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GREEN TRANSITION AND ALGORITHMS: AN ECONOMIC ASSESSMENT OF THE ROLE OF ARTIFICIAL INTELLIGENCE IN THE DECARBONISATION OF INDUSTRIAL ENTERPRISES (THE EXPERIENCE OF GERMANY AND PROSPECTS FOR UZBEKISTAN)

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Abstract: this article examines the economic effects of applying artificial intelligence and intelligent energy management system to the decarbonisation of industrial enterprises, comparing the existing of Germany with the conditions and prospects of Uzbekistan. The study argues that machine learning in industry should be assessed as an economic rather rather than an environmental instrument, since the same algorithms that reduce specific energy consumption also reduce operating costs and exposure to carbon pricing. Using ad decomposition of industrial emissions the article separates the effect of artificial intelligence on the energy intensity of output from its effect on the carbon intensity of the energy consumed. The funding shows that German industrial decarbonisation rests on a binding carbon price combined with targeted transformation finance, while Uzbekistan processes a large technical efficiency reserve but lacks the price signals and measurement infrastructure that convert this potential into investment. Enterprises with foreign capital participation are identified as the most realistic channel for transferring both the technology and the managerial standards that make it effective.
Keywords: green transition, artificial intelligence, industrial decarbonisation, energy intensity, energy management, Germany, Uzbekistan, carbon border adjustment, mechanism, joint ventures, green economy, competitiveness.

INTRODUCTION.

The decarbonisation of industry now determines the terms on which manufactured goods are traded. Since 1 January 2026 the Carbon Border Adjustment Mechanism of the European Union has entered its definitive phase, requiring importers of cement, iron and steel, aluminium, fertilisers, electricity and hydrogen to purchase and surrender certificates covering the emissions embedded in those goods. For economies whose exports rest on energy-intensive commodities, the carbon content of a product has become a price parameter rather than a reputational one.

The classical instruments of industrial decarbonisation, namely equipment replacement, fuel switching and carbon capture, all require capital expenditure that developing economies can mobilise only selectively. This raises a question that is economic rather than technological: are there instruments that deliver measurable emission reductions at a cost per tonne low enough to be financed from operating budgets? Artificial intelligence applied to industrial energy management is one candidate, because it acts on the efficiency of existing assets rather than requiring their replacement.

For Uzbekistan the question is directly relevant. According to the International Energy Agency, the energy intensity of the gross domestic product of Uzbekistan is about 35 per cent higher than that of Kazakhstan and roughly three times that of Germany, while industry, which frequently operates on outdated technological processes, accounts for approximately 40 per cent of

all energy consumed[1]. The national target is to halve the energy intensity of the economy by 2030. Germany is chosen as the comparator because it is the European economy in which energy-intensive manufacturing retains the largest weight, and because it is the leading Western European economic partner of Uzbekistan, with 244 enterprises with German participation operating in the republic as of 1 June 2025 and bilateral trade of about 1.4 billion US dollars in 2025.

The perspective adopted here is partly that of a practitioner. Applied work on producing hydrogen from water using alternative renewable electricity and using it to heat greenhouses showed that the binding constraint is rarely the technology itself, but the efficiency with which intermittent energy is matched to a variable load. That matching problem is precisely what machine learning addresses, which is why this article treats optimisation and generation technologies as complements rather than as alternatives.

LITERATURE REVIEW

The theoretical basis of the study draws on three lines of research. Porter and van der Linde argued that properly designed environmental standards can trigger innovations that offset the cost of compliance, since regulation exposes inefficiencies in resource use that firms had no prior incentive to identify. Digital energy management illustrates this proposition clearly, because the resource being saved is measurable, priced, and already recorded in the operational data that the algorithm consumes.

The second line concerns the decomposition of emissions. The identity formulated by Kaya, which expresses emissions as the product of activity, energy intensity and carbon intensity, remains the standard instrument for separating structural change from efficiency effects, and it locates the point at which digital tools actually operate.

The third and most recent line concerns the energy effects of artificial intelligence. The special report of the International Energy Agency entitled Energy and Al provides the first systematic quantification[2]. It estimates that the optimisation of production processes could reduce energy costs by three to ten percentage points in energy-intensive industries, that energy savings of about 8 per cent by 2035 are achievable in light industry under the widespread adoption scenario, and that existing applications across all end-use sectors could deliver reductions of 1,400 million tonnes of carbon dioxide in 2035. The same report notes that emissions from electricity used by data centres are projected to rise from about 180 million tonnes today to around 300 million tonnes by 2035, and flags the uncertainty attached to rebound effects. Enterprise-level evidence remains largely case-based and self-reported: a 2025 survey of 263 sustainability leaders conducted by Siemens with Reuters Events reported average energy savings of 23 per cent among adopters, while Siemens Energy offers the more conservative engineering benchmark that process optimisation and equipment upgrading can lower industrial energy consumption by up to 20 per cent.

For Uzbekistan the literature consists mainly of strategic documents. The Green Economy Strategy for 2019-2030, reinforced by Presidential Resolution PP-436 of 2 December 2022, establishes energy efficiency as a central objective, and the updated Nationally Determined Contribution commits the country to reducing greenhouse gas emissions per unit of gross domestic product by 35 per cent from the 2010 level by 2030. Presidential Resolution PP-358 of 14 October 2024 approved the Strategy for the Development of Artificial Intelligence Technologies until 2030.

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[1] IEA. Uzbekistan energy profile: Market design. — Paris: International Energy Agency. - URL: https://www.iea.org/reports/uzbekistan-energy-profile/market-design

[2] IEA. Energy and Al. World Energy Outlook Special Report. - Paris: International Energy Agency, 2025. - URL: https://www.iea.org/reports/energy-and-ai

What is missing is an analysis connecting these two policy tracks, and it is this gap that the present article addresses.

METHODOLOGY, ANALYSIS AND RESULTS

The study uses structural-logical modelling combined with comparative institutional analysis and the case method, drawing quantitative material exclusively from official statistics, national regulatory acts and the publications of international organisations. Emissions of an industrial enterprise are expressed as:

$$CO2 = Q \times (E/Q) * (CO2/E)$$

where Q denotes output or gross value added, E/Q the energy intensity of output, and CO/E the carbon intensity of the energy consumed. Artificial intelligence operates mainly on the second term, through predictive control of thermal processes, load forecasting, anomaly detection and predictive maintenance, all of which can be implemented on existing assets. It operates on the third term indirectly, by shifting consumption towards periods of low-carbon supply and improving the self-consumption of on-site renewable generation. The economic evaluation follows from this: the net annual benefit equals the value of energy saved, plus the avoided carbon cost, plus avoided production losses, less the annualised cost of sensors, data infrastructure and qualified personnel. The decisive variable is therefore not the performance of the algorithm but the carbon price and the energy tariff, since these determine whether an identical technical saving is commercially attractive or commercially irrelevant.

Applied to Germany, this framework explains an apparent paradox. Germany emitted approximately 649 million tonnes of carbon dioxide equivalent in 2025, a reduction of 0.1 per cent compared with 2024 and 48 per cent compared with 1990, yet the decline in industrial emissions of 5.7 million tonnes was attributed principally to weak economic conditions rather than to structural transformation[3]. The conclusion drawn in German policy is that a carbon price alone does not finance the transformation of energy-intensive processes, because the cost gap between conventional and low-carbon production routes exceeds the allowance price for a prolonged period.

The instrument developed in response is the climate protection contract, structured as a carbon contract for difference. In the first bidding round, contracts were signed with 15 of the 17 companies that submitted bids, with a maximum funding volume of approximately 2.8 billion euros and expected savings of up to 17 million tonnes of carbon dioxide equivalent over fifteen years[4]. Digital capability at enterprise level completes the configuration, although unevenly: harmonised Eurostat data show that 26 per cent of German enterprises with ten or more employees used at least one artificial intelligence technology in 2025, against 55 per cent among large enterprises in the European Union.Artificial intelligence is therefore economically viable in German industry not because the technology performs differently there, but because emissions carry an enforceable price and the residual investment gap is closed contractually.

Uzbekistan presents the inverse profile. The efficient reserve is large by construction: where equipment is old and instrumentation sparse, the first 10 to 15% of savings typically comes from operational discipline and load management rather than from capital replacement, which is exactly the domain in which data driven control performs best. The target of halving energy intensity by 2030 cannot realistically be met through equipment replacement alone within the available investment envelope. Renewable capacity is also advancing: the pilot green hydrogen facility

[3] Umweltbundesamt. Greenhouse gas data reveals the need for fresh momentum in climate action. Press release. — Dessau-Rosslau: UBA, 2026.

[4] BMWK. Handover of Carbon Contracts for Difference,first bidding round, 16 October 2024. - URL: https://www.co2-differenzvertraege.info/news/handover-ccfds-first-bidding-round

developed by ACWA Power comprises a 20 MW electrolyser in Chirchiq supplied by a 52 MW wind power plant in the Bukhara region, producing approximately 3,000 tonnes of renewable hydrogen annually, which substitutes for methane-derived hydrogen in ammonia and fertiliser productions[5]. Since fertilisers fall within the scope of the Carbon Border Adjustment Mechanism, the emissions embedded in this production have become a determinant of export value rather than an environmental externality.

The constraints, however, are structural. There is no domestic carbon price, which removes the largest single component from the benefit side of the evaluation expression; tariffs have historically been low, which extends payback periods; and most enterprises lack the metering infrastructure and historical consumption data on which machine learning depends, since an algorithm cannot optimise a process that is not measured.

Parameter	Germany	Uzbekistan
Carbon price on industrial emissions	EU ETS, mandatory	Absent
Targeted transformation finance	Climate protection contracts, approx. EUR 2.8 bn in the first round	Absent as as dedicated instrument
Energy intensity of the economy	Reference level	Approximately three times higher
Share of industry in energy consumption	Lower, service-oriented structure	Approximately 40 percent
Principal binding constraint	Cost gap at low-carbon production routes	Absence of measurement data and price signals

Table 1. Comparative conditions for the industrial application of artificial intelligence

The practical implication is that German policy instruments should not be imported directly, since they presuppose a carbon price that does not exist in Uzbekistan, but that the enterprise-level sequence which made those instruments effective can be reproduced. That sequence has four stages: instrumentation, meaning sub-metering of production lines and the accumulation of at least twelve months of consumption data; diagnostic analytics, in which forecasting and anomaly detection identify the causes of excess consumption and reduce peak loads at no capital cost; predictive control and maintenance, which requires integration with control systems and is justified by the savings demonstrated at the previous stage; and finally carbon accounting integrated with low-carbon supply, which serves both compliance with the Carbon Border Adjustment Mechanism and the optimisation of renewable self-consumption. The 244 enterprises with German capital operating in Uzbekistan are the natural site for this sequence, since they already report under standards derived from their parent companies and are directly exposed to European carbon regulation through their sales.

[5] OECD. Green Hydrogen Case Study: ACWA Power, Uzbekistan. Clean Energy Finance and Investment Mobilisation Programme. - Paris: OECD.

The order matters more than any individual technology: enterprises that begin at the third stage without completing the first accumulate infrastructure without data, which is the most common form of unproductive digital investment.

CONCLUSION

Artificial intelligence in industrial decarbonisation should be evaluated as an economic instrument acting principally on the energy intensity of output. Its distinguishing feature is not the magnitude of the savings, which the International Energy Agency places at three to ten percentage points of energy costs in energy-intensive sectors, but the fact that these savings are obtained on existing assets and can be financed from operating budgets rather than from capital programmes. For an economy in which capital for industrial renewal is scarce, this property is decisive.

The German experience shows that technical potential does not become investment without a price signal, and that where the price signal is insufficient it must be supplemented by an instrument that removes residual risk. Uzbekistan holds the larger share of the opportunity and the smaller share of the conversion mechanism: energy intensity roughly three times the German level and an industrial sector responsible for around 40 per cent of national energy consumption define an efficiency reserve that no other single measure can access as cheaply, while the missing elements are measurement infrastructure at enterprise level and an economic signal that prices emissions, whether domestic or transmitted from outside through the Carbon Border Adjustment Mechanism.

Enterprises with foreign capital participation therefore offer the most realistic transmission channel, and the proposed sequence can be implemented at plant level without waiting for national carbon pricing. Practical experience with producing hydrogen from water using renewable electricity confirms the general conclusion of the comparison: the value of a low-carbon energy source is realised only when the load it serves is intelligently matched to its variable availability. Generation technology and optimisation technology are not competing decarbonisation strategies but two halves of the same one.

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