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08.00.01 Iqtisodiyot nazariyasi
08.00.02 Makroiqtisodiyot
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08.00.16 Raqamli iqtisodiyot va xalqaro raqamli integratsiya
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MUNDARIJA

MUNDARIJA СОДЕРЖАНИЕ CONTENTS

CHALLENGES AND OPPORTUNITIES IN IMPLEMENTING GREEN ECONOMY INDICATORS IN UZBEKISTAN'S INDUSTRIAL SECTOR UNDER THE FOURTH INDUSTRIAL REVOLUTION

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Abstract: This study explores the challenges and opportunities associated with implementing green economy indicators in Uzbekistan's industrial sector amidst the Fourth Industrial Revolution (Industry 4.0). Uzbekistan is undertaking parallel transformations digital modernization and transitioning to a green economy aiming to achieve ambitious national targets, including significant reductions in energy intensity and greenhouse gas emissions by 2030. Using qualitative analysis of policy documents, industrial case studies, and international best practices, the research identifies key barriers such as outdated infrastructure, insufficient digital readiness, institutional and regulatory weaknesses, high investment requirements, and skills shortages. Nevertheless, substantial opportunities exist, including leveraging digital technologies like IoT, AI, automation, and big data analytics to significantly enhance energy efficiency, resource productivity, and environmental performance across industrial sectors such as oil and gas, metallurgy, and chemicals. Recommendations include strengthening institutional coordination, developing tailored regulatory incentives, scaling Industry 4.0 pilot projects, building human capital, and securing innovative financing. The analysis underscores that integrating digitalization and green industrial strategies can generate substantial economic, environmental, and social benefits, positioning Uzbekistan as a regional exemplar in sustainable industrial growth.

Key words: Green economy, Industry 4.0, Digital transformation, Energy efficiency, Sustainability indicators, Industrial modernization, Uzbekistan, Fourth Industrial Revolution, Greenhouse gas emissions, Environmental performance.

Annotatsiya: Ushbu tadqiqot To'rtinchi sanoat inqilobi (Sanoat 4.0) sharoitida O'zbekiston sanoat sektorida yashil iqtisodiyot ko'rsatkichlarini joriy etish bilan bog'liq muammolar va imkoniyatlarni o'rganadi. O'zbekiston 2030-yilga borib energiya intensivligi va issiqxona gazlari emissiyasini sezilarli darajada kamaytirishni o'z ichiga olgan ulkan milliy maqsadlarga erishishga qaratilgan parallel transformatsiyalarni – raqamli modernizatsiya va yashil iqtisodiyotga o'tishni amalga oshirmoqda. Siyosiy hujjatlar, sanoat misollari va ilg'or xalqaro tajribalarning sifat tahlilidan foydalangan holda, tadqiqot asosiy to'siqlarni aniqlaydi, masalan, eskirgan raqamli institutlar, o'qish va o'qish infratuzilmasidagi eskirganlik. zaif tomonlari, yuqori investitsiya talablari va malakalarning etishmasligi. Shunga qaramay, neft va gaz, metallurgiya va

kimyo kabi sanoat tarmoqlarida energiya samaradorligi, resurslar unumdorligi va atrof-muhit ko'rsatkichlarini sezilarli darajada oshirish uchun IoT, AI, avtomatlashtirish va katta ma'lumotlar tahlili kabi raqamli texnologiyalardan foydalanish kabi katta imkoniyatlar mavjud. Tavsiyalar orasida institutsional muvofiqlashtirishni kuchaytirish, moslashtirilgan tartibga soluvchi rag'batlarni ishlab chiqish, Sanoat 4.0 pilot loyihalarini kengaytirish, inson kapitalini shakllantirish va innovatsion moliyalashtirishni ta'minlash kiradi. Tahlil shuni ta'kidlaydiki, raqamlashtirish va yashil sanoat strategiyalari integratsiyalashuvi katta iqtisodiy, ekologik va ijtimoiy manfaatlar keltirib, O'zbekistonni sanoatning barqaror o'sishi bo'yicha mintaqaviy namuna sifatida ko'rsatishi mumkin.

Kalit so'zlar: Yashil iqtisodiyot, Sanoat 4.0, Raqamli transformatsiya, Energiya samaradorligi, Barqarorlik ko'rsatkichlari, Sanoat modernizatsiyasi, O'zbekiston, To'rtinchi sanoat inqilobi, Issiqxona gazlari emissiyasi, Ekologik ko'rsatkich.

Аннотация: В этом исследовании изучаются проблемы и возможности, связанные с внедрением показателей зеленой экономики в промышленном секторе Узбекистана в условиях Четвертой промышленной революции (Индустрия 4.0). Узбекистан проводит параллельные преобразования – цифровую модернизацию и переход к зеленой экономике – с целью достижения амбициозных национальных целей, включая значительное сокращение энергоемкости и выбросов парниковых газов к 2030 году. Используя качественный анализ политических документов, промышленных тематических исследований и передовой международной практики, исследование выявляет ключевые барьеры, такие как устаревшая инфраструктура, недостаточная цифровая готовность, институциональные и нормативные недостатки, высокие инвестиционные требования и нехватка квалифицированных кадров. Тем не менее, существуют существенные возможности, включая использование цифровых технологий, таких как IoT, ИИ, автоматизация и аналитика больших данных, для значительного повышения энергоэффективности, производительности ресурсов и экологических показателей в таких промышленных секторах, как нефть и газ, металлургия и химия. Рекомендации включают укрепление институциональной координации, разработку индивидуальных нормативных стимулов, масштабирование пилотных проектов Индустрии 4.0, наращивание человеческого капитала и обеспечение инновационного финансирования. Анализ подчеркивает, что интеграция цифровизации и стратегий зеленой промышленности может принести существенные экономические, экологические и социальные выгоды, позиционируя Узбекистан как региональный пример устойчивого промышленного роста.

Ключевые слова: Зеленая экономика, Индустрия 4.0, Цифровая трансформация, Энергоэффективность, Индикаторы устойчивости, Промышленная модернизация, Узбекистан, Четвертая промышленная революция, Выбросы парниковых газов, Экологические показатели.

INTRODUCTION

Uzbekistan is undergoing a dual transformation: embracing the Fourth Industrial Revolution (Industry 4.0) while pursuing a transition to a “green” economy. Industry 4.0 refers to the integration of advanced digital technologies such as automation, artificial intelligence (AI), Internet of Things (IoT), and big data–into industrial processes to create smart, efficient systems. In parallel, the “green economy” agenda emphasizes sustainability through metrics like energy efficiency, greenhouse gas (GHG) emissions per unit output, and resource productivity. Many advanced economies now view digitalization and sustainability as twin transitions, with neither succeeding without the other[1]. For example, the European Union explicitly links digital transformation with the Green Deal, recognizing that smart technologies can help reduce carbon footprints and optimize resource use[2]. This synergy suggests that Industry 4.0 can be a powerful enabler of green economy objectives by making industrial operations more energy-efficient, less wasteful, and more transparent in their environmental impact.

Uzbekistan’s industrial sector – especially oil and gas, metallurgy, and chemical industries – is both an economic backbone and a major consumer of energy and resources. These heavy industries historically operated with high energy and carbon intensity, leading to inefficient resource use and significant emissions. Indeed, Uzbekistan has been among the most energy-intensive economies in the world, though its energy intensity has been declining in recent years[3]. Rapid industrialization and population growth have increased resource demand and environmental pressures, revealing “low levels of energy efficiency, irrational consumption of natural resources, and slow updating of technologies” that hinder sustainable development (Resolution of the President of the Republic of Uzbekistan “About approval of Strategy for transition of the Republic of Uzbekistan to “green” economy”...)[4]. Recognizing these challenges, the government has launched ambitious strategies to modernize industry and go green simultaneously.

1 https://digital-strategy.ec.europa.eu/en/policies/green-digital
2 https://digital-strategy.ec.europa.eu/en/policies/green-digital
3 https://www.enerdata.net/estore/country-profiles/uzbekistan.html
4 https://cis-legislation.com/document.fwx?rgn=119513

In 2019, the President approved the **Strategy for the Transition of the Republic of Uzbekistan to a "Green" Economy (2019–2030)** (Presidential Resolution No. PP-4477), which set national targets for greener growth. This strategy calls for a twofold increase in energy efficiency of the economy by 2030 and a decrease in the carbon intensity of GDP, alongside **modernizing industrial infrastructure to improve energy efficiency by at least 20%** through clean technologies (Resolution of the President No. PP-4477 of 2019 on the Strategy for the Transition to a Green Economy for 2019-2030 | ESCAP Policy Documents Managment)[5]. It also aims to raise the share of renewables in electricity to over 25% and reduce GHG emissions per GDP by 10% from 2010 levels (a target later made more ambitious). Uzbekistan reaffirmed its commitment under the Paris Agreement by pledging a **35% reduction in GHG emissions per unit of GDP by 2030 relative to 2010**. To achieve these goals, **green economy indicators** such as energy use per output, emissions intensity, and resource productivity have been integrated into national planning.

Concurrently, Uzbekistan is pushing for **digital transformation of industry**. In 2020, President Shavkat Mirziyoyev set the goal of **fully digitizing all processes in oil and gas, chemical, metallurgical and other industries**[6]. This directive kicked off a nationwide Industry 4.0 drive, establishing tech-friendly economic zones and investing in digital infrastructure. The motivation is clear: smart manufacturing technologies can make factories more efficient and **less wasteful**, aligning with green objectives[7]. For instance, intelligent automation and data-driven process optimization can cut energy usage and emissions while boosting productivity. Global examples illustrate this potential – *Daimler* in Germany achieved a **30% improvement in energy efficiency** in robotic systems by deploying Industry 4.0 techniques, and a Canadian manufacturer cut energy consumption 15% using real-time IoT energy monitoring. These cases underscore how Industry 4.0 innovations can directly advance green indicators like energy efficiency and emissions reduction.

This research article examines **how Uzbekistan can integrate Industry 4.0 technologies into its industrial sector while implementing green economy indicators**, focusing on heavy industries (oil and gas, metals, chemicals). We analyze the institutional framework and policies guiding this twin transition, assess current progress and outcomes, and discuss the challenges and opportunities that lie ahead. Drawing on official strategies (e.g. Resolution PP-4477 on green economy, and subsequent decrees) and international best practices, we aim to identify pathways for Uzbekistan's industrial modernization that are both technologically advanced and environmentally sustainable.

LITERATURE REVIEW ON THE TOPIC

J. Sachs[4] in his fundamental work analyzes the main theories and practical approaches to the implementation of green economy indicators for sustainable development. The author focuses, in particular, on the issues of increasing energy efficiency in the industrial sector, reducing carbon emissions and expanding the use of renewable energy sources. Sachs emphasizes that public policy, international financial institutions and technological innovations play an important role in the transition to a green economy. This work serves as a theoretical basis for making recommendations on the use of green indicators in the industrial sector of Uzbekistan. M. Porter and M. Kramer[5] in their research analyze the issues of improving green economy indicators by combining economic activity and social responsibility. The authors show that the efficient use of resources in production processes, waste reduction and the implementation of sustainability criteria in practice increase economic competitiveness. This article offers a practical approach to developing sustainable development strategies for industrial enterprises, which may be important for the implementation of green economy indicators in Uzbekistan.

This report, published by UNEP[6], highlights global experiences in sustainable development and the challenges and opportunities encountered in the transition to a green economy. The authors note the importance of technological innovations, public-industry-private sector cooperation, and financial mechanisms in implementing green indicators in the industrial sector. The report can also serve as a key resource for developing practical measures to develop a green economy in the conditions of Uzbekistan.

In the study, the authors M. Geissdoerfer et al.[7] consider the issues of improving green indicators by implementing the principles of a circular economy in the industrial sector. Strategies for reducing waste in production processes, efficient use of materials, and recycling are discussed in detail. By applying these approaches in Uzbek industrial enterprises, valuable experiences are provided on further strengthening the green economy criteria and reducing the carbon footprint.

The article by E. Carayannis et al.[8] examines the specific principles of implementing green economy indicators through innovation in the context of the fourth industrial revolution. The authors analyze strategies for

5 https://policy.asiapacificenergy.org/node/4379
6 https://globalcio.com/articles/main/digital-transformation-of-uzbekistan/#3
7 https://www.unido.org/unido-industry-40

improving the green indicators of industrial enterprises using the “Five Helix” innovation model, which includes the state, universities, industry, civil society and the environment. The approaches presented in this article can serve as a practical basis for improving green economy indicators in Uzbek industry through technological innovation and maintaining ecological balance.

RESEARCH METHODOLOGY

This study adopts a qualitative research methodology grounded in policy analysis and comparative case review. We conducted a comprehensive literature and document review, gathering information from government strategy documents, laws, and official decrees, as well as reports from international organizations (United Nations, World Bank, OECD, Asian Development Bank) and academic literature on green industrialization and digital transformation. Key national policy sources included the Uzbekistan “Green Economy” Transition Strategy 2019–2030 (Presidential Decree PP-4477) and the 2022 Presidential Resolution No. PP-436 which updated and reinforced green economy reforms[8]. These documents provided insight into Uzbekistan’s targets for green indicators (energy intensity, emissions, resource use) and the planned measures to achieve them.

We also reviewed sector-specific initiatives and news regarding the adoption of Industry 4.0 technologies in Uzbekistan’s industries. This involved analyzing case studies of digital innovation in the oil & gas sector, mining/metallurgy, and chemical production. Sources such as industry reports, press releases, and expert analyses (e.g., Global CIO article on Uzbekistan’s digital transformation were used to identify what Industry 4.0 applications (IoT, big data, automation, etc.) are being implemented and with what early results.[9]

To incorporate international comparisons and best practices, we examined literature on how other countries integrate digital and green transitions. This included examples from industrialized nations (like Germany’s experience with Industry 4.0 improving energy efficiency) and policy frameworks like the European Union’s concept of the twin digital and green transition We also consulted publications by UN agencies (UNIDO, UNEP) and development banks highlighting the role of advanced technology in enhancing sustainability in industry.

Our analysis is structured according to the IMRAD format. In the Results, we synthesize findings on Uzbekistan’s policy framework, current implementation status in key sectors, and any observable impacts on green indicators. In the Discussion, we interpret these findings to outline the institutional, technological, and economic challenges faced, and the opportunities and recommendations for successfully integrating green economy indicators with Industry 4.0 in Uzbekistan’s industrial sector. All information is supported by citations from credible sources, and numerical targets or examples are drawn from official data where available. By triangulating policy documents, case studies, and global insights, this research ensures a well-rounded understanding of the progress and prospects of Uzbekistan’s green industrial transformation.

ANALYSIS AND RESULTS

Policy Framework for a Green Economy Transition. Uzbekistan’s government has established a robust policy framework to steer the country toward a green, resource-efficient economy by 2030. The “Strategy for Transition to a Green Economy 2019–2030” (approved by Presidential Resolution PP-4477 in October 2019) is the cornerstone of these efforts. This strategy defines priority areas and **targets for green economic development**, which directly translate into measurable indicators for industry:

Energy Efficiency: The strategy seeks a *twofold increase in energy efficiency* across key sectors of the economy by 2030. For industry, this means major reductions in energy consumption per unit of output through technological upgrades and process improvements.

Carbon Intensity: It sets a goal to *decrease the carbon intensity of GDP* (GHG emissions per GDP) significantly, originally by at least 10% from 2010 levels. This target was subsequently raised; at the Glasgow COP26 summit in 2021, Uzbekistan committed to a **35% reduction in GHG emissions per GDP by 2030** compared to 2010 (), indicating a stronger climate ambition aligned with its updated Nationally Determined Contribution (NDC).

Industrial Modernization: A key provision is the *modernization of industrial infrastructure to ensure sustainability*, mandating that enterprises increase their energy efficiency by **at least 20%** through wider use of clean and environmentally friendly technologies and processes This implies retrofitting factories with modern equipment, adopting energy management systems, and cleaner production techniques.

Resource Productivity: Although not explicitly labeled in the decree, improving **resource efficiency** (more output per unit of raw material, water, or energy) is an implicit goal. The resolution notes that inefficient

8 https://www.e3s-conferences.org/articles/e3sconf/pdf/2024/104/e3sconf_congreentax2024_01004.pdf
9 https://globalcio.com/articles/main/digital-transformation-of-uzbekistan/#3

resource use and slow tech renewal are problems to overcome, and calls for rational consumption of natural resources and technology upgrade.

Renewable Energy Integration: The strategy aims to diversify energy sources by increasing the share of renewables (solar, wind, hydro) in the energy mix to over 25% of electricity generation. Greening the power supply for industry will directly lower the emissions per output of industrial production.

To operationalize these goals, Uzbekistan has adopted action plans and institutional measures. An Interdepartmental Council on Green Economy was formed to coordinate implementation, and the Ministry of Economic Development and Poverty Reduction was designated as the lead agency for promoting green economy initiatives. Each relevant ministry was assigned specific responsibilities: for example, the Ministry of Energy is accountable for improving the national energy efficiency indicator and expanding renewables, while the Ministry of Economic Development is responsible for reducing the carbon intensity of GDP and upgrading industrial infrastructure with clean technologies. This high-level accountability reflects an institutional recognition that industrial policy and environmental goals must be aligned.

Additionally, the Presidential Resolution No. PP-436 (Dec 2022) introduced a Green Economy Action Plan to reinforce reforms through 2030. It updated targets and laid out concrete steps for 2022–2026. One outcome was the setting of shorter-term targets: for instance, reducing the energy intensity of GDP by 20% by 2026 relative to 2022 through sector-specific energy savings measures. Such interim milestones drive near-term action in industries to curb fuel and power use. Another development was the creation of a National Green Economy Taxonomy in 2023, defining what qualifies as “green” investment or activity. This taxonomy helps channel finance to sustainable projects and set standards for industry (e.g. efficiency thresholds, cleaner production criteria)[10].

International cooperation supports this policy framework. Uzbekistan joined the Global Methane Pledge in 2022, agreeing to cut methane emissions 30% by 2030 (methane being significant in oil/gas operations)[11]. The country is also working with the World Bank and other donors on programs like “Uzbekistan’s Green Growth Strategy” and has received technical assistance (e.g., a World Bank study “Towards a Greener Economy” assessing climate change impacts and policy responses). Donor-funded projects are targeting green industry specifically: for example, a partnership with GIZ (Germany) is providing €12 million to implement green industrialization projects in Uzbekistan. These initiatives indicate that the policy groundwork for integrating green indicators into industry is not only locally driven but also backed by global expertise and finance.

In summary, Uzbekistan’s policy landscape now explicitly links industrial development with green economy metrics. Energy efficiency, emissions reduction, and sustainable resource use are built into national targets, and heavy industries are expected to contribute to these goals through modernization. The presence of clear targets and institutional mechanisms provides a guiding scaffold for the industrial sector’s transition under Industry 4.0, as discussed next.

Industry 4.0 Adoption in Key Industrial Sectors. In parallel with green economy planning, Uzbekistan has been actively promoting **Industry 4.0 adoption** across its major industrial sectors. The government recognizes that achieving green indicators in industry will require technological innovation and digitalization to optimize processes. Below, we review the status of Industry 4.0 integration in the **oil and gas**, **metallurgy/mining**, and **chemical** industries – sectors that are both critical to the economy and central to the green transition due to their high resource and energy use.

Oil and Gas Sector: The oil and natural gas industry, which forms a substantial part of Uzbekistan’s GDP and exports, has seen significant moves toward digital transformation. Following the President’s 2020 directive, Uzbekneftegaz and other energy companies have started to **digitize exploration, production, and refining operations**. The aim is to leverage Industry 4.0 technologies to improve efficiency and environmental performance. Digital solutions are “penetrating deeper and deeper into the business processes of oil and gas companies,” which are now actively collaborating with IT firms and establishing in-house digital competence centers. This trend is a direct manifestation of the Fourth Industrial Revolution in the sector. Key technologies being implemented include:

Big Data and AI: Companies are deploying big data analytics and AI for managing geologic data and optimizing drilling and production. These tools help handle huge datasets (seismic surveys, reservoir models) and can identify patterns to enhance resource extraction with minimal waste;

Industrial Internet of Things (IIoT): IoT sensors and networks monitor equipment and processes in real-time, from pipeline pressures to emissions levels. In oil extraction, IIoT enables remote, automated monitoring of well performance and early detection of anomalies (e.g., leaks, inefficiencies). This not only improves safety but also prevents resource loss and environmental damage;

10 https://blogs.worldbank.org/en/climatechange/uzbekistan-s-green-leap-#
11 https://theasiatoday.org/news/transition-to-a-green-economy-in-uzbekistan-strategies-and-challenges/

Robotics and Drones: The industry has begun using robots for hazardous tasks (like inspections in confined or high-temperature environments) and drones for aerial surveillance of pipelines and facilities. These technologies reduce the risk of accidents and can promptly identify issues like gas leaks or inefficient flaring, contributing to lower emissions;

Digital Twins: Oil & gas companies are experimenting with digital twin models of fields and processing plants. A digital twin is a virtual replica of a physical asset that simulates its behavior. By using digital twins, engineers can test process adjustments or new technologies virtually to see their impact on output and emissions before implementing them in reality. This can greatly aid in optimizing operations for energy efficiency;

Advanced materials and 3D Printing: While still nascent, the sector is exploring smart materials (e.g., wear-resistant alloys that prolong equipment life) and 3D printing for rapid prototyping of components. Longer-lasting equipment and faster maintenance reduce downtime and material waste.[12]

These digital initiatives in oil and gas are expected to improve energy efficiency and reduce emissions per unit of fuel produced. For instance, better data analytics can lead to more efficient gas processing, and IoT monitoring can cut methane leakage (a potent GHG) during production. A milestone reflecting both Industry 4.0 and green ambitions is the Uzbekistan GTL (Gas-to-Liquids) plant, launched in late 2021. This state-of-the-art facility uses advanced technology to convert natural gas into 1.5 million tons of cleaner synthetic liquid fuels annually, meeting Euro-5 standards. The GTL plant, one of the largest in Central Asia, exemplifies how technological innovation can yield higher-value products with lower environmental impact (Euro-5 fuel has significantly reduced sulfur and pollutant content). It aligns with the green indicator of reducing emissions per output, as these cleaner fuels will produce fewer emissions when used in vehicles.

Mining and Metallurgy: Uzbekistan is rich in minerals (gold, copper, uranium, etc.) and metallurgy/mining is another heavy industry focus for modernization. The Almalyk Mining and Metallurgical Complex (AMMC) – a major copper and gold producer – offers a case study in digital transformation. In 2022, AMMC developed a five-year roadmap for digital transformation, implementing dozens of projects annually to automate both technical and management processes. By 2023, the company had digitized its geologic and mineral resource data and introduced electronic systems for document management and production tracking. Notably, AMMC implemented a transport management and control system in its mining operations, which in one year saved 16.8 thousand tons of diesel fuel (worth 151 billion soums). This is a direct improvement in energy efficiency and cost savings, achieved via digital monitoring of fleet and haulage optimization. Additionally, at an AMMC copper processing plant, introducing a real-time Plant Information (PI) System doubled the speed of decision-making and increased production efficiency by 5%. These improvements mean more output per energy used, contributing to better resource productivity and lower emissions per ton of metal.

The mining/metallurgical sector is also exploring automation (e.g., autonomous haul trucks, robotic ore sorting) and advanced analytics for mineral processing. Such Industry 4.0 applications lead to **reduced waste**, as processes can be controlled more precisely. For example, sensors can detect the ore grade in real time and adjust grinding or chemical use, thereby saving electricity and reagents when lower-grade material is being processed. This aligns with green indicators like reduced energy or water per unit of ore processed. Uzbekistan's strategy to increase the value-added in mining (as indicated by $3.5 billion of projects in 2023 for the sector) is intertwined with using modern technologies to ensure this growth is efficient and sustainable.

Chemical Industry: Uzbekistan's chemical industry, including fertilizer production and chemicals for textiles and agriculture, is crucial for both economic diversification and as an input provider to other sectors. It is also energy-intensive (e.g., fertilizer plants consume large volumes of natural gas). Recognizing the need for reform, a Presidential Decree in Feb 2021 set out "measures for further reforming and financial rehabilitation of chemical industry enterprises, and development of production of chemical products with high added value". A significant aspect of this decree is the push for modernization through technology: it calls for introduction of modern software systems for enterprise management and accounting based on international standards, and labelling and tracking of products. In practice, large chemical enterprises have begun adopting ERP (Enterprise Resource Planning) systems to integrate their operations. By shifting from outdated, manual management to modern digital systems, these companies can optimize supply chains, reduce inventory waste, and improve energy management in production.

Furthermore, the chemical sector is encouraged to invest in cleaner production technology. This includes updating equipment like more efficient reactors, boilers, and distillation columns that lower energy use per unit of output. While detailed results in this sector are not yet public, early steps like ERP implementation are foundational for future Industry 4.0 upgrades (since data integration is a prerequisite for IoT and advanced analytics). We can anticipate that, as these digital management systems mature, chemical plants will incorporate IoT sensors to monitor energy consumption, emissions (for instance, measuring CO_2 or pollutant outputs in

12 https://globalcio.com/articles/main/digital-transformation-of-uzbekistan/

real time), and resource use, enabling them to meet environmental standards more easily. The government's emphasis on high value-added chemical products also means new facilities are likely to be built with cutting-edge, efficient processes, avoiding the inefficiencies of Soviet-era installations.

Other Sectors and Initiatives: Although oil/gas, mining, and chemicals are the focus, Uzbekistan's Industry 4.0 drive extends to other industries like automotive manufacturing. The national automobile company (UzAuto) has been implementing a large-scale transition to digital systems such as SAP for enterprise resource planning since. They have also partnered with universities to train specialists in digital manufacturing. While the automotive sector itself is not the highest polluter, its digitalization illustrates a broader trend: building human capital and technical know-how in Industry 4.0 that can spill over into heavy industries. Moreover, digitalizing sectors like automotive and construction materials (another focus of foreign investment) contributes to overall industrial energy efficiency and helps reduce waste, indirectly easing pressure on energy supply and the environment.

In summary, Uzbekistan's heavy industries are in the early but active stages of an Industry 4.0 transformation. Government mandates and corporate initiatives have led to the introduction of IoT, AI, automation, and modern software in oil & gas fields, mines, smelters, and factories. These changes are beginning to yield results: streamlined operations, energy savings (as seen with AMMC's diesel reduction), improved productivity, and presumably lower emissions intensity in those operations that have digitized (even if comprehensive data on emissions is not yet available). The digital infrastructure and culture in these sectors is being built – a critical prerequisite to achieving the green economy targets set out in policy. Notably, these efforts are supported by significant public investment, such as the creation of 19 free economic zones and 400 small industrial zones with around 10 trillion soums allocated for industrial infrastructure upgrades (including digital infrastructure). By modernizing its industrial base technologically, Uzbekistan is creating the enabling environment for embedding green indicators into day-to-day industrial management.

Green Economy Indicators: progress and early outcomes. Implementing **green economy indicators** in industry means concretely measuring and improving performance in areas like energy use, emissions, and resource utilization. Thanks to the policies and digital initiatives described, Uzbekistan is starting to make progress on some of these fronts, although challenges remain in fully quantifying and attributing improvements. Here we outline the status and early outcomes for key indicators:

Energy Efficiency (Energy Intensity of Output): At the macro level, Uzbekistan's energy intensity (energy per GDP) has been on a declining trend, falling roughly 6.5% per year since 2000[13], due to economic restructuring and efficiency improvements. However, it remains high globally, indicating substantial room for improvement in industry. In terms of industrial output, the government's target of a 20% reduction in energy intensity by 2026 suggests aggressive action[14]. Early outcomes in specific enterprises are promising: as noted, the mining company AMMC achieved fuel savings of over 16,000 tons in one year by using digital fleet management. This directly translates to lower energy use per ton of ore mined. In oil and gas, while detailed data is scarce, the introduction of modern control systems at new facilities (e.g., the GTL plant) and optimization of existing ones are expected to improve the energy efficiency of fuel production. Anecdotal evidence from operators hints at efficiency gains – for instance, better pipeline monitoring has reduced downtime and flaring of gas. The widespread implementation of energy management systems (as part of Industry 4.0 upgrades) is anticipated to further cut energy waste in industrial processes. We can infer progress also from the fact that Uzbekistan's electricity consumption per unit of industrial output has started to plateau despite industrial growth, as noted in some government reports – a sign of decoupling growth from energy use.

GHG Emissions per Output: Measuring emissions per unit of industrial output (e.g. per barrel of oil, per ton of steel) requires granular data, which Uzbekistan is working to develop through its green monitoring systems. Nonetheless, national commitments and projects indicate positive movement. The commitment to reduce GHG per GDP by 35% by 2030 () is ambitious and has spurred projects like afforestation and renewable energy that will indirectly lower industrial emissions factors (by greening the power supply). Direct industrial emissions (from factories) should start to decline as efficiency measures take hold. One concrete result is in fuel quality improvement: the launch of the GTL plant producing Euro-5 fuels means that for every liter of fuel used by end consumers, the emissions (sulfur dioxide, particulate, etc.) are much less compared to older fuel. This shifts the overall emissions per output of Uzbekistan's oil sector towards cleaner products. Similarly, the metallurgical sector's modernization (e.g., new electric arc furnaces or efficient smelters under construction) will cut emissions per ton of metal. Uzbekistan has also begun implementing an emissions monitoring and trading pilot with the World Bank's support (the iCRAFT project) to quantify and reduce GHG emissions in energy and industry. While still in early stages, this is building the institutional capacity to track emission indicators at the enterprise level.

13 https://www.enerdata.net/estore/country-profiles/uzbekistan.html
14 https://theasiatoday.org/news/transition-to-a-green-economy-in-uzbekistan-strategies-and-challenges

Resource Productivity (Output per unit of materials/water): Industry 4.0 enhancements contribute to resource productivity by reducing waste and optimizing use of raw materials. For example, in chemical plants, better process control reduces off-spec production (which would be scrapped), meaning more final product per input. In mining, improved ore grades control means less waste rock processed per unit of metal. Although national statistics on material productivity are not yet reported in detail, qualitative improvements are visible. The adoption of modern analytics in gold mining has likely improved extraction rates from ore. And the push for recycling and circular practices (as part of green economy efforts overseen by the State Committee for Ecology) is slowly entering industrial practice – e.g., metal scrap recycling is being expanded, which improves overall resource productivity of the metallurgy sector by using secondary materials. The energy saving example from AMMC also reflects resource productivity: diesel fuel is a resource, and saving it means achieving the same haulage output with less resource consumption.

Institutionalization of Green Metrics: A notable outcome on the institutional side is that green indicators are being mainstreamed into corporate and governmental evaluation. The Action Plan on green economy requires industries to report on fuel and energy savings. Major state-owned enterprises (SOEs) are now expected to include energy and emissions metrics in their annual reports, and some have begun doing so. The National Green Economy Taxonomy mentioned earlier provides definitions for what counts as a green outcome (for example, a project qualifies as green if it reduces energy consumption by X% or emissions by Y%). State development funds are starting to use these criteria to approve investments. An example is the Uzbekistan Fund for Reconstruction and Development prioritizing loans for industrial projects that have clear energy efficiency components. Such institutionalization ensures that progress on green indicators is tracked and incentivized. As an illustration, the state-owned Entrepreneurship Development Company has committed to increase its share of green projects to 35%, using the taxonomy as a guide – meaning more financing for industrial upgrades that explicitly target reduced emissions or waste.

International Comparison of Progress: Compared to some peers, Uzbekistan's integration of green and digital in industry is nascent but accelerating. Some countries in Eastern Europe and Central Asia have only recently set similar targets for energy intensity reduction, but Uzbekistan's 20% cut by 2026 is among the more rapid goals. In terms of Industry 4.0 adoption, Uzbekistan lags global leaders like Germany or South Korea, but it has leapfrogging potential by importing proven technologies. Global best practices provide a benchmark: German manufacturers have demonstrated that digitization can significantly enhance energy performance (as with Daimler's 30% gain in robot energy efficiency) (). If Uzbek industries can achieve even a fraction of those improvements, the impact on national green indicators will be substantial. There is evidence that policymakers are aware of and learning from these examples. The presence of partnerships with international tech firms and the participation of Uzbekistan in forums like the Global Manufacturing and Industrialization Summit (GMIS) shows exposure to best practices.

In conclusion of the Results, Uzbekistan has put in place the strategies and initial technological interventions to start moving the needle on green economy indicators in industry. Early results, such as energy savings and improved efficiency at the enterprise level, are encouraging and align with international experience that Industry 4.0 technologies can drive sustainable industrial performance. However, these are just initial steps. The extent to which these positive trends can be scaled up across all major industries will depend on addressing the challenges analyzed in the next section. The co-evolution of digital transformation and green reform in Uzbekistan's industrial sector presents both significant opportunities and complex challenges, which we now discuss.

Uzbekistan's endeavor to simultaneously advance Industry 4.0 and green economy goals in its industrial sector is a bold and forward-looking strategy. The findings above highlight early successes–policy frameworks are in place, some industries have begun reaping efficiency gains, and international support is being mobilized. However, realizing the full vision of a digitally enabled green industrial economy faces multifaceted challenges. In this discussion, we examine the key institutional, technological, and economic challenges that must be overcome, and then outline the corresponding opportunities and best practices that Uzbekistan can leverage to address those challenges. Finally, we reflect on how the country can capitalize on the synergies of the twin transition to ensure sustainable industrial growth.

Institutional and Policy Challenges:

A major challenge lies in the institutional realm – translating high-level strategies into effective action on the ground. Uzbekistan's government has demonstrated strong commitment through policies and the assignment of responsibilities, but several issues persist:

Coordination and Governance: Implementing green and digital transitions requires coordination across multiple ministries (Energy, Economy, Investments, Industrial sectors, etc.) and between public and private sectors. Ensuring that all these actors move in concert is challenging. The Interdepartmental Council on Green Economy is a step toward coordination, but it must overcome bureaucratic silos. Past analysis indicated that

weak participation of certain sectors (like small businesses) in green innovation efforts hindered progress). Engaging a wide range of stakeholders large SOEs, private companies, SMEs, and regional authorities in a cohesive effort is an ongoing governance challenge.

Legislative and Regulatory Frameworks: While strategies exist, specific regulations and standards to enforce green practices in industry are still evolving. For example, setting **mandatory energy efficiency standards** for industrial equipment or **emission limits** for factories would drive compliance, but such regulations need to be updated and strictly enforced. The Asia Today analysis notes that *transformation of legislative initiatives to increase their effectiveness is necessary, and deeper implementation of environmental standards is important*. In other words, Uzbekistan's laws and technical norms need refinement (and possibly new laws) to make green indicators a legal requirement in industrial operations, not just voluntary or aspirational goals.

Institutional Capacity: Ministries and agencies must have the technical capacity to guide and monitor the transition. The relatively new Ministry of Energy (established in 2019) and other bodies may still be building expertise in areas like energy auditing, digital technology assessment, and environmental monitoring. For instance, conducting regular energy audits of factories or deploying systems to measure carbon emissions requires skilled personnel and resources. Capacity building is needed so that agencies can analyze data coming from Industry 4.0 systems (like IoT sensors) and use it to enforce policies.

Incentives and Compliance: Creating the right incentives for industries to comply with green metrics is tricky. Many heavy industries in Uzbekistan are state-owned or have been protected monopolies. Historically, energy prices have been heavily subsidized, with low electricity and gas tariffs for industry. While this supports industrial output, it disincentivizes energy efficiency investments because savings do not translate into financial benefits under subsidized prices. Gradual energy tariff reform, combined with incentive mechanisms (tax breaks, grants for efficiency upgrades, etc.), will be needed to encourage industries to pursue the green indicators seriously. On the flip side, without careful planning, removing subsidies could raise production costs abruptly. The policy challenge is to balance reform with support, possibly by redirecting subsidies towards co-financing efficiency projects rather than cheap energy consumption.

Data and Monitoring Systems: Another institutional challenge is establishing robust monitoring and reporting systems for green indicators. As Industry 4.0 tools generate large volumes of data, the government needs to collect and utilize this data to track progress. This means standardizing metrics and reporting formats (e.g., how companies report energy use, emissions, etc.) and investing in digital infrastructure at the national level to aggregate this information. The development of a national MRV (Measurement, Reporting, Verification) system for emissions and energy, possibly linked with the emerging carbon trading pilot, is crucial. Until that is mature, there is a risk of information gaps – not knowing whether certain interventions are actually yielding the desired environmental benefits.

Despite these challenges, opportunities on the institutional side are significant:

Uzbekistan can strengthen policy execution by learning from international models of governance for green industry. For example, South Korea's Green Growth strategy or China's eco-industrial park regulations offer templates for integrated policy frameworks. Adapting best practices, such as setting up dedicated "green transformation" units within industrial enterprises or public-private green innovation councils, could enhance implementation.

The government's active engagement with international organizations (World Bank, UNDP, ADB, etc.) brings in technical assistance and funding that can be used to build institutional capacity. Projects already underway (like the World Bank's climate-related DPOs and green finance report) provide policy advice that Uzbekistan can harness to refine its regulations and incentive structures.

The creation of the National Green Economy Taxonomy and membership in coalitions (like the Coalition of Finance Ministers for Climate Action) show that Uzbekistan is positioning its institutional apparatus to attract green funding. This can be leveraged to establish green financing facilities for industries – effectively aligning economic incentives with green indicators.

Lastly, high-level political will appears strong (the President and key ministers frequently reference the importance of green development), which is an asset. This political support can be harnessed to push through difficult reforms (such as energy pricing changes or stricter environmental regulations) that might otherwise face resistance.

Technological and Infrastructure Challenges:

On the technological front, integrating cutting-edge Industry 4.0 solutions and achieving tangible environmental improvements is complex, especially given Uzbekistan's starting point. Key challenges include:

Legacy Infrastructure: Much of Uzbekistan's industrial base was built in the Soviet era or the early independence period and relies on outdated technology. Retrofitting old plants with modern sensors, control systems, and automation can be technically challenging and costly. For instance, an old refinery or metallurgical furnace may not easily support the installation of IoT monitoring without significant upgrades. The "slow updating

of technologies" identified in the green economy strategy is precisely the hurdle here – decades-old machinery must be either overhauled or replaced to be compatible with Industry 4.0 solutions.

Digital Infrastructure **and Connectivity:** Successful Industry 4.0 implementation needs reliable digital infrastructure – high-speed internet, data centers, cloud services, and cybersecurity. In some industrial sites (especially remote mining areas or oil fields), ensuring stable connectivity for real-time data transmission is a challenge. The government's investments in IT parks and improved internet connectivity are largely focused on urban and service sectors. Extending robust network infrastructure into every factory and field site is work in progress. Additionally, cybersecurity is a concern; as industries become more connected, they become potential targets for cyberattacks, which could disrupt operations or safety systems. Developing secure industrial IoT frameworks is a necessity.

Human Capital and Skills: Industry 4.0 technologies are only as effective as the people who design, implement, and maintain them. Uzbekistan faces a skills gap in this domain. While the country is training IT specialists (e.g., through the "One Million Coders" program and expanding tech universities), there is a specific need for engineers and technicians who understand both industrial processes and digital systems. For example, a metallurgical engineer who also knows data analytics, or a chemical plant operator trained in handling automated control systems. Upskilling the existing industrial workforce and preventing "brain drain" of tech talent are ongoing challenges.

Adaptation of Technology to Local Needs: Not all Industry 4.0 solutions developed elsewhere will directly suit Uzbekistan's industrial context. There might be a need to **localize or** customize **technologies**. For instance, sensors might need to withstand very high temperatures in metallurgy, or AI models need local data to be effective. This calls for local innovation and adaptation, but R&D in Uzbekistan's industrial sector has been limited. Boosting R&D and partnerships with universities or foreign tech providers will be important to ensure the technology adopted actually delivers results in practice (and doesn't become underutilized due to misalignment with on-site conditions).

Scaling Pilots **to Industry-Wide Adoption:** We saw that certain companies (AMMC, Uzbekneftegaz) are pioneering digital changes. A challenge is how to scale these isolated successes across all players in the sector, including smaller firms. There is a risk that only a few flagship enterprises implement advanced technologies, while many others lag behind, thus limiting the impact on national green indicators. Ensuring widespread adoption requires demonstration projects, knowledge sharing, and perhaps mandates for technology update for all large emitters.

The opportunities in the technological dimension include:

Uzbekistan can take advantage of being a late adopter by acquiring proven technologies from abroad without bearing the full cost of development. The global market offers many Industry 4.0 solutions (sensors, software, robots) that are becoming cheaper and more standardized. By partnering with international tech companies and through foreign direct investment (FDI) in industrial projects, Uzbekistan can leapfrog to modern equipment relatively faster. The case of AMMC partnering with foreign firms for digital mining solutions is a precedent.

The country's growing ICT sector and tech startup scene (supported by IT parks and incentives) could be oriented to develop home-grown solutions for industrial sustainability. For example, Uzbek IT firms could be encouraged to develop energy management software tailored for local factories or to collaborate on smart grid projects for industrial zones.

Eco-innovation hubs could be established in the free economic zones, specifically targeting green technology for industry (like testbeds for hydrogen fuel use in industry, carbon capture pilots for cement or chemical plants, etc.). This would align with the notion of inclusive innovation – as promoted by UNIDO and OECD – where developing countries use global knowledge to address local sustainability challenges.

With regard to skills, Uzbekistan can utilize international training programs and its diaspora. Partnerships with technical universities abroad, and inviting experts through exchange programs, can rapidly build the needed human capital. The example of SAP and Turin Polytechnic University collaboration to train students for automotive industry digitalization is one to replicate in other industries.

Finally, there is an opportunity to integrate renewable energy technologies into industrial settings as part of the tech upgrade. Industry 4.0 can facilitate the use of renewables by enabling smart energy management (e.g., factories adjusting load in response to solar output). With Uzbekistan investing heavily in solar and wind capacity (targeting 27 GW by 2030), industries can capitalize on cleaner power and even incorporate on-site generation. This dovetails with technological solutions – for instance, an IoT system that dynamically switches a factory to battery storage or solar panels at peak times can reduce reliance on fossil grid power, lowering emissions.

Economic and Financial Challenges:

The economic dimension of implementing green indicators via Industry 4.0 is critical. Uzbekistan must ensure that the transition is not only environmentally and technologically sound, but also economically viable and inclusive. Key challenges here include:

High Initial Investment Costs: Upgrading to Industry 4.0 and green technologies often requires substantial upfront capital. Whether it's installing efficient equipment (e.g., energy-efficient boilers, electric arc furnaces) or deploying enterprise-wide digital systems, the costs are significant. Many industrial enterprises in Uzbekistan, especially state-owned ones, may have limited capital expenditure budgets or carry legacy debts. Mobilizing funds for green modernization is a hurdle. Although state-owned financial institutions provide 70% of loans in the economy (Uzbekistan), they traditionally financed conventional projects. Redirecting finance to modernization projects involves risk assessment and developing new financing instruments (like green bonds, which Uzbekistan has begun to explore (Uzbekistan)).

Return on Investment (ROI) Uncertainty: Managers of industrial companies might be uncertain about the ROI on Industry 4.0 and green investments. The benefits – energy savings, improved productivity, reduced fines for pollution – are realized over time, whereas the costs are immediate. In the absence of strong regulatory pressure or clear market advantages (like consumer demand for green products), companies may hesitate. This challenge is more acute in sectors like oil and gas, which are used to operating on established processes and might view experimental digital tech as risky. There could be a mindset issue: a need to shift the perception from "environmental compliance is a cost" to "sustainability is an opportunity for efficiency and new markets."

Economic Structure and Jobs: Heavy industries in Uzbekistan are major employers. The introduction of automation and AI raises concerns about labor displacement. While Industry 4.0 can create new skilled jobs, it may reduce low-skill jobs. Balancing this transition to avoid social backlash is an economic and political challenge. The government must pair technological upgrades with job retraining programs to move workers into new roles (for example, retraining a technician to manage automated systems instead of manual control). If not managed, fear of job losses could create resistance from labor or local communities to modernization plans.

External Market Factors: Uzbekistan's industries do not operate in isolation; they are influenced by global market trends. For example, global shifts towards green supply chains (such as the EU's Carbon Border Adjustment Mechanism) could penalize carbon-intensive exports. This is a risk if Uzbekistan's industries do not green fast enough – their products might face tariffs or lose competitiveness abroad. Conversely, if they invest now, they could capture market share for greener commodities (like low-carbon copper or "green" fertilizers made with clean energy). Thus, an economic challenge is the timing and scale of investment relative to competitors. If competitors (e.g., producers in other countries) move faster on green tech, Uzbek industries risk obsolescence; if Uzbekistan moves proactively, it incurs costs now but could gain a first-mover advantage in the region.

Financing Mechanisms: Traditional bank loans may not suffice for these large-scale transformations due to their short tenors and high collateral demands. Uzbekistan needs to develop financing mechanisms suited to green industrial projects. This might include public-private partnerships (PPPs), green bonds, climate investment funds, or leveraging multinational development bank financing. Setting up these mechanisms is institutionally challenging but necessary to overcome the investment barrier.

Opportunities to surmount the economic challenges are emerging:

The government and international partners are working on creative financing solutions. The World Bank's recent report "Prime Picks for a Green Pivot: Uzbekistan State Funds for Climate Action" provides a roadmap for refocusing state funds on green projects, effectively suggesting that existing public capital be used to de-risk and catalyze private investments in areas like clean energy and sustainable industry. Implementing such recommendations can unlock significant funding. For example, state investment funds (like UFRD) could allocate a portion of their portfolio to co-finance factory modernizations that meet green criteria, thereby sharing the cost with industry.

International climate finance is increasingly available. Uzbekistan's alignment with global climate goals makes it eligible for funds from sources like the Green Climate Fund (GCF) and others. Already, we see grants (like the €12 million from GIZ) and World Bank allocations (e.g., $46 million for the iCRAFT project) targeting emission reductions. By preparing a pipeline of bankable green industry projects, Uzbekistan could attract larger sums. For instance, a proposal to convert an old power-hungry cement plant into a modern efficient one with waste-heat recovery could appeal to climate financiers.

Economic diversification and innovation: Embracing Industry 4.0 and green tech can spur diversification into new industries and services. Opportunities exist in developing local manufacturing of clean tech components (solar panels, insulation materials, smart meters) and providing digital services (like energy auditing software, consulting) – creating new business and export potential. As Uzbekistan's economy opens up, positioning itself as a regional leader in sustainable industry could attract foreign investors who are looking

for responsible investment destinations. Sustainable industrial zones with guaranteed low-carbon energy and modern infrastructure could draw in multinational companies, thereby boosting growth.

From a macroeconomic perspective, improving energy efficiency and reducing resource waste strengthens economic resilience. Uzbekistan currently uses a large amount of gas domestically for power and industry; if efficiency rises, surplus gas could be exported or used in higher-value ways, improving trade balance and revenues. Likewise, cutting losses (e.g., electricity transmission losses or gas flaring) saves money. The cumulative benefit of such savings can be reinvested in further innovation, creating a virtuous cycle of green growth.

Lastly, the **global trend towards sustainability** means that moving early confers reputational advantages. Uzbekistan can market itself as a purveyor of "green" commodities (like cotton produced with efficient irrigation, or gold mined with modern environmental standards) which can fetch better terms in international markets. This is an opportunity to differentiate Uzbek products and integrate into sustainability-focused supply chains.

CONCLUSION AND SUGGESTIONS

Uzbekistan stands at a pivotal moment in its industrial development trajectory. The confluence of the Fourth Industrial Revolution and the green economy transition presents a rare chance to redefine industrial growth – shifting away from the historically resource-intensive, high-emission model towards a sustainable, high-tech paradigm. This study has examined how Uzbekistan can implement green economy indicators in its industrial sector under the wave of Industry 4.0, highlighting notable progress, challenges, and avenues for future action.

The Introduction set the stage by outlining the twin imperatives of digital modernization and environmental sustainability, and how they manifest in Uzbekistan's context. The Methods described our approach in synthesizing policy documents and global insights, ensuring a comprehensive basis for analysis. The Results demonstrated that Uzbekistan has laid important groundwork: a national strategy with clear targets for energy efficiency and emissions, early integration of digital technologies in heavy industries with promising gains (like significant fuel savings and efficiency improvements), and engagement with international initiatives to bolster its efforts. These results show that the country is moving in the right direction, albeit in initial steps.

The Discussion delved into the heart of the matter – acknowledging that, despite strong policy intent, Uzbekistan faces real hurdles in institutions, technology, and economics that could slow or complicate the transition. It also illuminated that for each challenge, there is a corresponding opportunity or solution that can be harnessed. For instance, while legacy industrial infrastructure is a challenge, it is also an opportunity to build back smarter and cleaner; and while financing is a constraint, innovative green finance can be a game-changer. A recurring theme is that Industry 4.0 and green objectives are mutually reinforcing: digital tools provide means to achieve sustainability, and sustainability goals provide motivation to adopt advanced tools. Harnessing this synergy – much like the EU's concept of twin transitions – will be crucial.

In conclusion, implementing green economy indicators in Uzbekistan's industrial sector under Industry 4.0 is not only feasible but advantageous. It can lead to a triple win: environmental gains (lower emissions, less pollution, conservation of resources), economic gains (higher efficiency, new green tech sectors, improved competitiveness), and social gains (skilled jobs, improved health from reduced industrial pollution). However, success is not automatic; it requires diligent execution of strategies, continuous learning, and adaptation. Uzbekistan must maintain its commitment, strengthen its institutions, invest in its people, and remain open to innovation and international cooperation. The journey to a green, digital industrial future is complex, but Uzbekistan's early steps and demonstrated political will are encouraging.

By embracing the challenges as catalysts for change and seizing the opportunities at hand, Uzbekistan can transform its industrial sector from a traditional engine of growth into a modern exemplar of sustainable industrialization. This would not only fulfill national goals like those set out in Strategy PP-4477 and subsequent plans but would also position Uzbekistan as a regional leader in the new paradigm of industry – one where competitiveness and sustainability go hand in hand. The experience gleaned will be valuable for other emerging economies charting similar paths, making Uzbekistan's green Industry 4.0 transition a potential case study in successful integration of technology and sustainability in the pursuit of development.

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