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Article

Machine Learning as an Enabler of the Green Economy Transition: A Comparative Framework for the European Union, Uzbekistan and Kazakhstan

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Abstract: The article examines how machine learning (ML) can support the transition to a green economy in Uzbekistan and Kazakhstan, using the European Union as a reference model. The study combines a comparative analysis of national green-economy and artificial-intelligence strategies with a structured review of recent research on ML for energy, water and emissions management. It proposes a four-layer framework (data, models, decisions and governance) and maps six ML use cases to the priorities of the two countries. Building on existing impact frameworks, it also proposes a "net climate benefit" rule for public ML projects, under which the energy footprint of computing is counted against the emissions it helps avoid. The results show that renewable-energy forecasting and irrigation management offer the highest returns for both countries, while data availability and governance capacity are the main constraints.

Keywords: Machine learning, green economy, sustainable development, renewable energy forecasting, twin transition, artificial intelligence policy, Uzbekistan, Kazakhstan, European Union.

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1. Introduction

The green transition and the digital transition are now treated as one policy agenda. The European Green Deal set the goal of climate neutrality by 2050 and described digital technologies as a key enabler of that goal [1]. Central Asian countries have adopted similar long-term targets. Uzbekistan approved its Strategy for the Transition to a Green Economy for 2019-2030 [2], and Kazakhstan approved its Strategy for Achieving Carbon Neutrality by 2060 in February 2023 [3]. Both countries now face the same practical question: how to integrate large volumes of variable solar and wind power, use scarce water more efficiently and measure emissions credibly, while their economies keep growing quickly.

The aim of this article is to build a framework that helps policymakers and universities in Uzbekistan and Kazakhstan decide where machine learning (ML) should be applied first, and on what conditions, by learning from the experience of the European Union.

Literature review

A widely cited survey by Rolnick et al. identified high-impact applications of ML for climate mitigation and adaptation, covering power systems, buildings, transport and land use, and stressed that ML is effective only when combined with domain expertise and policy [4]. Vinuesa et al. concluded that AI could act as an enabler for a large share of the Sustainable Development Goal targets, but could also inhibit some of them, and that its

development needs regulatory oversight [5]. Sector reviews show that deep learning and hybrid models generally outperform classical statistical methods in short-term solar and wind forecasting, especially when combined with numerical weather prediction data [6; 7].

A second stream of research addresses the environmental cost of ML itself. Strubell et al. showed that training large neural models can have a substantial energy and carbon footprint [8]. Kaack et al. proposed a systematic framework that separates the computing-related emissions of ML, the immediate effects of its applications and its system-level effects [9], and the International Energy Agency now treats data centres as a fast-growing source of electricity demand [10]. Most of this research, however, comes from advanced economies. Little work links ML use cases to the specific strategies, institutions and data conditions of Central Asia. This article addresses that gap.

2. Research methodology

The study uses three methods. First, a comparative policy analysis covers the main strategic documents of the EU, Uzbekistan and Kazakhstan on the green economy and artificial intelligence adopted between 2019 and 2026. Second, a structured review covers recent peer-reviewed literature and international agency reports on ML in energy, water and emissions management. Third, the framework is built by synthesis: ML use cases from the literature are matched to the stated priorities of the two countries and assessed qualitatively by the author on three criteria: expected environmental impact, data readiness and implementation cost. The assessment is expert-based and is intended as a starting point for later empirical validation, not as a measured result.

3. Analysis and results

Policy context.

In the EU, the green and digital agendas are linked through binding regulation. The Artificial Intelligence Act introduced a risk-based framework for AI systems [11], and the recast Energy Efficiency Directive requires large data centres to report their energy performance [12]. The European Environment Agency has warned that the environmental footprint of data centres, networks and devices keeps growing and argued that efficiency improvements will not be enough to compensate for this growth [13]. The EU lesson is therefore twofold: ML should be used actively for decarbonisation, but the energy use of digital infrastructure must also be governed.

Uzbekistan has set some of the most ambitious renewable-energy targets in the region: the President has announced plans to raise the share of renewables in the energy balance to 54% by 2030 [14]. In parallel, the Strategy for the Development of Artificial Intelligence Technologies until 2030, approved in October 2024, aims to place Uzbekistan among the top 50 countries in AI development [15]. Kazakhstan's carbon-neutrality strategy relies on gradually replacing coal with renewable and alternative sources [3]. In both countries the energy and AI strategies were developed largely separately, which creates an opportunity to connect them deliberately, as the EU has done.

A four-layer framework.

Based on the review, the article proposes a framework of four interdependent layers. The **data layer** includes meteorological, smart-meter, satellite and administrative data and the rules for sharing them. The **model layer** covers forecasting, classification and optimisation models. The **decision layer** connects model outputs to operational decisions, such as grid dispatch, irrigation schedules or emissions inspections. The **governance layer** covers risk management, transparency, data protection and the accounting of the energy footprint of computing. Projects usually fail in the first and last layers rather than in modelling itself: models are relatively easy to obtain, while reliable data and institutional ownership are not. Table 1 maps six ML use cases to green-economy policy areas.

Table 1. ML use cases for the green economy and their priority for Uzbekistan and Kazakhstan

Green-economy domain (conference section)	ML task	Typical methods	Priority for Uzbekistan and Kazakhstan
Renewable power integration (1)	Day-ahead and intraday forecasting of solar and wind output	Gradient boosting, LSTM/CNN hybrids on weather and satellite data	Very high: renewable capacity is growing fastest here, and grids need balancing
Electricity demand and grids (3)	Load forecasting, loss detection, flexible demand	Regression ensembles, anomaly detection, reinforcement learning	High: rising demand, ageing networks, high technical losses
Industry and buildings (1)	Predictive maintenance, process energy optimisation	Sensor-based classification, digital twins	High for energy-intensive mining, metals and cement
Agriculture and water (2)	Irrigation scheduling, evapotranspiration and yield estimation	Random forest, remote-sensing models	Very high: irrigated agriculture and scarce water in both countries
Emissions monitoring (3, 5)	Monitoring, reporting and verification (MRV) of GHG emissions, methane leak detection	Computer vision on satellite imagery	High: needed for credible NDC reporting and carbon markets
Green finance and services (5)	Climate-risk and ESG scoring of projects and borrowers	Interpretable credit-risk models	Medium: growing green bonds and international project finance

Source: compiled by the author based on [4; 6; 7; 16].

Priority use cases.

Two use cases stand out. The first is forecasting renewable generation. For systems that are adding gigawatts of solar and wind capacity, better forecasts directly reduce balancing costs and curtailment, and the required data weather data and plant output already exists at most new plants [6]. The second is irrigation and water management. Agriculture in both countries depends heavily on irrigation, and ML models that estimate crop water needs from weather and satellite data can support more precise irrigation scheduling. Here the main obstacle is not the method but the lack of field-level measurements and digital water accounting, which makes the data layer the first investment priority.

The net climate benefit principle.

The IEA projects that electricity consumption by data centres will roughly double from about 485 TWh in 2025 to about 950 TWh in 2030, reaching around 3% of global demand [10]. For Uzbekistan and Kazakhstan, which plan to build national computing capacity under their AI strategies, green-economy goals and AI goals can therefore come into conflict. Building on the impact framework of Kaack et al. [9], the article proposes to turn this analysis into a practical approval rule for public investment, the principle of the **net climate benefit** of ML: a public ML project in the energy, water or industrial sector should estimate, before approval, the emissions it is expected to avoid and subtract the emissions from the computing it requires. Projects with a clear positive balance should be prioritised. Lightweight models, such as gradient boosting for forecasting, often deliver most of the benefit at a small fraction of the computing cost of very large models [8]. This principle adapts the EU approach to data-centre reporting [12; 13] to the earlier stage of digital development in Central Asia.

4. Conclusions and suggestions

Machine learning can significantly accelerate the green transition in Uzbekistan and Kazakhstan, but only if it is introduced as part of a system that includes data, decisions and governance, not as a stand-alone technology. The analysis leads to the following suggestions: (1) link national AI strategies explicitly to green-economy and carbon-neutrality targets; (2) begin with renewable-energy forecasting and irrigation management, where the expected impact is highest; (3) invest first in open, standardised data on energy, weather and water; (4) require a net-climate-benefit assessment for publicly funded ML projects, drawing on EU practice; and (5) use IT universities as training centres and neutral data-sharing partners between utilities, ministries and researchers. Future research should test the proposed framework empirically on national energy and water datasets.

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