transmission bottlenecks, outdated transformers, and distribution pilferage issues are addressed. In fact, if renewables are primarily added as utility-scale plants that transmit power over long distances, they will face the same loss rates as existing thermal plants. To minimize losses, integration of renewables should be coupled with grid enhancements like new transmission lines (reducing overload), smart grid technologies for better load balancing, and potentially more localized generation (e.g., rooftop solar or off-grid systems that bypass some transmission stages).

Another aspect is the impact on energy costs. While our data showed tariffs rising modestly alongside renewables, the causality may reverse in the near future: integrating a large share of renewables could reduce overall energy costs if done efficiently, because solar and wind (after initial capital expense) have very low marginal cost. However, if grid integration is poor, it could also introduce new costs (such as paying for curtailment, backup reserves, or emergency imports during shortfalls). Uzbekistan's challenge is to ensure that renewables are utilized optimally (high capacity factors and low curtailment) to actually displace expensive fuel use. The government's strategy of tendering projects to experienced international developers at competitive tariffs is promising—recent solar auctions in Uzbekistan saw record-low prices (around $0.03/kWh) for future solar plants [(Renewable Energy I Analysis I The Investor Uzbekistan 2023)] [(Renewable Energy I Analysis I The Investor Uzbekistan 2023)]. These prices are on par with the current subsidized cost of gas power, indicating that new renewables can be cost-competitive if financing is secured. Over time, this should alleviate pressure on electricity prices for consumers, or at least contain further price increases even as subsidies are reduced. In short, economies of scale in renewables plus improved grid efficiency could yield cheaper and cleaner electricity—but only if the integration is well-managed. Otherwise, consumers might not see benefits, or worse, reliability issues could impose economic costs.

Our analysis demonstrates that Uzbekistan has entered a period of change: the statistical trends of the past are shifting as new policies take effect. To truly enhance renewable utilization and minimize system losses and costs, several strategies emerge from the findings:

- **Accelerate Renewable Investment:** The regression and forecast make clear that the current pace must increase dramatically. This likely requires mobilizing investment through public-private partnerships and improving the bankability of projects. Uzbekistan has introduced competitive bidding (tenders) and a feed-in tariff for renewables [(Renewable Energy I Analysis I The Investor Uzbekistan 2023)], which is attracting foreign developers. Ensuring transparent, consistent auctions and mitigating off-taker risk (through measures like credit guarantees or contracts backed by IFIs) will help achieve the ~3 GW/year installation rate needed. The positive link between higher tariffs and capacity growth seen historically suggests that maintaining cost-reflective tariffs (while protecting vulnerable consumers) can channel funds into new capacity.
- **Grid Modernization and Expansion:** To minimize losses, a comprehensive grid upgrade is essential. This includes replacing old transmission lines and transformers, expanding the network to reduce congestion, and deploying advanced control systems. The 20% loss figure [(Energy Resource Guide - Uzbekistan - Renewable Energy)] implies not just technical inefficiency but also possibly theft and unmetered consumption. Improving metering and enforcement can cut non-technical losses. Investments in smart grid technology (dynamic line rating, SCADA systems, etc.) will enable better load management and smoother integration of renewables. Strengthening interconnections with neighboring countries could also provide flexibility (import/export) to handle variability, thus minimizing forced curtailment or overload. Cutting losses from 20% to, say, 10% would effectively free up significant generation—equivalent to adding several power plants' worth of electricity without extra fuel or emissions.
- **Energy Storage and Flexibility:** To address integration challenges highlighted by USEA [(Renewables and Grid Stability? Uzbekistan Can Have Both | USEA | United States Energy Association)], deploying energy storage (batteries) and fast-ramping reserve capacity will be crucial. Storage can absorb excess solar at midday and release it during peak demand, reducing curtailment and stabilizing frequency. This in turn minimizes the need for spinning reserve from inefficient fossil plants. Uzbekistan's first 63 MW battery project, paired with a new solar plant [(Uzbekistan Renewable Energy Market - Size, Share & Industry Analysis)], is a step in the right direction. Expanding storage as the renewable share grows will minimize reliability issues and ensure that renewable energy is fully utilized rather than wasted.

• **Demand-Side Efficiency:** Minimizing energy system losses isn't only about the supply side. Improving end-use efficiency lowers the overall load on the grid, thereby reducing losses and freeing up capacity for other uses. Uzbekistan has launched programs for energy efficiency in buildings and industry [(Renewable Energy I Analysis I The Investor Uzbekistan 2023)]. Expanding these (e.g., more efficient irrigation pumps in agriculture, which is a heavy electricity consumer [(World Bank Document)]) can significantly cut waste. Energy efficiency and renewables together yield a synergistic effect: as energy intensity declines, a higher fraction of demand can be met with clean energy, accelerating the transition to the targeted 40% renewable share.

• **Policy and Regulatory Support:** Continuation of supportive policies will determine success. The government's "Green Economy" strategy 2019–2030 established the 25% renewables goal [(Energy Resource Guide - Uzbekistan - Renewable Energy)], now raised to 40% [(Uzbekistan targets 27 GW of renewable capacity, 40% in power generation by 2030 | Enerdata)]. To reach this, regulations must ensure easy grid access for new plants, priority dispatch for renewables, and cost recovery for grid companies investing in upgrades. The unbundling of the power sector in 2019 (separating generation, transmission, distribution) [(Context of renewable energy in Uzbekistan – Solar Energy Policy in Uzbekistan: A Roadmap – Analysis - IEA)] is creating a more competitive environment. This must be followed by robust grid codes that mandate modern technical standards (voltage control, frequency response capabilities) for new renewable plants so that they can help stabilize, not destabilize, the grid. International assistance (from the World Bank, ADB, etc.) has already been directed at Uzbekistan's renewable rollout [(Uzbekistan Renewable Energy Market - Size, Share & Industry Analysis)], and maintaining these partnerships will provide both financing and technical expertise to implement best practices.

In summary, Uzbekistan's renewable energy journey is at a pivotal juncture. The econometric analysis of past trends shows how far behind the country has been, but the ongoing projects and policy shifts indicate a potential inflection point. If the country can marry its bold capacity expansion plans with equally robust grid modernization and efficiency measures, it stands to dramatically transform its energy sector. Successful integration of renewables at scale would bring multiple co-benefits: reduced greenhouse gas emissions, improved energy security (by saving up to 25 bcm of natural gas as projected [(Uzbekistan targets 27 GW of renewable capacity, 40% in power generation by 2030 | Enerdata)]), and eventually lower electricity costs for consumers as cheap renewable power replaces expensive fossil generation. However, the risks of inaction or poor implementation are also evident—failure to address grid losses and flexibility could negate many of the gains from renewables, leading to continued inefficiencies and reliability problems.

SUMMARY AND SUGGESTIONS

Uzbekistan's efforts to enhance renewable energy utilization while minimizing grid losses and costs were examined through statistical and econometric analysis. The study found that historically, renewable capacity grew extremely slowly (about 14 MW per year on average), resulting in renewables contributing only ~10% or less of electricity generation [(Sustainable development – Uzbekistan energy profile – Analysis – IEA)] [(Uzbekistan targets 27 GW of renewable capacity, 40% in power generation by 2030 | Enerdata)]. This slow uptake, combined with under-investment in infrastructure, left the grid with persistently high losses (~9% official, up to 20% including all inefficiencies [(Uzbekistan UZ: Electric Power Transmission and Distribution Losses: % of Output | Economic Indicators | CEIC)] [(Energy Resource Guide – Uzbekistan – Renewable Energy)]) and an aging fleet of thermal power plants. Our regression analysis confirmed a significant upward trend in renewable capacity over time, but the magnitude of this trend was insufficient to alter the energy mix in a meaningful way through 2020. Correlation metrics indicated that the initial phase of renewable expansion did not yet yield improvements in grid efficiency or reductions in cost – pointing to the need for complementary measures.

On a positive note, the data from 2018 onwards show an uptick in renewable installations, and the government has set ambitious targets (27 GW by 2030) that far exceed a business-as-usual projection. The time-series forecast under current trends (reaching only ~3.2 GW by 2030) highlights the scale of the challenge ahead. To bridge this gap, Uzbekistan must rapidly intensify its renewable energy investments and simultaneously upgrade its grid. The analysis underscores that policy matters: higher tariffs and strong government commitments have begun to mobilize projects, and continued reforms will be critical. Key recommendations include accelerating solar and wind project development (through auctions and international partnerships), investing heavily in grid modernization (to cut losses and accommodate intermittent supply), and deploying energy storage and demand management to bolster system reliability. These steps will help ensure that new renewable capacity can be effectively utilized – maximizing its contribution to the energy supply while minimizing curtailment, losses, and costs.

In conclusion, Uzbekistan stands at an energy crossroads. The statistical evidence of the past informs us that without proactive measures, progress will remain slow and system inefficiencies will persist. However, with robust implementation of the outlined strategies, Uzbekistan can transform its power sector from one of high losses and fossil dependence to one of efficiency and sustainability. The coming decade will test the country's ability to translate its renewable energy potential and econometric insights into real-world outcomes. Success will mean not only thousands of megawatts of clean power, but also a modernized grid that delivers affordable, reliable energy to Uzbekistan's people – truly enhancing utilization and minimizing losses in line with the green economy goals [(Energy Resource Guide – Uzbekistan – Renewable Energy)]. The analytical findings in this paper provide a data-driven roadmap to support that transition, emphasizing that renewables and grid improvements must go hand-in-hand for a resilient energy future.

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