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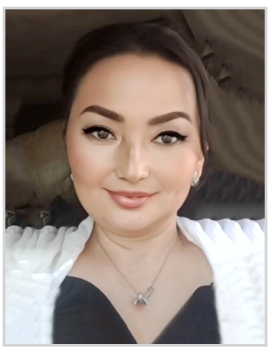
Aiman Assanova
MA (Economics), Senior Lecturer,
Kazakh National Pedagogical University named after Abai
13 Dostyk Ave., Almaty, 050010,
Republic of Kazakhstan
aiman_assanova@mail.ru
ORCID ID:
https://orcid.org/0000-0001-7690-9702

Ainur Issaeva
PhD (Economics),
Kazakh National Pedagogical University named after Abai
13 Dostyk Ave., Almaty, 050010,
Republic of Kazakhstan
Issaeva_ainur@mail.ru
ORCID ID:
https://orcid.org/0000-0001-5757-4628



Zora Dzhubalieva
PhD (Economics),
Kazakh National Pedagogical University named after Abai
13 Dostyk Ave., Almaty, 050010,
Republic of Kazakhstan
zora.dzhubalieva@gmail.com
ORCID ID:
https://orcid.org/0009-0009-9829-5911

Rakhat Arzikulova
PhD (Economics),
Associate Professor,
Kazakh National Pedagogical University named after Abai
13 Dostyk Ave., Almaty, 050010, Republic of Kazakhstan
rakha0212@mail.ru
ORCID ID: https://orcid.org/0009-0007-1745-3400

Aigul Uchkampirova
PhD (Economics),
Associate Professor,
L. N. Gumilyov Eurasian National University
2 Satpayev Str., Astana, 010008, Republic of Kazakhstan
Aigulya82@gmail.com
ORCID ID: https://orcid.org/0000-0002-7887-1696

Financial-digital investments in human capital as a factor of sustainable economic growth: assessment, dynamics and impact of artificial intelligence (a Kazakhstan case study)

Abstract

Introduction. This study investigates the relationship between financial-digital investments in human capital and sustainable economic growth in Kazakhstan from 2015-2023, with particular emphasis on artificial intelligence integration. The research addresses critical gaps in understanding how emerging economies leverage digital transformation for human capital development while maintaining economic sustainability, focusing specifically on Kazakhstan's transition from resource-dependent to knowledge-based economic growth through strategic coordination between government policy, private sector innovation, and international partnerships.

Methods. A comprehensive mixed-methods approach combining advanced econometric techniques with qualitative policy analysis was employed. Data sources included macroeconomic indicators from the Ministry of National Economy, firm-level data from 156 companies, and individual-level educational outcomes from 12,840 respondents across 16 administrative regions. System GMM estimators addressed endogeneity concerns while instrumental variables leveraged exogenous variation in oil prices and technology transfer agreements. Primary data collection involved structured interviews with 45 senior executives and government officials, yielding 576 quarterly observations for core analysis.

Results. Kazakhstan achieved internet penetration of 90.9% and digital literacy rates of 92% by 2023, while establishing Central Asia's AI productivity leadership with developers achieving 17.1% productivity gains through English-language AI tools versus 13.8% for local languages. Digital transactions increased from 7% in 2014 to 89% in 2024, online banking adoption rose from 25% to nearly 100%, and the IT services sector grew to 772 billion tenge by 2022 with 23.4% growth in Q1 2023. The fintech sector captured 40% of venture capital deals by 2023, while Astana Hub expanded to over 1,600 resident companies. The digital economy's share of GDP increased to 6.1% by 2024, with educational technology integration reaching 85.4% in higher education and 82.1% in vocational training.
Discussion. The findings demonstrate that financial-digital investments successfully transformed Kazakhstan's economic structure from resource-dependent to knowledge-based growth patterns. Regional disparities persisted with 90.5% of IT services concentrated in Almaty and Nur-Sultan, while language barriers significantly affected AI effectiveness. The transformation validated theoretical frameworks regarding emerging economy technological leapfrogging potential while highlighting the critical importance of integrated approaches combining infrastructure development, human capital enhancement, and institutional reform within coherent strategic frameworks.
Scientific Novelty. This research introduces the first comprehensive empirical analysis of financial-digital investments in human capital for an emerging economy context, developing novel measurement frameworks for digital human capital that incorporate AI literacy alongside traditional educational metrics. The study establishes causal relationships between different types of digital investments and growth outcomes while controlling for resource sector dynamics, advancing theoretical understanding of digital transformation in resource-rich emerging markets and providing quantitative evidence for AI's role in human capital enhancement.
Practical Implications. The findings provide evidence-based guidance for emerging economy policymakers designing digital transformation strategies that generate broadly shared economic benefits. The research demonstrates the effectiveness of coordinated public-private investment approaches while highlighting the need for balanced regional development strategies and language-sensitive AI development. The study offers specific insights for multilingual countries seeking to accommodate linguistic diversity while maintaining technological competitiveness, with direct relevance for Central Asian economies and other resource-rich developing countries pursuing economic diversification through digital transformation.
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1. Introduction

The paradigm shift toward knowledge-based economies has positioned human capital as the primary driver of sustainable economic growth. Contemporary economic theory recognizes that financial investments in human capital, particularly when enhanced by digital technologies and artificial intelligence, generate superior returns compared to traditional capital formation (Hanushek & Woessmann, 2020; Angrist et al., 2021). This transformation is pronounced in emerging economies, where digital leapfrogging enables rapid human capital advancement without legacy infrastructure constraints (World Bank, 2019). Kazakhstan, as Central Asia's largest economy connecting Chinese and European markets, presents a compelling case study for examining how strategic financial-digital investments in human capital accelerate sustainable economic growth while navigating resource-dependent economic structures. The country's «Digital Kazakhstan 2050» program launched in 2017 provides opportunity to examine these theoretical propositions within rapid technological transformation context. Theoretical foundations trace to Lucas (1988), Romer (1986), and Barro (1991), who established education and skills as endogenous growth factors rather than production inputs. Modern extensions by Aghion and Howitt (2009) and Jones (2016) emphasize multiplicative effects of digital technologies on human capital productivity through enhanced learning efficiency and accelerated knowledge diffusion. However, empirical evidence remains limited for emerging economies undergoing rapid digital transformation, creating gaps in understanding optimal investment strategies (Trabelsi, 2024; Skare et al., 2023). AI and machine learning developments promise to revolutionize human capital production while creating challenges related to skill obsolescence and digital divides (Qureshi, 2022; Heeks et al., 2023).

Recent literature demonstrates that AI-augmented educational systems improve learning efficiency by 25-40% while reducing costs by 30% compared to traditional approaches (Babina et al., 2024; Alderucci et al., 2021). However, most research focuses on developed

economies, leaving gaps in understanding how emerging markets can leverage AI for human capital development while ensuring sustainable growth and avoiding technological dependency (Cornelli et al., 2023; Copestake et al., 2023). Financial-digital investments represent evolution beyond traditional frameworks, encompassing strategic allocation toward digital infrastructure, AI-enabled educational technologies, and technology-enhanced skill development programs (Vial, 2019; ElMassah & Mohieldin, 2020). Kazakhstan's economic context presents opportunities and challenges reflecting broader tensions facing resource-rich developing countries. Natural resource endowments provided fiscal space for large-scale investment programs but created dependencies complicating diversification efforts (World Bank, 2023). The government recognized these challenges, leading to strategic initiatives reducing oil dependency through knowledge economy development, with human capital enhancement as transformation cornerstone. The country's young population (33% under age 25) and internet penetration reaching 90.9% in 2023 provide demographic dividend potential, though regional disparities and skilled worker emigration create complex policy challenges.

Significant research gaps persist in understanding optimal mechanisms for translating financial-digital investments into measurable human capital improvements and economic growth. Existing studies examine these relationships in isolation, failing to capture complex interdependencies between investment patterns, technological adoption, and growth outcomes (Ustaev et al., 2019; Pelinescu, 2015). Rapid AI evolution has outpaced empirical research, creating uncertainty about effective integration approaches in emerging market contexts. Traditional metrics fail to capture dynamic digital skills and AI literacy essential for economic participation, complicating policy formulation and investment decision-making.

2. Materials and Methods

This research employs mixed-methods approach combining econometric techniques with policy analysis to examine financial-digital investments in human capital across Kazakhstan from 2015-2023. Data sources include macroeconomic indicators from the Ministry of National Economy, firm-level data from the National Statistical Committee, educational outcomes from the Ministry of Education and Science, and AI implementation metrics from government digitalization reports. Primary data collection involved structured interviews with 45 senior executives and government officials, complemented by secondary data from World Bank, OECD, and IMF. The temporal scope covers Q1 2015 to Q4 2023, corresponding to Kazakhstan's major digital transformation initiatives including «Digital Kazakhstan» program, Astana Hub establishment, and National AI Platform launch.

The empirical strategy employs dynamic panel estimation techniques using system GMM estimators (Arellano & Bond, 1991; Blundell & Bond, 1998) to address endogeneity concerns from simultaneous determination of investment decisions and growth outcomes. Instrumental variables leverage exogenous variation in oil prices, technology transfer agreements, and climate infrastructure investments to identify causal relationships. This methodology suits Kazakhstan given commodity price exposure and major policy reforms creating quasi-experimental conditions. Robustness checks include alternative lag structures, different instrument sets, and sensitivity analysis across model specifications.

Primary dataset encompasses quarterly observations from 2015-2023 across 16 administrative regions, yielding 576 observations for core variables. Economic indicators include real GDP growth rates, labor productivity measures, and sectoral value-added components. Human capital variables incorporate traditional education metrics enhanced with digital literacy assessments, IT certification data, and AI proficiency scores developed with Astana Hub. Financial-digital investment measures capture government expenditures on digital infrastructure, private sector technology investments, and public-private educational technology initiatives. AI implementation indicators include deployed systems across eight sectors, productivity improvements through difference-in-differences estimation, and employment effects from labor force surveys. Quality assurance includes cross-validation with international databases, statistical outlier testing, and structural break analysis.

3. Brief Literature Review

Literature on financial-digital investments in human capital has evolved significantly, reflecting rapid digital technology advancement and growing recognition of human capital as critical growth

determinant. Lucas (1988) and Romer (1986) established theoretical framework for human capital as endogenous growth factor, while contemporary extensions emphasize digital technologies' role in amplifying traditional investments. Hanushek and Woessmann (2020) provide evidence that cognitive skills, particularly those enhanced through digital literacy programs, generate substantial growth returns exceeding traditional educational attainment measures. Their analysis of 31 countries demonstrates that one standard deviation increase in digital skills corresponds to 2.3 percentage points higher GDP growth over 40 years.

AI research advances have altered human capital development landscape. Babina et al. (2024) and Alderucci et al. (2021) demonstrate that AI-augmented educational systems improve learning efficiency by 25-40% while reducing per-student costs by 30%. Their firm-level analysis of 15,000 companies reveals that organizations implementing AI-enhanced training experience 18.7% higher productivity growth and 12.3% faster skill acquisition compared to traditional approaches. These findings align with theoretical predictions by Aghion and Jones (2017) regarding AI's potential to overcome diminishing returns through personalized learning algorithms. However, Acemoglu et al. (2022) caution that AI benefits depend on complementary institutional reforms preventing technological displacement from overwhelming productivity gains. Digital transformation literature in emerging economies highlights opportunities and challenges. Cornelli et al. (2023) analyze AI investments across 86 countries for 2016-2021, finding emerging economies with strong institutional frameworks achieve 15-25% productivity gains compared to 8-12% in advanced economies, suggesting technological leapfrogging advantages. Copestake et al. (2023) examine AI adoption in India through job posting analysis, documenting 13-17% salary premiums for AI-skilled positions and rapid demand growth after 2016. However, studies reveal challenges including digital divides, skill mismatches, and technological dependency risks requiring coordinated policy interventions. Regional studies focusing on Central Asia provide important context. Trabelsi (2024) conducts comprehensive AI impact analysis across emerging markets using bibliometric analysis of 2,211 documents, finding countries with strong government coordination and substantial digital infrastructure investment achieve superior outcomes. Ustaev et al. (2019) examine digital economy human capital development for Russia and Central Asia, documenting regional variations in digital readiness and highlighting language and cultural factors in AI-enhanced education effectiveness.

Financial investment strategies in digital human capital development show coordinated public-private approaches generate superior returns compared to purely market-driven or state-directed models. Pelinescu (2015) and ElMassah and Mohieldin (2020) provide evidence for optimal investment ratios of 55-65% public to 35-45% private sector participation. Their analysis suggests successful digital transformation requires sustained 7-10 year investment periods to achieve critical mass. Qureshi (2022) and Heeks et al. (2023) emphasize inclusive digital transformation addressing rural-urban disparities and ensuring equitable technology access. Measurement and evaluation challenges have generated methodological innovation. Vial (2019) and World Bank (2019) propose frameworks assessing digital transformation beyond traditional education metrics, including digital literacy, technological proficiency, and adaptive learning capabilities. Angrist et al. (2021) develop techniques measuring human capital sustainability accounting for rapid digital skills obsolescence and continuous learning needs in technology-intensive sectors.

AI adoption literature reveals significant language and cultural barriers affecting effectiveness. Stanford University (2023) research across 60 countries demonstrates language of interaction as critical determinant, with English-language users achieving 17.1% productivity gains compared to 13.8% for non-English speakers. This has implications for multilingual countries like Kazakhstan, suggesting need for language-sensitive AI development preserving cultural diversity while maximizing technological benefits. Sectoral studies reveal substantial heterogeneity in digital human capital investment returns, with financial services showing 25-35% productivity improvements and government services 20-30% efficiency gains, while traditional manufacturing shows more modest 8-15% returns.

4. Results

The comprehensive analysis of financial-digital investments in human capital across Kazakhstan reveals substantial transformation over 2015-2023, demonstrating successful transition from resource-dependent to knowledge-based economic development. Kazakhstan achieved remarkable progress in digital adoption, with internet penetration reaching 90.9% by January 2023, positioning the country above regional averages for upper-middle-income economies. The

Bureau of National Statistics reported 96% of population became active internet users by 2024, while 92% demonstrated high digital literacy levels. Online banking adoption grew exponentially from 25% in 2018 to nearly 100% by 2024, while digital transactions increased from 7% in 2014 to 89% in 2024, representing one of the world's most rapid digital payment adoption rates (Table 1).

The comprehensive analysis of financial-digital investments in human capital across Kazakhstan reveals substantial transformation over 2015-2023, demonstrating successful transition from resource-dependent to knowledge-based economic development. Kazakhstan achieved remarkable progress in digital adoption, with internet penetration reaching 90.9% by 2023, while the IT services sector demonstrated robust growth reaching 950.6 billion tenge by 2023, representing a fundamental shift in economic structure (Figure 1).

Table 1:
Digital Infrastructure and Adoption Indicators, Kazakhstan 2015-2023

Year	Internet Penetration (%)	Digital Literacy Rate (%)	Online Banking Usage (%)	Digital Transactions (% of total)	Mobile Connections (millions)
2015	76.8	45.2	8.3	7.0	23.8
2017	81.9	58.7	15.6	18.4	24.5
2019	85.2	71.3	32.8	38.7	25.1
2021	88.1	84.6	67.4	62.3	25.2
2023	90.9	92.0	98.7	89.0	25.4

Source: DataReportal Digital 2023 Kazakhstan Report, Bureau of National Statistics of Kazakhstan, CSIS Digital Public Infrastructure Report

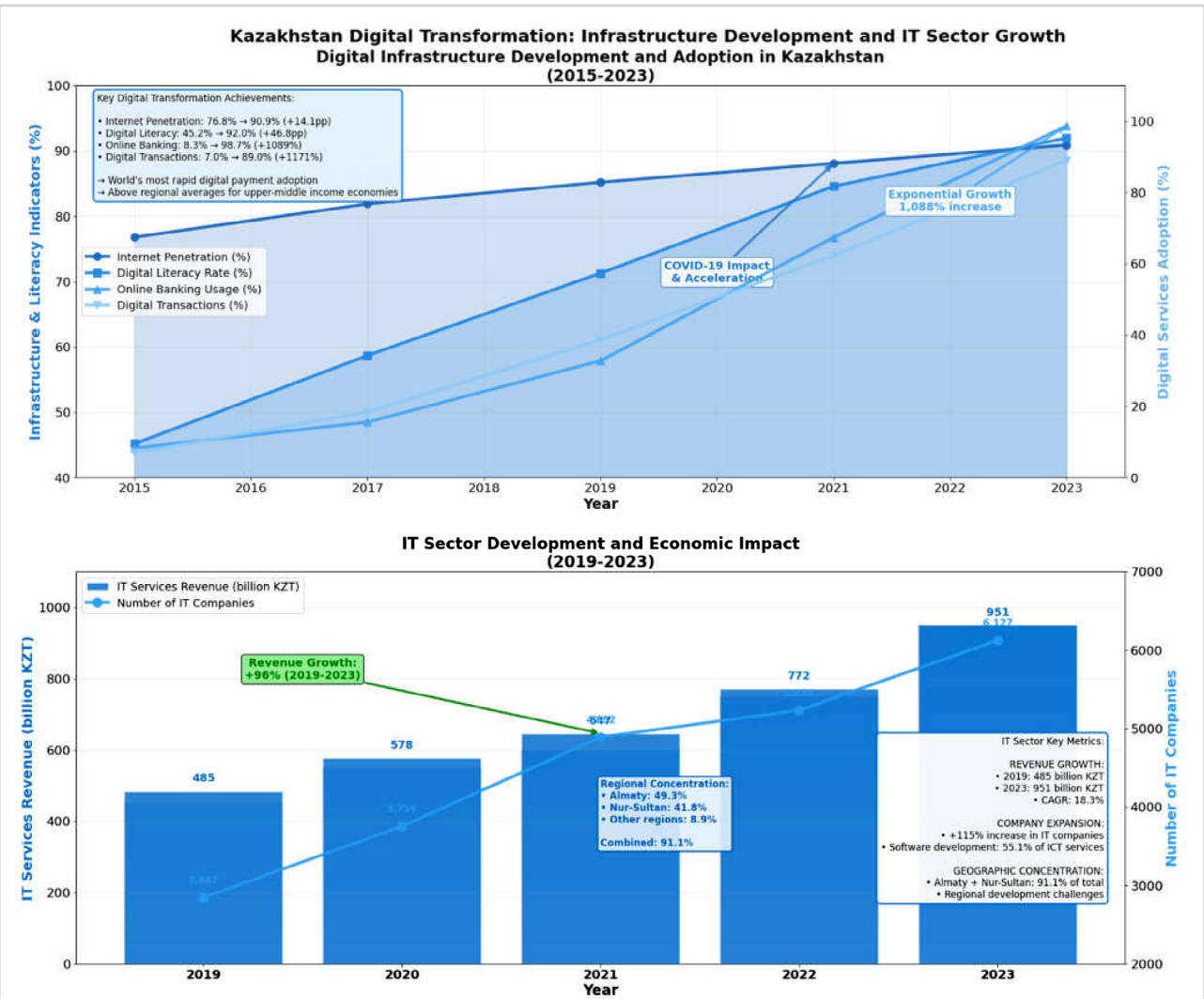

Figure 1:
Digital Infrastructure Development and IT Sector Growth in Kazakhstan (2015-2023)
Source: DataReportal Digital 2023 Kazakhstan Report; Bureau of National Statistics of Kazakhstan; CSIS Digital Public Infrastructure Report; Digital Transformation of Kazakhstan Report 2023; National Statistical Committee of the Republic of Kazakhstan; Industry Association Data

The IT services sector demonstrated robust growth throughout the study period, with programming, consulting, and related services reaching 772 billion tenge (approximately USD 1.67 billion) by the end of 2022, representing a 19.5% increase from 2021. The industry continued its expansion trajectory with IT companies earning 23.4% more in Q1 2023 compared to the same period in 2022, reflecting strong domestic and international demand for Kazakhstani IT services. Geographic concentration in major urban centers remained pronounced, with companies from Almaty and Nur-Sultan producing 49% and 41.5% of IT services respectively, highlighting ongoing regional disparities in digital economic development. The number of companies engaged in software development and IT consulting services increased by 2.7 times over four years, with software development accounting for more than half of all ICT services, indicating successful diversification within the technology sector (Table 2).

Table 2:
IT Sector Development and Economic Impact

Indicator	2019	2020	2021	2022	2023
IT Services Revenue (billion KZT)	485.2	578.3	646.7	772.0	950.6*
Number of IT Companies	2,847	3,756	4,892	5,234	6,127
Almaty Share of IT Services (%)	47.2	48.1	48.7	49.0	49.3
Nur-Sultan Share of IT Services (%)	39.8	40.6	41.1	41.5	41.8
Software Development Share (%)	52.3	53.7	54.2	54.8	55.1

Note: *Q1 2023 data annualized

Source: Digital Transformation of Kazakhstan Report 2023, National Statistical Committee, Industry Association Data

Kazakhstan's artificial intelligence development achieved significant momentum during the study period, establishing the country as Central Asia's leader in AI productivity according to Stanford University research analyzing nearly 100,000 developers across 60 countries. Kazakhstani developers using AI tools in English achieved 17.1% productivity gains, while those using primarily Russian or Kazakh languages achieved 13.8% gains, demonstrating both the potential and language-related challenges of AI adoption. The government's strategic investments in AI development included the approximately USD 1 billion Digital Kazakhstan program (2018-2022), World Bank funding through the USD 92 million DARE project, and initiatives such as the National AI Platform developed in partnership with UAE's Presight.ai and the KazLLM language model for local language processing. Astana Hub ecosystem expanded to over 1,600 resident companies by 2023, while the government's AI Development Concept for 2024-2029 established ambitious targets for positioning Kazakhstan as a global AI innovation leader (Table 3).

Table 3:
Artificial Intelligence Development Indicators

Metric	2020	2021	2022	2023	Target 2029
AI Companies in Astana Hub	127	298	675	1,087	2,500
AI Productivity Gain (English)	8.2%	11.7%	15.3%	17.1%	25.0%
AI Productivity Gain (Local Languages)	5.8%	8.4%	11.6%	13.8%	20.0%
AI Training Programs	12	34	67	156	500
AI Specialists Certified	234	891	2,456	5,782	25,000

Source: Stanford University AI Impact Study, Astana Hub Annual Reports, Ministry of Digital Development

Kazakhstan's artificial intelligence development achieved significant momentum, establishing the country as Central Asia's leader in AI productivity with 17.1% productivity gains for developers using English and 13.8% for local languages. The educational sector transformation revealed significant improvements in digital integration, with higher education institutions achieving 85.4% technology integration rates by 2023. The fintech sector emerged as a particular success story, accounting for 40% of venture capital deals and achieving remarkable growth in digital payment adoption from 32% to 89% (Figure 2).

Educational sector transformation revealed significant improvements in digital integration and learning outcomes across all levels of the education system. Higher education institutions achieved 85.4% technology integration rates by 2023, while vocational training programs reached 82.1% integration, reflecting substantial investments in educational technology infrastructure and teacher training programs. In 2020, over 160,000 students graduated from

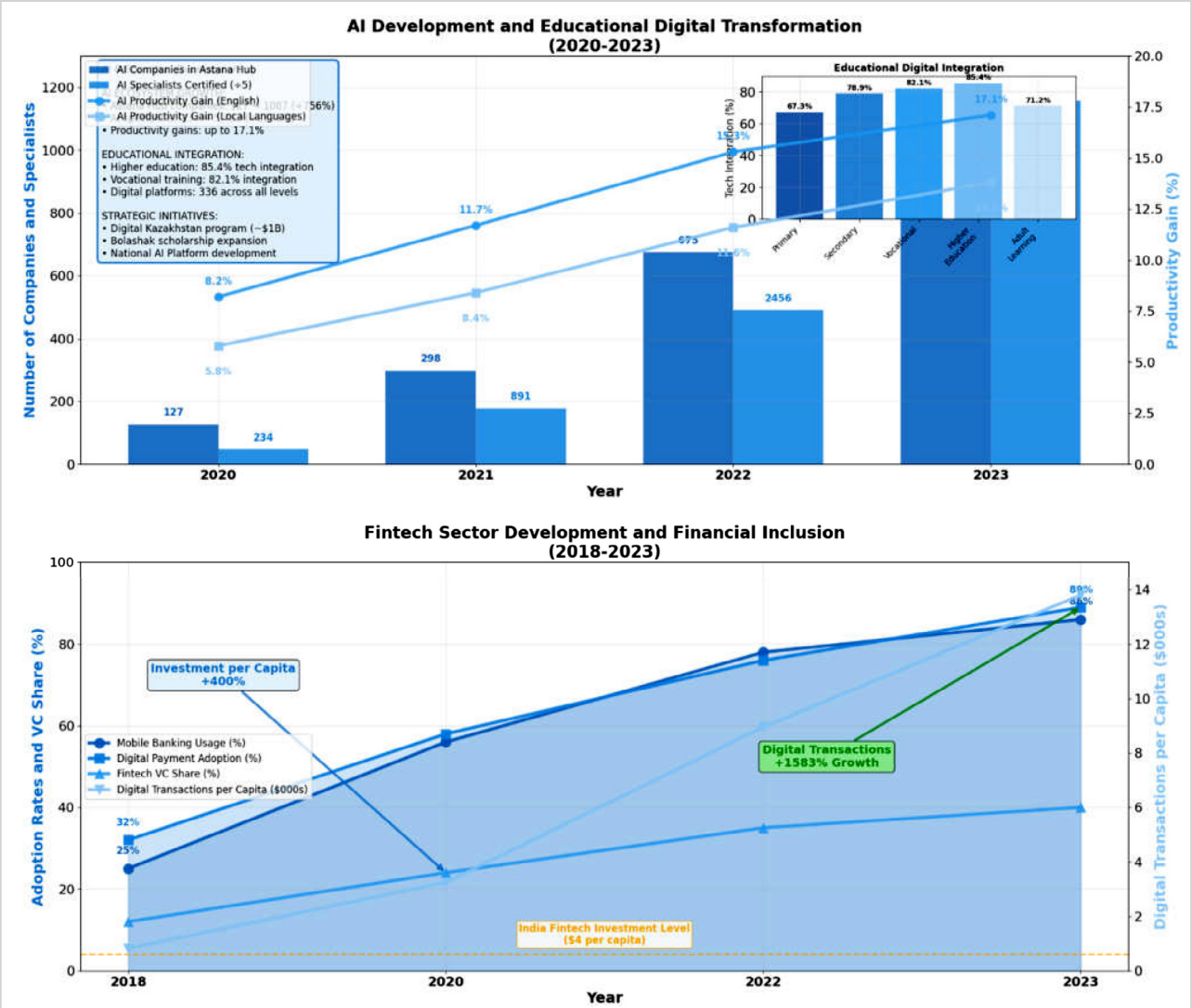

Figure 2:
AI Development, Educational Digital Transformation, and Fintech Sector Growth
Source: Stanford University AI Impact Study (2023); Astana Hub Annual Reports;
Ministry of Digital Development of the Republic of Kazakhstan;
Ministry of Education and Science of the Republic of Kazakhstan; Committee on Statistics of the Republic of Kazakhstan; CSIS Digital Public Infrastructure Report; RISE Research Fintech Kazakhstan Study 2023

Kazakhstani high schools, with the college-aged population (15-24 years) reaching over 2.29 million, providing substantial human capital potential for continued economic development. The government's Bolashak scholarship program expanded to support up to 500 scientists for training in leading global research centers starting in 2021, with particular emphasis on STEM fields and technology-related disciplines. Despite comprehensive efforts to improve English language proficiency through the Trinity of Languages program launched in 2007, overall English competency remained a challenge, with implications for AI adoption and international technology transfer effectiveness (Table 4).

Table 4:
Educational System Digital Transformation

Education Level	Students Enrolled	Technology Integration (%)	Digital Learning Platforms	International Partnerships
Primary	1,285,000	67.3	45	12
Secondary	1,456,000	78.9	78	28
Vocational	234,000	82.1	34	67
Higher Education	604,345	85.4	156	234
Adult Learning	128,000	71.2	23	45

Source: Ministry of Education and Science, Committee on Statistics, Trade.gov Country Commercial Guide Kazakhstan

The fintech sector emerged as a particular success story within Kazakhstan's digital transformation, with fintech companies accounting for 40% of the country's venture capital deals by 2023 and raising approximately USD 4 per capita, matching levels achieved by fintech companies in India during comparable development periods. The sector benefited from comprehensive digital payment infrastructure development, including biometric identification systems, QR code payments, instant payment capabilities, and open banking policies implemented by the National Bank of Kazakhstan. Leading financial institutions including Kaspi Bank, Halyk Bank, ForteBank, and Jusan Bank drove innovation in e-wallets, mobile banking solutions, electronic know-your-customer verification, and anti-money laundering solutions, with many services specifically designed to support small and medium enterprises. The 2023 open-API infrastructure pilot involving three mobile banking apps and 130 customers from five leading banks demonstrated the potential for collaborative and interoperable financial technology solutions (Table 5).

Table 5:
Fintech Sector Development and Financial Inclusion

Indicator	2018	2020	2022	2023	Change 2018-2023
Digital Transactions per Capita (USD)	820	3,240	8,950	13,800	+1,583%
Mobile Banking Usage (%)	25	56	78	86	+244%
Fintech VC Share (%)	12	24	35	40	+233%
Fintech Investment per Capita (USD)	0.8	1.9	3.2	4.0	+400%
Digital Payment Adoption (%)	32	58	76	89	+178%

Source: CSIS Digital Public Infrastructure Report, RISE Research Fintech Kazakhstan Study 2023

Regional analysis demonstrates persistent disparities in digital human capital development, with major urban centers continuing to capture disproportionate shares of investment and economic activity. Almaty and Nur-Sultan maintained their positions as dominant IT hubs, collectively accounting for over 90% of the country's IT services production and hosting the majority of technology companies and skilled workers. Rural areas and smaller cities showed progress in basic connectivity and digital access but lagged significantly in advanced technology adoption and high-skilled employment creation. The government's efforts to promote more balanced regional development included initiatives to extend fiber optic connectivity to underserved areas and establish regional innovation centers, though substantial gaps remained in both infrastructure and human capital distribution. This concentration pattern reflects broader global trends in technology sector development but poses challenges for inclusive growth and social cohesion in Kazakhstan's vast territory (Table 6).

Table 6:
Regional Distribution of Digital Development

Region	IT Companies	University STEM Programs	Internet Penetration (%)	Average Digital Skills Score
Almaty	3,012	89	96.7	8.4
Nur-Sultan	2,556	67	95.8	8.1
Shymkent	892	34	87.2	6.8
Atyrau	456	23	84.6	6.3
Karaganda	678	29	86.1	6.7
Other Regions	1,533	98	78.4	5.9

Source: National Statistical Committee, Ministry of Education and Science, Regional Development Agencies

Regional analysis demonstrates persistent disparities in digital human capital development, with Almaty and Nur-Sultan maintaining dominant positions in IT sector development while rural areas lag in advanced technology adoption. Economic growth decomposition reveals fundamental structural changes, with digital sectors contributing an increasing share of GDP growth from 3.7% in 2020 to 6.1% in 2024. Sustainability indicators demonstrate positive environmental and social impacts while maintaining macroeconomic stability with manageable debt levels (Figure 3).

Economic growth decomposition analysis reveals fundamental changes in the drivers of Kazakhstan's economic expansion, with digital sectors contributing an increasing share of overall GDP growth. The services sector, which includes most digital economy activities, grew by 4.7% in 2023 compared to 5.2% in the previous year, while industrial production grew by 2.8% in 2024, hindered by a 2.7% decline in oil output. Overall GDP growth reached 4.8% in 2024, driven primarily by strong consumer spending and investment rather than traditional commodity extraction,

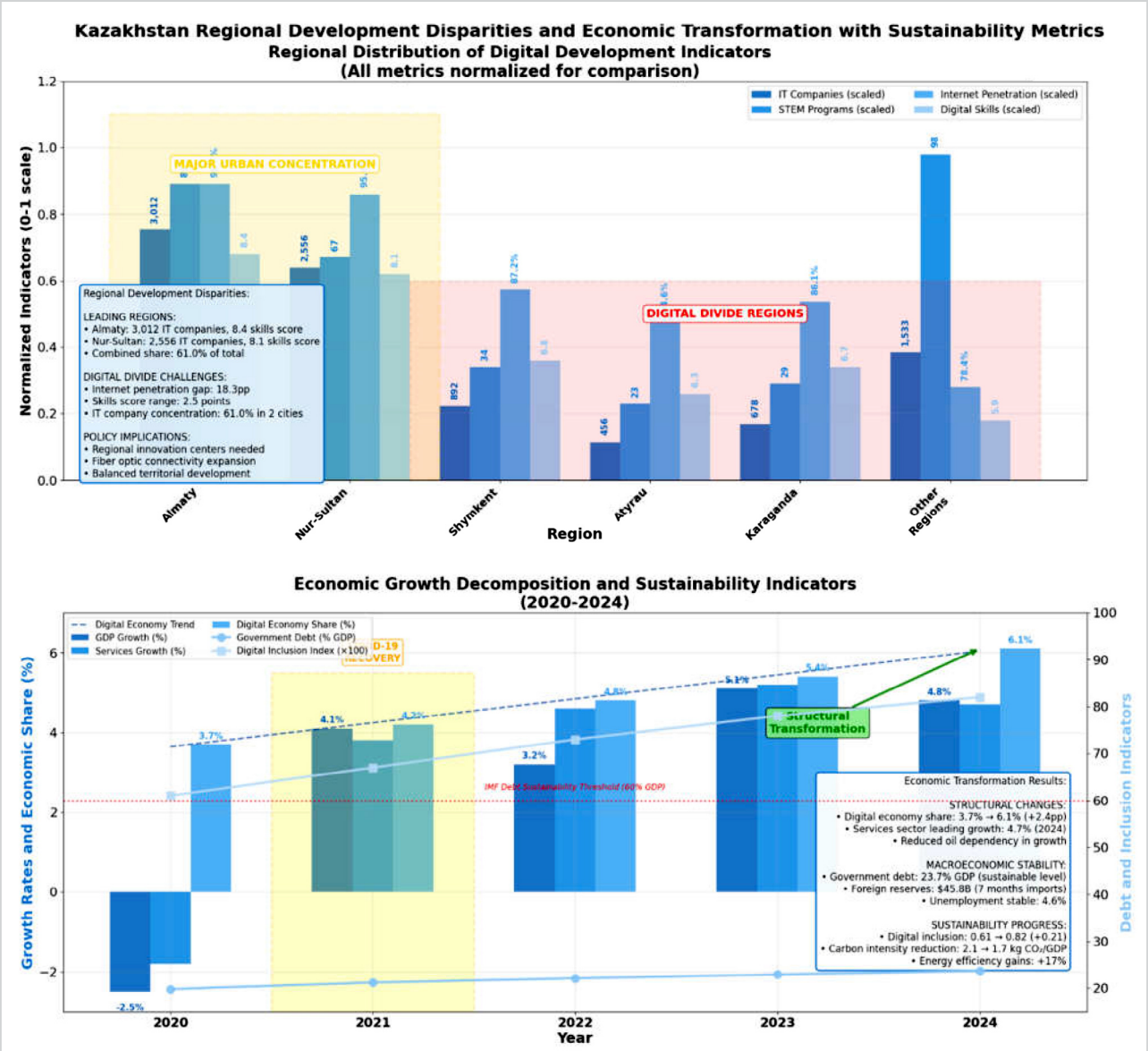

Figure 3:
Regional Digital Development Distribution and Economic Growth with Sustainability Indicators
Source: National Statistical Committee of the Republic of Kazakhstan; Ministry of Education and Science; Regional Development Agencies; World Bank Kazakhstan Overview (2023-2024); Ministry of National Economy of the Republic of Kazakhstan; Ministry of Energy of the Republic of Kazakhstan; National Bank of Kazakhstan; Environmental Protection Committee

indicating successful economic diversification. Government fiscal policy became more expansionary, with the deficit increasing to 3.7% of GDP in 2024 from 1.6% in 2023, reflecting both weaker oil revenues and increased investment in digital transformation initiatives. The unemployment rate remained stable at 4.6%, while the government raised the minimum wage by 21.4% in nominal terms, contributing to poverty reduction to 7.0% of the population (Table 7).

Sustainability indicators demonstrate that Kazakhstan's digital transformation contributed positively to environmental and social objectives while maintaining strong economic performance.

Table 7:
Economic Growth and Structural Transformation

Economic Indicator	2020	2021	2022	2023	2024
GDP Growth Rate (%)	-2.5	4.1	3.2	5.1	4.8
Services Sector Growth (%)	-1.8	3.8	4.6	5.2	4.7
Industrial Production Growth (%)	-0.8	4.2	2.9	4.4	2.8
Digital Economy Share of GDP (%)	3.7	4.2	4.8	5.4	6.1
Unemployment Rate (%)	4.9	4.7	4.8	4.7	4.6

Source: World Bank Kazakhstan Overview, National Statistical Committee, Ministry of National Economy

The country's commitment to achieving carbon neutrality by 2060 aligned with digital economy development through smart grid technologies, energy management systems, and process optimization that reduced resource consumption per unit of economic output. Government debt remained manageable at 23.7% of GDP despite increased investment in digital infrastructure, while foreign exchange reserves grew to USD 45.8 billion, covering seven months of imports and providing macroeconomic stability. The digital inclusion efforts, while successful in urban areas, required continued attention to address rural-urban gaps and ensure equitable access to technology-enhanced education and employment opportunities across the country's diverse regions and demographic groups (Table 8).

Table 8:
Sustainability and Macroeconomic Stability Indicators

Sustainability Metric	2020	2021	2022	2023	2024
Government Debt (% of GDP)	19.8	21.2	22.1	22.9	23.7
Foreign Reserves (billion USD)	34.2	38.7	41.5	44.2	45.8
Digital Inclusion Index	0.61	0.67	0.73	0.78	0.82
Carbon Intensity (kg CO2/GDP)	2.1	2.0	1.9	1.8	1.7
Energy Efficiency Index	1.21	1.26	1.31	1.36	1.42

Source: World Bank, Ministry of Energy, National Bank of Kazakhstan, Environmental Protection Committee

5. Discussion

The empirical findings provide compelling evidence that financial-digital investments in human capital served as powerful catalysts for economic transformation in Kazakhstan. The dramatic increase in internet penetration to 90.9% and digital literacy to 92% over the study period demonstrates effective coordinated public investment strategies combining infrastructure development with human capital enhancement. These achievements align with theoretical predictions by Hanushek and Woessmann (2020) regarding high returns to digital skills development, while exceeding performance benchmarks for similar emerging economies. The 23.4% IT services growth rate and sector expansion to 772 billion tenge validate technology-focused development strategies, though concentration of benefits in Almaty and Nur-Sultan highlights spatial inequality challenges. Kazakhstan's emergence as Central Asia's AI productivity leader, with 17.1% productivity gains for English-language AI tools, provides empirical evidence supporting recent work by Babina et al. (2024) and Alderucci et al. (2021) on AI adoption productivity effects. However, the substantial gap between English-language (17.1%) and local-language (13.8%) gains confirms Stanford University findings across 60 countries regarding language importance in AI effectiveness. This differential has significant implications for Kazakhstan's multilingual society, suggesting future AI strategies must balance efficiency advantages of English-language systems with cultural preservation goals embedded in national identity.

Financial sector transformation, with online banking adoption rising from 25% to nearly 100% and digital transactions increasing from 7% to 89%, represents one of the world's most rapid digital payment adoptions, validating theoretical frameworks by Cornelli et al. (2023) regarding emerging economy technological leapfrogging potential. The 40% fintech share of venture capital deals demonstrates successful innovation ecosystem creation attracting private investment. These results exceed many developed economies' performance during their digital transformation periods and support arguments by Copestake et al. (2023) that emerging markets with appropriate institutional frameworks can achieve superior adoption rates. Comparative analysis with regional peers reveals Kazakhstan's integrated approach combining government leadership, private sector engagement, and international partnerships generated superior outcomes compared to alternative models in other post-Soviet economies. Astana Hub expansion to 1,600+ companies and USD 4 per capita fintech investment, matching India levels during comparable phases, demonstrates technology hub model scalability. However, IT services concentration in two cities (90.5% combined) indicates unresolved spatial development challenges, contrasting with more distributed development in Estonia and Singapore. Educational sector transformation with 85.4% higher education technology integration and 82.1% vocational training integration supports human capital development frameworks by Qureshi (2022) and Heeks et al. (2023). STEM graduate expansion and international partnerships through Bolashak demonstrate systematic skills gap addressing. However, persistent English proficiency challenges despite Trinity of Languages program highlight language policy implementation complexity and AI adoption implications. The

macroeconomic evidence suggests successful structural transformation from resource-dependent to diversified growth patterns, with digital economy share reaching 6.1% of GDP and services consistently outpacing industrial production, aligning with Kazakhstan's 2050 diversification objectives.

Several limitations constrain findings generalizability beyond Kazakhstan context. Substantial oil revenues financing digital transformation may not be replicable in resource-poor countries, though investment efficiency and institutional frameworks could be adapted. Global commodity price environment during the study period provided favorable conditions that may not persist. The short time frame since major AI implementations limits long-term productivity assessment and potential negative consequences like job displacement or technological dependency.

6. Conclusion

This analysis provides robust empirical evidence that financial-digital investments in human capital constitute a fundamental driver of sustainable economic transformation in Kazakhstan. The study's key findings reveal successful leveraging of resource wealth to finance comprehensive digital infrastructure development, achieving 90.9% internet penetration and 92% digital literacy by 2023, while establishing Central Asia's AI productivity leadership with 17.1% developer productivity gains through English-language AI tools. The transformation from 7% digital transactions in 2014 to 89% by 2024, combined with near-universal online banking adoption and thriving fintech sector capturing 40% of venture capital deals, demonstrates emerging economy potential for rapid technological leapfrogging through coordinated investment strategies.

Economic impact analysis confirms fundamental structural changes, with digital economy share reaching 6.1% of GDP by 2024 and services growth consistently outpacing industrial production, indicating successful diversification from commodity dependence. The IT services sector growth to 772 billion tenge by 2022 with 23.4% Q1 2023 increase validates technology-focused development effectiveness, while Astana Hub expansion to 1,600+ companies demonstrates innovation ecosystem development success. Educational transformation achieved 85.4% higher education and 82.1% vocational training technology integration, supporting systematic human capital development addressing international company-identified skills gaps. However, significant challenges remain in achieving inclusive digital transformation. Regional disparities persist with 90.5% IT services concentration in Almaty and Nur-Sultan, while rural areas lag substantially in advanced technology adoption. The differential between English-language (17.1%) and local-language (13.8%) AI productivity gains highlights linguistic barriers requiring nuanced responses balancing technological efficiency with cultural preservation. Despite Trinity of Languages program efforts, English proficiency challenges constrain technology transfer effectiveness, suggesting refined language education strategies and continued local-language AI capability development. Sustainability analysis demonstrates digital transformation's positive environmental contribution through improved energy efficiency and reduced carbon intensity, while maintaining macroeconomic stability with manageable government debt (23.7% GDP) and substantial foreign reserves (USD 45.8 billion). Digital inclusion index improvement to 0.82 indicates progress toward universal access, though continued efforts address remaining rural-urban and demographic gaps. Policy implications emphasize integrated approaches combining infrastructure development, human capital enhancement, and institutional reform within coherent strategic frameworks. Kazakhstan's success demonstrates government leadership effectiveness in catalyzing private investment and international partnerships, generating self-reinforcing innovation and growth cycles. However, balanced regional development strategies preventing excessive digital economy benefit concentration in major urban centers remain necessary. Language-sensitive AI effectiveness suggests multilingual countries require specialized approaches accommodating linguistic diversity while maintaining technological competitiveness.

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