



## THE IMPACT OF DIGITAL TRANSFORMATION IN AZERBAIJAN'S ENERGY SUPPLY CHAIN ON SUSTAINABLE DEVELOPMENT

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**Abstract.** This study examines the digital transformation of Azerbaijan's energy supply chain and analyzes its role in enhancing efficiency and sustainability. The study reviews current challenges, technological impacts and multidimensional benefits while proposing policy recommendations. The research concludes that digitalization is essential for modernizing the sector.

**Keywords:** Azerbaijan, energy supply chain, digital transformation, sustainable development, technology application.

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### AZƏRBAYCANIN ENERJİ TƏCHİZAT ZƏNCİRİNDƏ RƏQƏMSAL TRANSFORMASIYANIN DAVAMLI İNKİŞAF TƏSİRİ

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**Xülasə.** Məqalədə Azərbaycanın enerji təchizati zəncirində rəqəmsal transformasiyası araşdırılmış və onun səmərəliliyin və dayanıqlığın artırılmasındakı rolu təhlil edilmişdir. Tədqiqatda mövcud çətinliklər, texnoloji təsirlər və çoxölçülü faydalar nəzərdən keçirilmiş və tövsiyələr təklif edilmişdir. Tədqiqat nəticəsində rəqəmsallaşmanın sektorun modernləşdirilməsi üçün vacib olduğu qənaətinə gəlinir.

**Açar sözlər:** Azərbaycan, enerji təchizati zənciri, rəqəmsal transformasiya, davamlı inkişaf, texnologiyanın tətbiqi.

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## 1. Introduction

As an important energy exporter in the Caspian region, Azerbaijan's energy supply chain digital transformation is of great significance, given the global changes in the energy mix and domestic policy adjustments. With increasing global attention on low-carbonization and digitalization, Azerbaijan's traditional oil and gas industry faces dual pressures: changes in international market demand and carbon neutrality goals. For example, the European Union's Green Deal is prompting it to reduce its dependence on fossil fuels and Azerbaijan needs to optimize its energy export structure and increase the proportion of clean energy. The government is advancing structural reforms and plans to build 6 gigawatts of wind and photovoltaic power plants by 2030. However, there are contradictions between energy marketization and people's livelihood needs, such as rising costs leading to social pressure and a decline in the growth rate of electricity demand.

Against this backdrop, digital transformation has become critical to balancing strategic energy goals with the economic affordability for the population.

The importance of digital transformation is reflected in several aspects. Regarding efficiency improvement, intelligent production management and logistics network optimization are key. For example, digital twin technology simulates gas field development, which can predict failures and reduce downtime. The Shah Deniz gas field compression project uses this

technology to improve recovery rates and reduce costs. Furthermore, blockchain tracks oil and gas transportation routes and smart grids dynamically adjust power distribution, which can improve logistics efficiency. In terms of cost reduction, it helps reduce dependence on fossil fuels and supports the coordinated operation of intermittent energy sources and traditional power grids. Concerning environmental protection, the Hizir - Absheron wind power project reduces carbon dioxide emissions by 400,000 tons per year and the digital publication of emissions reduction data can enhance investor confidence.

From a sustainable development perspective, digital transformation has significant effects on the economic, social and environmental dimensions. Economically, it generates new growth opportunities; Azerbaijan plans to improve the digital literacy of several companies and cultivate local technology service providers. Socially, smart grids guide residents to use electricity during off-peak hours and digital platforms provide transparent subsidy information. Environmentally, it optimizes the energy supply chain and reduces resource waste; for example, the ACG Oilfield combines digital simulation technology to improve recovery rates and reduce ecological impact. Its digital transformation can not only meet current challenges but also provide support for the country's sustainable development.

## **2. Literature review**

Research findings on the digital transformation of energy supply chains both domestically and internationally are abundant, covering technical frameworks, industry applications and sustainable development goals. At the technological level, emerging technologies such as the Internet of Things (IoT), blockchain, big data and artificial intelligence (AI) are widely applied. Blockchain enhances the transparency and security of energy transactions, while IoT enables real-time monitoring of production equipment status, optimizing inventory and logistics. Studies emphasize the importance of digitally integrating the “three flows” (logistics, capital flow and information flow) for improving the overall efficiency of energy supply chains. Within the power sector, the “dual carbon” goals drive the construction of green supply chains, where digital and intelligent transformation has become key to reducing carbon emissions and improving resource utilization efficiency.

While existing research provides valuable insights, it has limitations. First, the practical implementation of technologies and their industry-specific adaptability remain underaddressed. Much research stops at analyzing technical feasibility, lacking discussions on actual costs, complexity and industry-specific challenges - such as performance bottlenecks and standardization issues facing large-scale blockchain applications. Second, research on regional and sectoral variations remains weak, predominantly focusing on major economies while neglecting developing countries. Moreover, supply chains across different energy subsectors exhibit significant differences, making generic transformation frameworks ill-suited to address niche challenges. Third, assessments of long-term sustainability are lacking. Most studies concentrate on short-term effects, failing to systematically analyze dynamic factors like

technological iteration and policy shifts, which may lead to the failure of transformation strategies.

Digital technologies exert profound impacts on the energy sector. In terms of efficiency, intelligent dispatch systems reduce transportation empty-run rates and lower logistics costs; blockchain accelerates supply chain financial settlements, alleviating corporate capital pressures. Regarding transparency and traceability, digital tools enable end-to-end lifecycle visualization management of supply chains, enhancing consumer trust and helping enterprises meet international environmental standards. Digital transformation fosters innovative business models - such as platform-based services and sharing economy approaches - providing value-added service opportunities for energy companies, promoting collaborative development across industrial chains and driving the modernization of the energy sector.

### 3. Current status of Azerbaijan's energy supply chain

Azerbaijan's energy supply chain centers on oil and natural gas, with extraction, transportation and distribution forming a complex system. Extraction primarily relies on the Azeri-Chirag-Guneshli oil field and the Shah Deniz gas field in the Caspian Sea. In the first quarter of 2025, oil production reached 6.9 million tons, while natural gas production amounted to 12.6 billion cubic meters. Resource development is carried out through cooperation between international oil companies and the State Oil Company of Azerbaijan (SOCAR), combining government leadership with foreign investment participation. However, reliance on imported high-end technology and equipment, coupled with local enterprises predominantly handling midstream and downstream operations, results in insufficient technological autonomy, constraining supply chain efficiency improvements. Some oil fields and pipelines constructed during the Soviet era suffer from severe equipment aging. For instance, declining production at the ACG oil field impacts supply chain stability and economic efficiency.

**Table 1.** Azerbaijan energy supply chain

Energy Type	Production Volume (Q1 2025)	Major oil/gas fields	Major oil/gas fields output Q1 2025	Cumulative Production Volume (as of April 1, 2025)
Oil	6.9 million tons	Azeri-Chirag-Guneshli(AGG) Oil Field	4 million tons	Approximately 655.2 million tons of oil (including condensate).
Gas	12.6 billion cubic meters	Shah-Deniz gas field	6.8 billion cubic meters	476.8 billion cubic meters of natural gas

Transportation remains critical, relying on the Baku-Tbilisi-Ceyhan (BTC) pipeline for oil and the South Caucasus Pipeline (SCP) for natural gas to Turkey and European markets. However, the BTC pipeline operates near its design capacity, frequently reaching saturation and struggling to meet growing demand. Its route through the Caucasus region exposes it to

geopolitical risks. Domestically, oil and gas primarily fuel power generation, heating and industrial processes. Yet inefficient thermal power generation and high grid transmission losses exacerbate energy waste, underscoring the urgent need for technological upgrades in traditional energy supply chains.

Information asymmetry poses another challenge. Data remains fragmented across extraction, transportation and distribution segments, lacking a unified platform for integration and coordination. Government-regulated domestic energy prices exhibit weak linkage to international markets, hindering corporate strategic adjustments. Lagging regulation limits real-time monitoring capabilities, hindering rapid responses to sudden failures or market fluctuations. Information silos increase operational costs and reduce supply chain flexibility. Establishing a digital supply chain platform to enable data sharing and transparent management is key to improving efficiency. The oil and gas sector accounts for approximately 60% of the country's total carbon emissions, conflicting with emission reduction targets. Development of the Caspian oil fields also causes water pollution and biodiversity decline. Digital solutions are needed to optimize resource utilization and mitigate negative environmental impacts.

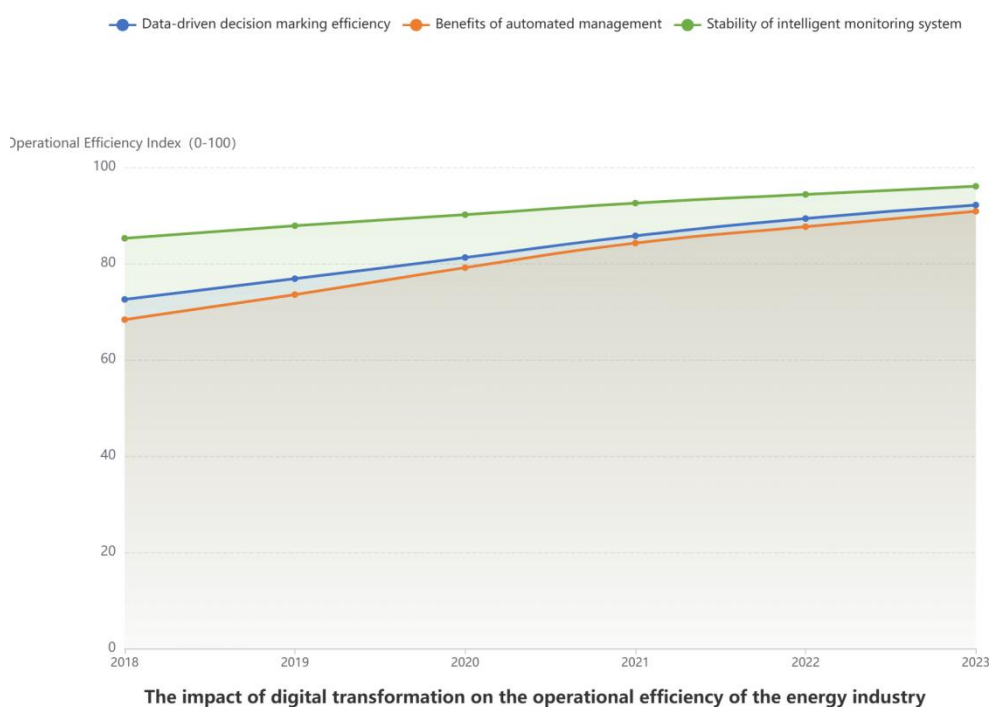
#### **4. The concept and characteristics of digital transformation**

Digital transformation, as a key driver of modern enterprise development, has demonstrated significant transformative effects within the energy sector. By deeply integrating emerging information technologies with traditional energy operations, digital transformation enables intelligent management across the entire energy lifecycle. For instance, data-driven decision-making in the energy sector leverages IoT and big data technologies to collect and analyze real-time energy usage patterns, thereby optimizing resource allocation. This data-based approach not only enhances operational efficiency across energy production, transmission, trading and consumption but also provides scientific foundations for corporate sustainability. Intelligent monitoring systems utilize sensors and communication technologies to track equipment status in real time, promptly identifying potential failures and issuing early warnings, thus ensuring the security and stability of energy supply.

Automated management represents another core feature of digital transformation. Through cloud computing and artificial intelligence, it enables automated processing and analysis of energy data, significantly boosting operational efficiency. For instance, automated control systems in petrochemical applications reduce manual intervention, lower safety risks and enhance production efficiency. Intelligent dispatch systems dynamically adjust energy allocation strategies based on market demand, ensuring supply-demand equilibrium. These technologies empower energy enterprises with enhanced adaptability and resource utilization rates when confronting market fluctuations and external shocks. Through digital transformation, the energy sector is progressively advancing toward a new phase of intelligent, data-driven and information-based operational management, laying a solid foundation for future green and low-carbon development.

**Table 2.** Types of digital transformation

Concepts/Features	Specific manifestations	Core features	Influence
Digital transformation	Emerging information technologies empower the energy industry	Optimize resource allocation, ensure security and enhance intelligent interaction.	Improve the intelligent, data-driven and information-based operation and management of energy enterprises
Data-driven decision making	Optimize decision output by applying emerging information technologies	Fully explore and utilize the value of data	Improve the operational efficiency of energy production, transmission, trading and consumption.
Intelligent monitoring	IoT technology enables devices to connect online in real time.	Massive device data collection and real-time monitoring	Improve the efficiency and safety of energy equipment management
Automated management	Cloud computing technology improves the efficiency of data collection, storage and analysis.	Automated processing and analysis of energy data	Improve the operating efficiency and resource utilization rate of energy enterprises



**Figure 1.** The impact of digital transformation on the operational efficiency of the energy industry

### 5. The technological foundation of digital transformation

Technologies such as the Internet of Things (IoT), big data, artificial intelligence (AI) and blockchain are key enablers for the digital transformation of energy supply chains. IoT leverages sensor networks to collect real-time equipment operation data, combined with 5G communication to achieve comprehensive monitoring of energy facilities. BP utilizes IoT for

asset monitoring, enabling proactive maintenance that reduces unplanned downtime, improves equipment utilization and minimizes economic losses. IoT provides dynamic monitoring for energy transportation, such as real-time tracking of pressure and temperature changes in oil and gas pipelines, ensuring safe and stable transport.

**Table 3.** Digital transformation technologies

Technology	Application Cases	Company Name	Improvement effect	Years
Internet of Things	Monitor asset health and performance	BP	Achieve proactive maintenance and reduce unplanned downtime.	2024
AI	Predicting interruptions and optimizing inventory levels	Shell	Improve decision-making and accelerate response time to disruptions.	2024
Digital twin	Simulated Refinery Operation	ExxonMobil	Improve operational predictability and reduce downtime	2024
cloud platform	Real-time communication and supply chain coordination	Total Energy	Enhance operational visibility and improve data sharing	2024
Blockchain	Documenting cobalt ore sources ensures responsible sourcing.	A battery manufacturer	Supply chain transparency increased by 30% and the risk of data tampering approached zero.	2024
Big Data	Identification of sudden increases in energy consumption	An electronics company	Timely identification of equipment malfunctions to avoid environmental risks	2024

Big data technology integrates and analyzes multi-source heterogeneous data to uncover latent value. An electronics company identified sudden spikes in energy consumption through big data, enabling timely troubleshooting and repair of equipment failures to avert environmental risks. Big data platforms centrally manage data from ERP, SCADA and other systems. Leveraging tools like Hadoop or Spark for efficient processing, visualization tools such as Tableau provide intuitive displays of supply-demand forecasts and carbon emission trends, informing decision-making. Shell employs artificial intelligence to predict disruptions, optimize inventory, enhance decision-making processes and accelerate response times, enabling energy companies to better adapt to complex market conditions.

Digital twin technology holds immense potential for simulating refinery operations. ExxonMobil built digital twin models to enhance operational predictability, reduce downtime and enable testing of operational scenarios in virtual environments - allowing early issue detection and solution planning. Cloud platforms facilitate real-time communication and data sharing among supply chain participants. TotalEnergies leveraged cloud platforms to boost operational visibility and achieve seamless upstream-downstream collaboration. Blockchain technology, with its decentralized and immutable nature, elevates supply chain transparency. A battery manufacturer uses blockchain to trace cobalt mine origins, ensuring responsible sourcing and boosting supply chain transparency by 30% while virtually eliminating data

tampering risks. These technologies are profoundly transforming traditional energy supply chain operations, propelling them toward greater efficiency, safety and sustainability.

## **6. The impact of digital transformation on the energy supply chain**

Azerbaijan's energy supply chain has achieved remarkable results in digital transformation, with improvements in resource utilization, logistics management and low-carbon development. Traditional energy extraction relied heavily on manual experience, resulting in low efficiency and resource wastage. Today, energy companies have introduced industrial IoT, big data analytics and artificial intelligence technologies, shifting from an “experience-driven” to a “data-driven” approach. For instance, digital twin technology in oilfield management constructs virtual models to simulate extraction plans, optimize drilling paths and refine water injection strategies - boosting resource recovery rates by 5% to 10%. Predictive maintenance technology collects real-time equipment operation data, leveraging machine learning algorithms to identify potential failures early, reducing unplanned downtime and increasing equipment utilization by 15% to 20% while minimizing resource wastage.

Logistics optimization stands as another key outcome of digital transformation. Azerbaijan's energy supply chain previously grappled with high costs and low efficiency in pipeline transportation, warehousing and distribution. The adoption of blockchain, smart contracts and real-time monitoring systems has made the entire logistics process more transparent and efficient. Distributed fiber optic sensing technology deployed along pipelines detects temperature and pressure changes in real time. Combined with AI algorithms, it rapidly locates leaks with sub-50-meter accuracy, significantly reducing response times. Intelligent flow control systems dynamically adjust throughput, reducing transportation energy consumption by approximately 10% to 15%. In warehousing, IoT connectivity across all links enables real-time inventory monitoring. Combined with demand forecasting models to adjust distribution plans, this reduces inventory backlog and stockout risks, enhancing overall logistics management efficiency.

Digital transformation is propelling the energy sector toward low-carbon development. Azerbaijan's energy sector accounts for 45% of national carbon emissions, making emissions reduction urgent. Digital tools enable clean energy integration, efficiency improvements and carbon management. Smart grid technology balances supply-demand fluctuations, supports distributed energy trading and reduces fossil fuel dependence; carbon capture and digital monitoring ensure secure, effective sequestration; energy efficiency platforms integrate data, using AI algorithms to identify high-consumption areas and propose optimizations, advancing the industry's greening.

## **7. The contribution of digital transformation to sustainable development**

Digital transformation has deeply integrated into Azerbaijan's economic, social and environmental development, providing robust momentum for sustainable growth. Economically, digital technologies have revitalized economic expansion by enhancing energy supply chain efficiency, optimizing resource allocation and driving industrial upgrading. Smart grid technologies have improved power transmission efficiency, reduced operational costs and facilitated large-scale integration of renewable energy, laying the foundation for energy structure transformation. The proliferation of digital platforms facilitates enterprises' expansion into international markets, enabling small and medium-sized enterprises to enhance competitiveness. This aligns closely with the economic growth objectives of the United Nations Sustainable Development Goals, highlighting digital transformation's potential to foster inclusive growth.

Socially, digital transformation significantly elevates public service quality and living standards. Smart energy management systems enable real-time monitoring and precise regulation of energy supply, ensuring stable residential electricity access. The expansion of digital education platforms extends quality educational resources to remote communities, narrowing urban-rural disparities. Telemedicine systems improve healthcare accessibility and efficiency, playing a crucial role in monitoring the health of energy sector workers. These initiatives not only meet fundamental societal needs but also enhance public awareness and support for sustainable development, fostering a positive social environment. Digital technologies cultivate future-ready professionals through skills training programs, boosting employment and talent development [13].

On the environmental front, digital transformation propels Azerbaijan toward green development. Intelligent monitoring and data analytics tools reduce energy waste and enhance resource efficiency. For carbon emissions management, digital technologies provide scientific decision-making foundations for energy enterprises, aiding in the formulation of rational reduction strategies. Digital methods optimize the siting and layout of renewable energy projects, maximizing environmental benefits. This data-driven management model advances Azerbaijan's transition to a low-carbon economy, offering valuable insights for global sustainable development.

## **8. Challenges of digital transformation**

Azerbaijan faces multiple constraints in advancing the digital transformation of its energy supply chain. Technical bottlenecks are particularly pronounced, with core equipment heavily reliant on imports. For instance, geological exploration and drilling equipment for geothermal power generation depend on the United States and Italy, while advanced heat exchange systems and power conversion equipment are partially sourced from Russia and Ukraine. This dependency not only drives up equipment maintenance costs but also hampers technological iteration. Despite a geothermal power generation capacity of 300 megawatts, it

accounts for less than 1% of the country's total electricity production. Weak system integration capabilities persist, with digitalization rates at refineries and petrochemical plants hovering at just 35% - far below international standards. The absence of smart grid dispatch systems hampers renewable energy integration efficiency, making it difficult to meet European market demands.

Insufficient capital investment presents another major obstacle, with high initial costs imposing significant financial pressure on enterprises. For instance, the 2025 “Industry 4.0” project entails transformation costs reaching millions of dollars per company. Despite substantial oil export revenues, funds must be allocated across multiple priorities, creating considerable strain. Financing channels remain limited, primarily relying on government budgets, international loans and foreign investment partnerships. Geopolitical risks could trigger foreign capital withdrawal, while an underdeveloped domestic green finance system exacerbates financing difficulties for small and medium-sized enterprises.

Talent shortages similarly constrain the transition process. The energy sector predominantly employs traditional petroleum engineering professionals, lacking multidisciplinary expertise. For instance, during SOCAR's collaboration with ExxonMobil, local staff participation in smart oilfield management and predictive maintenance fell below 30%. The education and training system lags behind, with universities lacking relevant programs and vocational institutions lacking cutting-edge courses. While Masdar in the UAE has cultivated talent through international cooperation, Azerbaijan remains in the early stages. These issues collectively lead to technological backwardness, rising costs, financing difficulties and talent drain, creating a vicious cycle that severely hinders the digital transformation of Azerbaijan's energy supply chain.

**Conclusion.** This study confirms that digital transformation enhances efficiency, transparency and sustainability in Azerbaijan's energy supply chain. However, challenges such as technological dependence, financing gaps and talent shortages must be addressed through targeted policies. Future research should explore the long-term impacts of AI and blockchain on energy governance and carbon neutrality.

To further advance digital transformation, the following policy recommendations and development strategies should be implemented: The government should refine the legal framework to ensure secure and lawful data sharing, while establishing tax incentives to encourage increased corporate investment in digitalization. This includes creating dedicated funds to support SMEs in upgrading IoT equipment and technologies. Strengthening talent development is crucial. Collaborations with universities and international institutions can establish specialized training systems to cultivate local digital skills talent, meeting the energy sector's transformation needs. International cooperation remains indispensable. Attracting foreign investment and technology transfer, particularly in cutting-edge fields like energy

storage and hydrogen energy, can accelerate green energy project implementation and enhance regional competitiveness.

From a long-term planning perspective, Azerbaijan should develop a clear digital transformation roadmap with phased objectives to gradually increase the share of green energy and integrate carbon neutrality principles into policy design. Active participation in international carbon trading markets, coupled with digital tools for precise carbon emissions accounting, will strengthen Azerbaijan's position in global energy governance. Through these measures, Azerbaijan stands poised to achieve comprehensive upgrades across its energy supply chain, providing robust support for sustainable development goals.

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