CAREC Think Tank Network Paper

DIGITALIZATION OF INFRASTRUCTURE AND DECARBONIZATION IN CENTRAL ASIA: OPPORTUNITIES AND CHALLENGES

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Definitions

Digitalization refers to using digital technologies to enhance, facilitate, or otherwise change the implementation of socio-economic, political, or business processes.

Digitalization of infrastructure is the process of integrating advanced digital technologies and solutions into various aspects of infrastructure, such as transportation, energy, water, and telecommunications. This involves the use of digital tools and data to optimize and enhance the performance, efficiency, and reliability of infrastructure systems.

Decarbonization relates to activities aimed at reducing CO_2 emissions, with the ultimate goal of the total removal of CO_2 emissions caused by human activities. CO_2 emissions, along with other greenhouse gas (GHG) emissions, are key contributors to the ongoing increases in global temperature, which, in its turn, is the main driver behind climate change.

Decarbonization of infrastructure is defined as the process of reducing or eliminating GHG emissions associated with various types of infrastructure, including energy, transportation, buildings, and industry. The primary goal of the decarbonization of infrastructure is to mitigate the effects of climate change and achieve a more sustainable and low-carbon economy.

Central Asia in this research includes Kazakhstan, Kyrgyz Republic, Tajikistan, Uzbekistan, and Turkmenistan.

Executive summary

Central Asia is set to benefit from the digitalization and decarbonization of infrastructure through its contribution to resource efficiency, environmental sustainability, increased regional cooperation, and the inclusive and resilient development of the region overall.

This research paper investigates the opportunities and challenges of infrastructure digitalization and the promotion of decarbonization in Central Asia. Policymakers, researchers, and stakeholders can use these insights to advance digitalization and decarbonization efforts in Central Asia. The study focuses on identifying the current situation, as well as plans for digital infrastructure that support decarbonization efforts; analysing the enabling environment, including legal frameworks and regulations; assessing the skills and capacity of local actors; examining the impact of digitalization on reducing GHG emissions; and exploring the challenges and barriers through expert surveys.

The current state of digitalization in the Central Asian region appears to be mixed. On the one hand, the region has made significant progress in increasing public access to the Internet and has made notable strides in the provision of e-government and e-services initiatives. On the other hand, the region lags behind in comparison with global advances.

The decarbonization record is uneven too. While all countries in the region have made commitments under the Paris Agreement, the implementation of these commitments is patchy, indicating the need for further efforts. The empirical findings reveal that digitalization in the region has a decreasing impact on decarbonization. The research underscores the importance of renewable energy development, energy efficiency measures, and international cooperation in driving sustainable development in the region.

1. Introduction

Digitalizing and decarbonizing infrastructure are vital for sustainable development. Using digital technologies enhances infrastructure efficiency, resilience, and reduces carbon footprint, fostering economic growth, environmental sustainability, and a better quality of life.

Digitalization supports decarbonization, especially in energy. The International Energy Agency estimates that the implementation of digital technologies in power plants saves about USD80 billion annually between 2016 and 2040, which accounts for 5 percent of global power generation costs (IEA, 2017). The ICT sector contributes 5 percent to 8 percent of global energy consumption, but its impact remains uncertain (Ross & Christie, 2022).

One key benefit is improved energy efficiency. Digitalization revolutionizes energy systems by offering operational data and decentralized energy management. While digitalization offers many advantages for decarbonization, it also poses challenges. The rapid advancement of ICT compared to energy transition may lead to imbalanced structural changes (Fouquet & Hippe, 2022).

Central Asia, with its abundant natural resources and rapid urbanization, faces unique challenges related to energy consumption, transport networks, and water management. By prioritizing the integration of digital technologies and clean energy solutions into infrastructure planning, Central Asian countries can achieve significant gains in resource efficiency, environmental sustainability, and regional cooperation and trade (Samad & Kim, 2022), ultimately promoting inclusive and resilient development.

Digitalization and decarbonization offer Central Asia the opportunity to leapfrog conventional development pathways and adopt innovative, needs-based solutions. Implementing smart grids, using data analytics for efficient resource allocation, and investing in renewable energy can help these countries reduce GHG emissions, enhance energy security, and work toward a low-carbon future. Additionally, fostering regional collaboration and knowledge exchange can magnify the positive impacts of digitalization and decarbonization efforts, contributing to the region's sustainable development goals (ADB, 2022).

Central Asia has experienced significant impacts from the ongoing climate crisis, including droughts, floods, and other climatic phenomena. These effects have posed socio-economic and political challenges for the governments and populations in the region (Sabyrbekov, Overland, & Vakulchuk, 2023). Addressing climate change in Central Asia is now a top priority. The region has already taken various measures to combat this pressing issue and mitigate its impacts on the environment, economies, and societies (see more in Sabyrbekov et al, 2023). However, continued efforts and comprehensive strategies are essential to effectively combat climate change and foster resilience in Central Asia. Decarbonization requires a substantial infrastructure overhaul, new policy approaches, behavioral changes, and meaningful international cooperation.[1]

[1] UNFCCC 2022, Andrea Meza, Deputy Executive Secretary of the United Nations Convention to Combat Desertification (UNCCD): 'Decarbonization cannot wait,' official statement dated 22 November 2022, available at https://unfccc.int/news/decarbonization-cannot-wait)

1.1. Research goals and scope of the report

The main objective of this report is to investigate the main opportunities and challenges of digitalization and decarbonization of infrastructure in Central Asia, with a focus on the following areas:

1. Identification of the current situation, as well as plans for digital infrastructure that promote decarbonization.
2. Analysis of the enabling environment for digitalization and decarbonization, including legal frameworks and regulatory policies.
3. Assessment of the skills and capacities of local actors, including government agencies, private sector firms, and civil society organizations, in terms of the implementation of digital infrastructure and decarbonization projects.
4. Examination of the impact of digitalization on decarbonization in the region—namely, a reduction in GHG emissions.
5. Exploration of the challenges and barriers to digitalization and decarbonization using data from expert surveys.

The report is structured into seven main sections. The first section covers the study's background, objectives, and conceptual framework. Sections two and three offer detailed overviews of the current digitalization and decarbonization in Central Asia. The fourth section delves into the benefits of digitalization, featuring an econometric approach and a detailed methodology description. The fifth part presents findings from the expert survey. The sixth section contains the conclusion, while the seventh section provides recommendations for key stakeholders on how to effectively promote digitalization and decarbonization in the region, considering existing capacities and challenges.

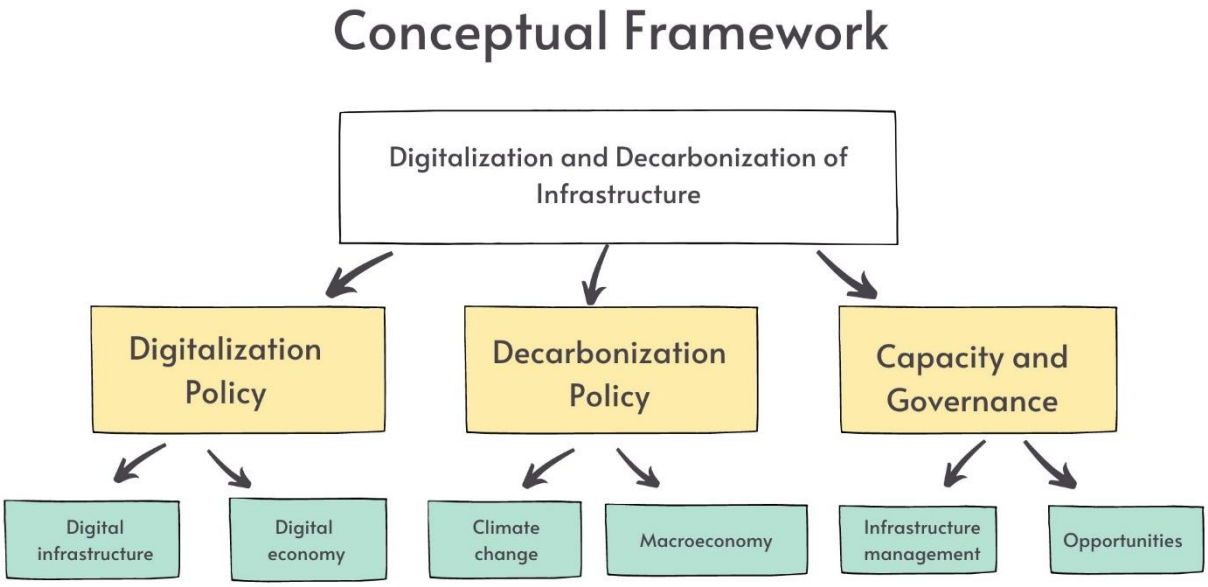
1.2. Conceptual framework and methods

The conceptual framework used here describes the relationship between digitalization and decarbonization of infrastructure by focusing on how digital technologies can reduce carbon emissions and improve efficiency in the built environment. This framework emphasizes the role of governance in implementing these changes.

Digital technologies are employed to optimize resource utilization and reduce waste in infrastructure systems. For instance, smart building technologies utilize sensors and automation to control heating, cooling, and lighting, resulting in lower energy consumption and carbon emissions. Similarly, digital solutions can enhance transportation systems by reducing congestion and encouraging the use of electric or low-carbon vehicles.

Additionally, digitalization facilitates the integration of renewable energy sources into the energy grid, reducing reliance on fossil fuels and promoting a transition to a low-carbon energy system.

Figure 1. Conceptual framework. Adapted from UN Digital Capacity Framework and OECD Decarbonization Framework



The conceptual framework for this study follows established approaches used by the United Nations, such as the Digital Government Capability Assessment and the Decarbonization Framework of the OECD. The three pillars of the conceptual framework are digital policy, decarbonization policy, and capacity and governance (Figure 1).

The research methodology employed three primary methods. First, it involved a desk review of existing literature on digitalization and decarbonization of infrastructure in Central Asia, including an analysis of relevant national strategies and programs. Second, an online survey was conducted among regional and international experts. The survey was distributed through social media platforms and direct requests from researchers and the CAREC Think Tank Network (CTTN) Secretariat. Lastly, the study utilized econometric modelling, applying contemporary methods from the literature and the most up-to-date data on digitalization and decarbonization in the region.

1.3. Digitalization of infrastructure: Improving productivity

Digitalizing infrastructure involves integrating advanced digital technologies into sectors such as transportation, energy, water management, and telecommunications. This enhances performance, efficiency, and reliability, responding to the rapid technological innovation and the demand for sustainable systems. It transforms society, improving public services, enhancing economic growth, and promoting e-commerce (World Bank, 2018; CAREC Institute, 2021c).

A key benefit of digital infrastructure is increased efficiency. Advanced technologies enable automation, leading to quicker decision-making, reduced downtime, increased capacity, and lower operational costs. Real-time monitoring and maintenance also help prevent failures and costly repairs.

Despite the world's growing population and increasing global connections, infrastructure lacks room for innovation. It is estimated that the global infrastructure financing gap will reach nearly USD15 trillion by 2040 (Global Infrastructure Hub, 2018). Infrastructure projects were traditionally built to last, not foreseeing the impact of rapid digitalization (Di Silvestre et al, 2018)

1.4. Decarbonization of infrastructure: A tool for climate policy

Digitalization plays a crucial role in decarbonization efforts across various sectors, specifically in energy sector. According to the International Energy Agency estimates, the adoption of digital technologies in power plants and network infrastructure has the potential to yield annual savings of USD80 billion during the 2016-2040 period, which accounts for 5 percent of total global power generation costs (IEA, 2017).

Digitalization contributes to decarbonization by aligning the energy sector with climate policy objectives, facilitates the integration of renewable energy sources into the grid. According to the IEA estimates, digitalization can reduce losses in solar photovoltaic and wind power from 7 percent to 1.6 percent by 2040 in the European Union, preventing the emission of 30 million tons of CO_2 (IEA, 2017).

Academic research is actively exploring the topics of digitalization and renewable energy, with a particular focus on topics such as smart homes and household solar energy production systems (Kim & Park, 2021). Additionally, Zhang et al (2022) highlight that the positive impact of the digital economy on low-carbon development may be underestimated or overlooked. Digitalization is emerging as a fundamental driver for regional low-carbon development through its contributions to environmental governance, technological innovation, and industrial structure upgrades.

2. Infrastructure and digitalization in Central Asia

Central Asian countries may lack explicit standalone strategies for the digitalization of infrastructure, but they have been proactive in adopting innovative approaches to modernize their infrastructure effectively. The integration of digitalization initiatives with decarbonization strategies has emerged as a method to address these dual priorities in their development agendas. Consequently, the impact of digitalization of infrastructure is evident across all sectors, signifying its far-reaching influence on the region's economic, social, and environmental dimensions. As these countries navigate this dynamic landscape, addressing the interplay between digitalization and decarbonization efforts has become essential, unlocking new opportunities for sustainable and inclusive growth.

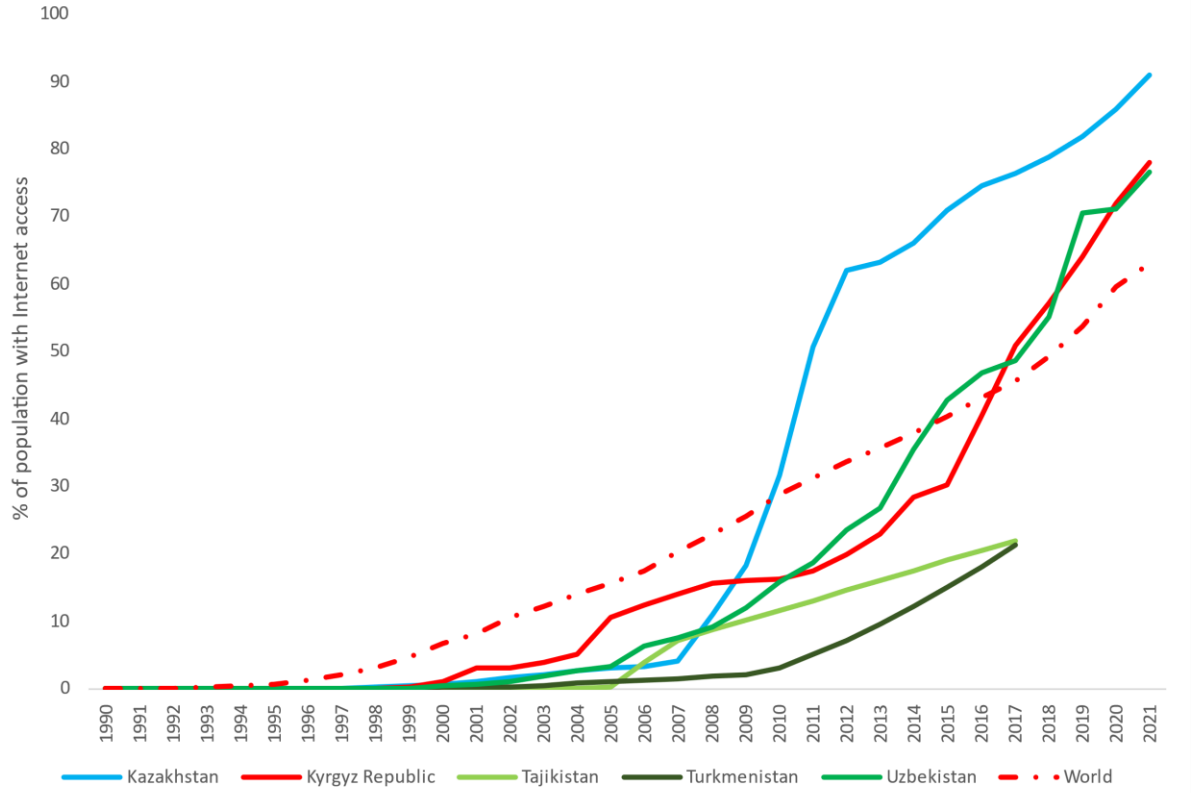
In Central Asia, infrastructure plays a critical role in socio-economic development and political stability, given the region's landlocked nature and aging infrastructure in need of replacement. This existing infrastructure largely reflects Soviet era grand construction initiatives that prioritized rapid industrialization during the Cold War, often without considering environmental consequences or the potential adverse effects of climate change acceleration (Aminjonov, 2018).

The region needs both physical infrastructure updates and the promotion of the digitalization of this physical infrastructure (Di Silvestre et al, 2018; ADB, 2021). Digitalization can have a major role in creating energy efficient infrastructure that can contribute to economic development. In recent years, there has been growing interest in the digitalization of infrastructure as a means of promoting regional development (Kalyuzhnova & Holzhacker, 2021).

Central Asia is currently undergoing a digital transformation of its non-physical infrastructure, making significant progress in digitalization, including the adoption of new technologies, the creation of digital ecosystems and developing digital services. In 2022, CAREC published a report titled ‘Digital CAREC: Analysis of the Regional Digital Gap,’ which examined the digital gap between CAREC economies based on various factors of the digital economy (Razzaq et al, 2022). The authors explored attributes of the digital divide in terms of digital infrastructure, digital payments, e-

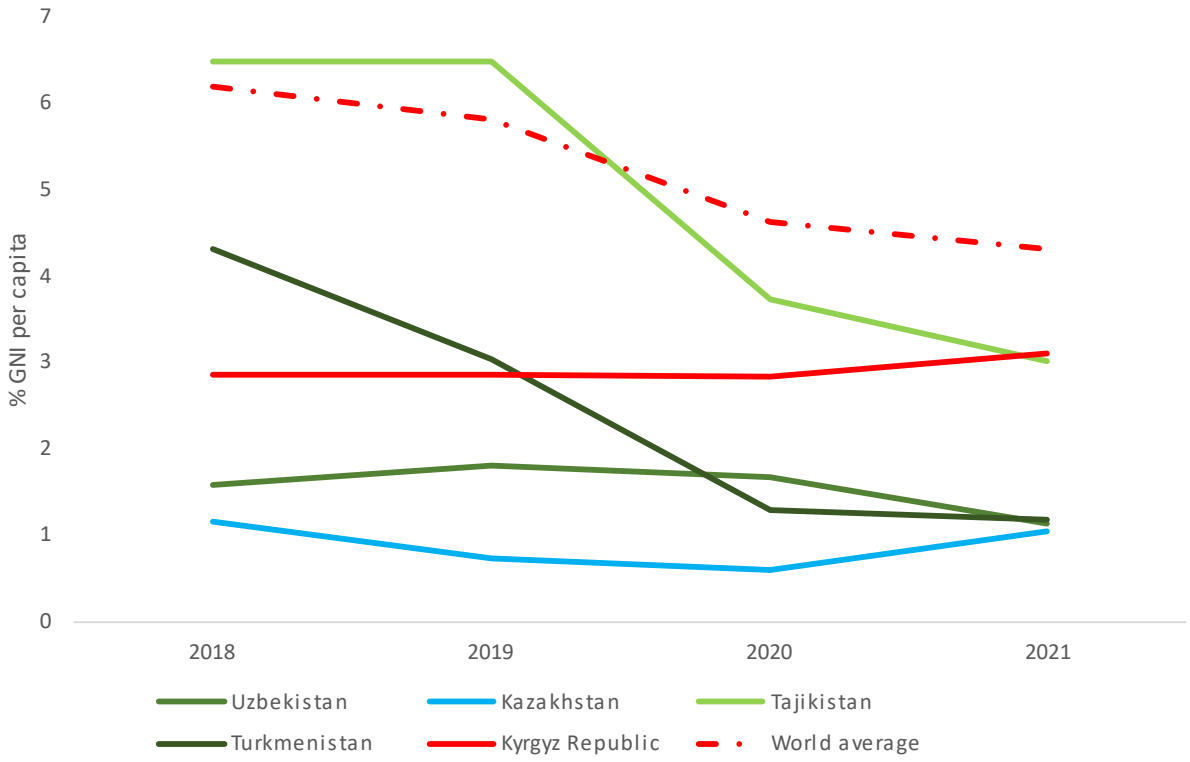
commerce, and Internet access. The results revealed that digital infrastructure and Internet access were the top-performing indicators of digital development in the CAREC region, while digital payments and e-commerce had lower average scores. Azerbaijan (59.9) and Uzbekistan (57.8) had relatively less digitally divided economies compared to Kyrgyz Republic (53.2), Pakistan (50.4), Tajikistan (45.6), and Afghanistan (39.0). Digitalization in the region remains uneven, with Kazakhstan and Tajikistan at opposite ends of the spectrum.

Figure 2. Internet users as a percentage of total population. Source: World Development Indicators, World Bank. Accessed on 05/29/2023. *No data for Tajikistan and Turkmenistan from 2017.



The share of the Central Asian population using the Internet has been rapidly growing since 2010 (Figure 2). The development of broadband infrastructure was a priority for governments, with investments made to expand the fiber optic networks. The development of digital infrastructure was supported by international organizations.

Figure 3. Affordability of ICT services. Mobile data and voice low-consumption basket.[2] Source: ITU Data Hub. Accessed on 05/29/2023



In recent years the cost of ICT services has seen a decline in almost all countries of the region (Figure 3). Tajikistan and Turkmenistan have made remarkable progress in improving affordability and access twice as measured in percentage of GNI per capita.

The outdated physical infrastructure in Central Asia is increasingly posing significant challenges for economic development and regional connectivity. Aging roads, railways, and power grids hinder smooth transportation and the flow of goods and services. National governments recognize the potential of digitalization as a solution to improving efficiency and effectiveness in various sectors. By embracing advancements in technology, such as digital infrastructure and smart systems, Central Asian nations hope to modernize their transportation networks, enhance energy management, and streamline administrative processes. The integration of digital tools and innovative solutions is seen as a key driver in transforming the region's infrastructure and stimulating economic growth.

2.1. Digital economy

Central Asia made progress in developing digital ecosystems, with the establishment of technology parks, innovation centers, and startup incubators in the region. In Kazakhstan, the Astana Hub technology park was established in 2018, providing a platform for startups and tech companies to develop and grow.

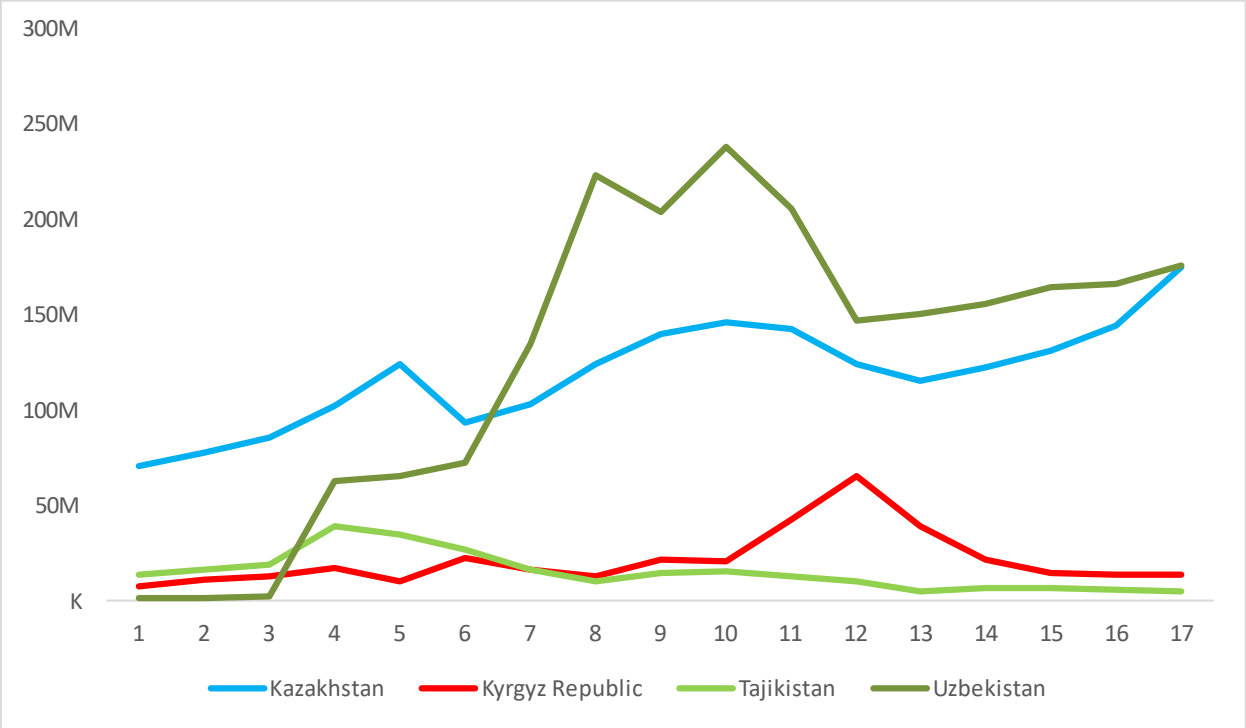
[2] Mobile data and voice low-consumption basket refers to the cheapest plan providing at least 70 minutes of voice, 70 SMS and 2GB of high-speed data over 30-day period from operator with the largest market share in each economy. (Source: ITU: https://www.itu.int/en/ITU-D/Statistics/Dashboards/Pages/IPB.aspx)

Kyrgyz Republic introduced a tax incentive to encourage the development of a sustainable digital ecosystem in the country. The Park of High Technologies offers a simplified taxation regime for Kyrgyz Republic residents to attract high-tech businesses to the country.

Tajikistan has been gradually embracing digitalization, with efforts to improve Internet connectivity and expand access to digital services. The government had shown interest in promoting digitalization to drive economic growth, particularly in the areas of e-government services and digital infrastructure development. However, challenges such as limited Internet penetration, infrastructure deficiencies, and the need for further investment in education and digital skills hindered the rapid development of a robust digital economy.

In Uzbekistan 4G network covers 80 percent of the country's settlements and plans to introduce 5G are in place (USAID DECA, 2022). The telecommunications sector remains dominated by government-owned enterprises and private companies with a large government share; no immediate plans exist to create conditions for a competitive open market. There is a significant urban–rural divide in the adoption of digital payment systems.

Figure 4. ICT service exports (Balance of payments, in current USD). Source: World Development Indicators, World Bank



According to World Bank data (Figure 4), Uzbekistan and Kazakhstan have the highest volumes of exports for ICT service, while Kyrgyz Republic and Tajikistan are lagging. No data on Turkmenistan is available.

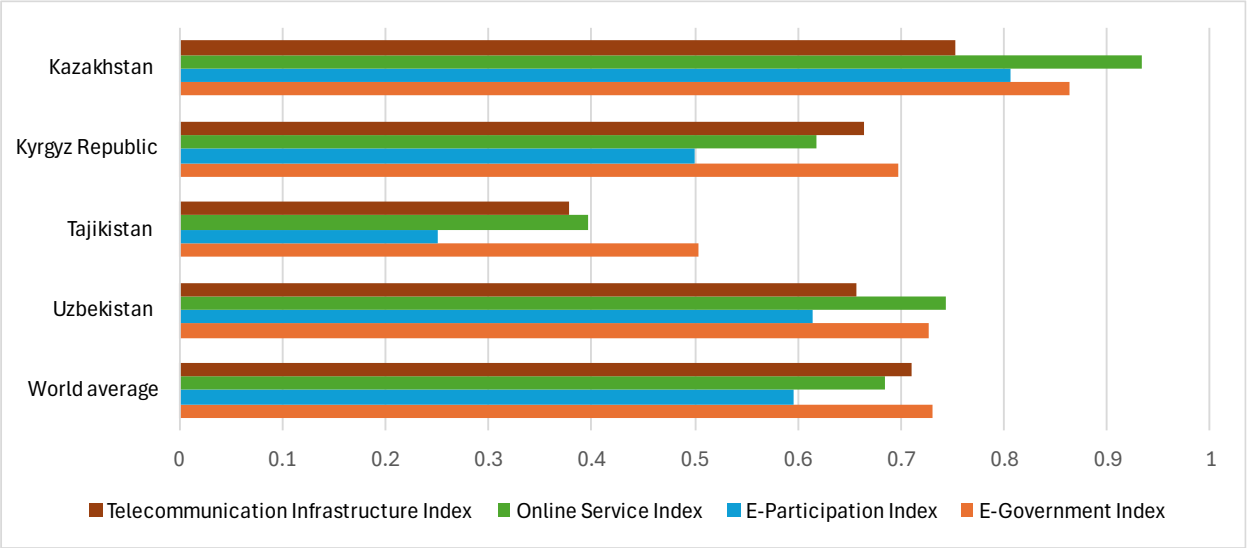
In 2022, conflict in Ukraine drove Russian IT professionals and companies to relocate to Central Asia, potentially boosting the IT sector in the region. Assessing the long-term impact is challenging owing to data limitations.

2.2. Digitalization strategies in the region

Central Asia has made progress in the development of digital ecosystems and the establishment of digital infrastructures, including robust telecommunications networks and reliable Internet connectivity. The progress among the countries of the region is uneven; however, the region overall has witnessed the expansion of e-government services enabling citizens to access information, submit applications, and conduct various administrative tasks online.

All the countries of the region have adopted national strategies on digitalization or government e-services development. Central Asian countries have also made considerable progress in digitalizing sectors such as education, healthcare, and finance. The outbreak of COVID-19 pushed the region to develop online learning platforms in pursuit of uninterrupted education during lockdowns. Moreover, digital banking and e-commerce solutions increased, simplifying financial transactions and promoting financial inclusion (ADB, 2021).

Figure 4. State of e-government in Central Asia in 2022. Source: UN E-governance Knowledgebase. Accessed on 06/01/2022



Digitalization is uneven across the region and sectors (Figure 4). Kazakhstan launched its e-government portal in 2005, and it has since become one of the most advanced e-governments in the region. Kazakhstan introduced online information and booking platforms in a variety of sectors, which has certainly contributed to increased transparency and better access to information for both external stakeholders and the domestic public.

Kyrgyz Republic has made strides in the development of e-government services as well, with the launch of its 'Taza Koom' (transparent society) digital transformation program in 2018. The country has also introduced digital products under its broader tax reform. All taxpayers and the private sector can perform tax-related transactions via online tax accounts.

Tajikistan's Concept for Electronic Government aims to enhance the effectiveness and public service quality of executive authorities through ICT use. It simplifies processes, reduces delivery times and costs, promotes information availability, fosters a unified information exchange system, and encourages Internet and tech use. It outlines tasks like developing information systems, automating

interactions, boosting transparency, ensuring information security, and addressing digital inequality via ICT infrastructure development.

Turkmenistan actively implements its 'Concept for the Development of the Digital Economy in Turkmenistan for 2019-2025' and the 'State Program for the Development of the Digital Economy in Turkmenistan for 2021-2025.' These policies are planned to enhance digital education and healthcare, train skilled personnel, and gradually consolidate digital services on a single platform for government services.

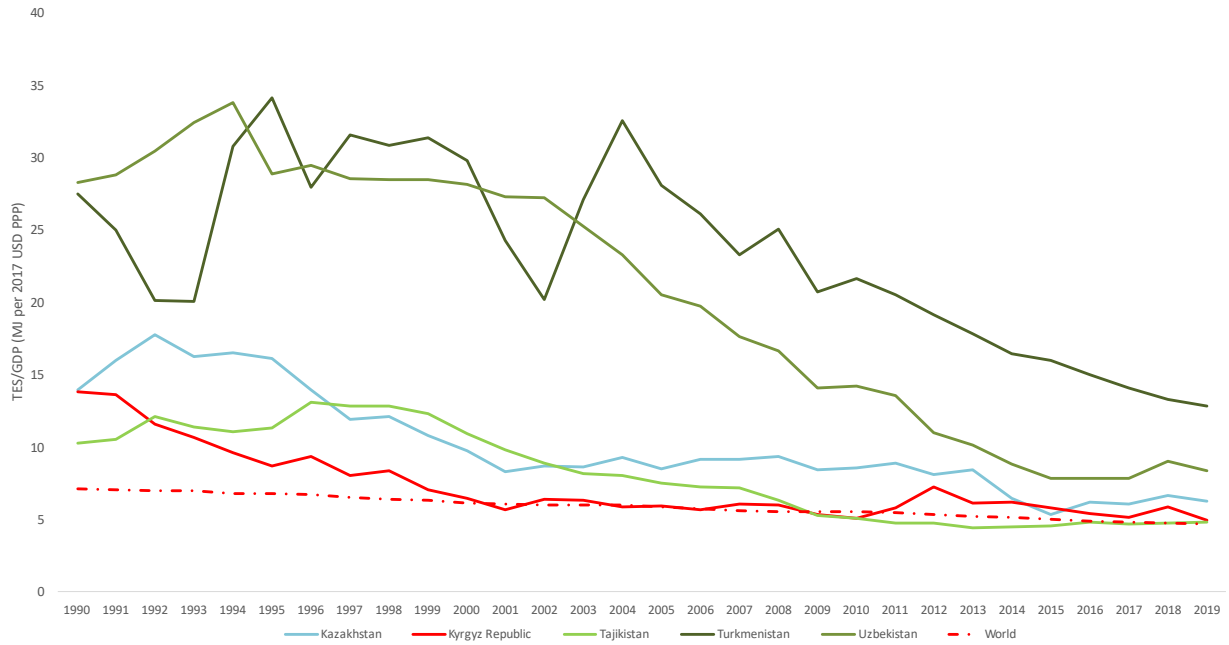
In 2020, the Uzbek government adopted its new strategy—the Digital Uzbekistan 2030 Strategy. The strategy sets out five priority areas: digital infrastructure, e-government, digital economy, the national IT sector, and IT education. The Ministry for the Development of Information Technologies and Communications oversees development and implementation of the unified policy for ICT and e-government; the State Unitary Enterprise E-Government and Digital Economy Project Management Center is responsible for managing e-government projects as a part of the 'Digital Uzbekistan 2030' program, conducting expert reviews of projects and regularly monitoring the progress of projects, and advancing proposals; and UZINFOCOM is a think-tank that develops regulatory and legal frameworks in the sphere of ICT, as well as a unitary company that develops interagency interoperability software with a guarantee of information security.

Overall, Central Asia has made significant progress in the digitalization of its infrastructure, including via the development of digital infrastructure, e-government services, and digital ecosystems. The countries demonstrate a commitment to prioritizing digitalization and e-governance, leading to the establishment of high-tech tax-free zones and improved economic efficiency. Both state and private projects have benefited from these initiatives, incorporating digital tools as an integral component. Progress has been made, but challenges remain. Central Asia has untapped digitalization opportunities for economic growth and social development.

3. Decarbonization of infrastructure in Central Asia

The economies of Central Asia countries are highly carbon intensive and are thus inefficient (Figure 5). This is because of the existing built infrastructure, which is heavily dependent on fossil fuels for energy production and industrial activities (Sabyrbekov & Ukueva, 2019). Of regional GHG emissions, 60 percent to 80 percent are from the energy sector, which was built predominantly in the mid-twentieth century. Kazakhstan is one of the world's largest producers and exporters of oil and gas, and about 80 percent of its domestic energy consumption relies on fossil fuels. Turkmenistan is dependent on natural gas exports as a major source of revenue, while Uzbekistan has significant gas reserves and uses coal for power generation and industrial production. Coal consumption in Kyrgyz Republic and Tajikistan has been steadily growing in the last two decades despite the large hydropower potential (Vakulchuk et al, 2022).

Figure 5. Energy intensity of GDP by Central Asian country. Source: IEA (2021), World Energy Balances



The topic of decarbonization of infrastructure in Central Asia remains rather under-researched, and overall climate change research is limited (Vakulchuk et al, 2022; Sabyrbekov et al, 2023). Yet, it is possible to identify several—mostly policy—publications, which have contributed to a better understanding of the challenges and opportunities for successful decarbonization in the region.

The CAREC Energy Outlook has identified several trends across a range of sectors in the CAREC region, including in Central Asia (ADB, 2022). First, it argues that energy efficiency investments are a potent tool to introduce technology shifts and accelerate decarbonization. Second, consolidation of hydropower potential and development of hydrogen technologies can contribute to climate change mitigation and become a key lever in energy sector decarbonization. Third, decarbonization of the transport sector in landlocked Central Asia remains challenging, while the decarbonization of such transport modes as aviation and maritime remain long-term targets. The fourth trend is universal in that it refers to the need to include all potential stakeholders in the decarbonization process. The fifth trend highlights the difficulty of getting past the fossil stage: the phaseout of coal remains a distant goal in most emerging markets, including those of Central Asia.

3.1. National decarbonization policies

3.1.1. Decarbonizing Kazakhstan: A petrostate with renewable energy ambition

Kazakhstan urgently needs to decarbonize its economy owing to its heavy reliance on fossil fuels and high GHG emissions. Fossil fuels dominate both energy production and consumption, resulting in the fourth-highest carbon intensity globally (Morena, 2023). In 2020, coal represented 69 percent of the energy mix, with a forecasted contribution of 36 percent to 64 percent by 2030.

Despite this, Kazakhstan leads the region in energy efficiency and renewable energy efforts. It is the sole Central Asian country with established carbon pricing mechanisms (ADB, 2022; Overland & Sabyrbekov, 2022). The country aims to increase the share of renewable energy sources to 16 percent to 18 percent by 2030 (Government of Kazakhstan, 2023).

The Green Economy Development Programme (2019-2023) focuses on seven priority sectors: green energy, agriculture, industry, transportation, tourism, waste management, and cities. To support the transition to a green economy, Kazakhstan promotes sustainable financing, fiscal incentives, sustainable public procurement, capacity building, and public awareness. The State Energy Register monitors energy efficiency in the most energy-intensive industries.

Kazakhstan committed to reducing its carbon footprint in its first nationally determined contribution (NDC) in 2016. The unconditional target aims for a 15 percent reduction in GHG emissions by 2030 compared to 1990. The conditional target, contingent on external support and access to low-carbon technology, seeks a 25 percent reduction by 2030 (DIW Econ, 2022). In 2021, the president introduced the Doctrine for Carbon Neutrality by 2060, outlining a framework for low-carbon development and energy transition. With Kazakhstan's resources and ambitious goals, these aspirations hold the potential for global impact.

3.1.2. Decarbonizing Kyrgyz Republic: Growing emissions and ambitious carbon-reduction goals

Kyrgyz Republic's legal and normative framework for its decarbonization strategy consists of various international commitments, national laws, and policy documents, which shape the implementation of decarbonization mechanisms to 'green' the country. The National Development Strategy 2018-2040 envisions a future with 'negative CO_2 emissions' with increasing carbon capture of its natural ecosystems. This is an ambitious goal and an important political commitment for the Kyrgyz government (Kyrgyz Government, 2018).

Kyrgyz Republic's NDC sets out a roadmap for implementing reforms across sectors. Kyrgyz Republic's NDC is set to reduce the country's GHG emissions by 16.63 percent by 2025 and 15.97 percent by 2030 in the usual business case. With sufficient international support, Kyrgyz Republic has pledged 36.61 percent by 2025 and 43.62 percent by 2030 (Government of Kyrgyz Republic, 2021).

Kyrgyz Republic is focused on enhancing its energy sector through renewable energy, improving energy efficiency, expanding the natural gas network, and promoting electric vehicle adoption. These efforts are expected to contribute to a 93 percent reduction in GHG emissions. In agriculture, the NDC emphasizes livestock productivity improvement, organic crop production expansion, optimized manure utilization, and biogas generation. The forestry and land use measures are aimed at increasing forest coverage and establishing perennial plantations. These initiatives underscore Kyrgyz Republic's commitment to addressing climate change challenges. The overall strategy outlines the need for green finance to enhance resilience in various sectors, with the NDC's success hinging on support from external partners and government action (Sabyrbekov et al, 2023).

3.1.3. Decarbonizing Tajikistan: Emphasizing hydropower and climate resilience

Tajikistan is actively advancing its decarbonization efforts through various initiatives. The Asian Development Bank (ADB) and the Tajik Government's Country Partnership Strategy (CPS) for 2021-2025 places a strong emphasis on decarbonization. This strategy aims to enhance livelihoods and reduce carbon emissions through investments in low-carbon renewable energy, resilient infrastructure, and innovative climate-resilient technologies (WBG & ADB, 2021).

Additionally, Tajikistan's collaboration with the World Bank Group includes a Country Partnership Framework (CPF) for 2019-2023, where climate change is a central theme. The CPF recognizes the

urgency of emissions reduction and decarbonization across all sectors, emphasizing low-emission growth opportunities and climate resilience (WBG & ADB, 2021).

Tajikistan has launched a development strategy for the energy sector until 2030, focusing on improving energy security, promoting renewable energy sources, and improving energy efficiency. Tajikistan's participation in the Central Asia–South Asia Electricity Transmission and Trade Project (CASA-1000 Project) aims to transport surplus hydropower to Afghanistan and Pakistan to benefit from increased electricity exports, which will facilitate further development (IEA, 2022).

The Rogun HPP Project, a multibillion dollar effort with a 3.6 GW capacity, is a significant development for Tajikistan's energy needs and regional electricity exports. Although it faced opposition and financial challenges, international support—notably from the World Bank in 2023—is driving its progress. However, the transit through Taliban-controlled Afghanistan poses challenges for Dushanbe.

Tajikistan's NDC targets a reduction of GHG emissions to 60 percent to 70 percent of the 1990 level, with the aim of reaching 50 percent to 60 percent with international support (Government of Tajikistan, 2021). Priority sectors encompass agriculture, energy, forestry and biodiversity, industry and construction, and transport and infrastructure. While the NDC lacks specific GHG emission targets, it emphasizes renewable energy promotion, infrastructure resilience enhancement, energy efficiency improvements, and non-motorized transport promotion. The NDC focuses primarily on adaptation and building climate resilience, particularly in modernizing existing energy infrastructure, including hydropower plants.

3.1.4. Decarbonizing Turkmenistan: An emission hotspot

The government has adopted the National Strategy on Climate Change and the National Strategy for the Development of Renewable Energy until 2030. The green transition in Turkmenistan focuses on the improvement of the existing energy infrastructure, expansion of export capabilities, improvement of energy efficiency, and development of renewable energy. Turkmenistan's NDC prioritizes energy efficiency and promotes the sustainable utilization of natural gas and the use of renewable energy sources. In its second NDC, Turkmenistan commits to reducing its GHG emissions by 20 percent by 2030, relative to the levels recorded in 2010 (Government of Turkmenistan, 2023).

However, these efforts are taking place against a large-scale emissions issue. The west coast of Turkmenistan is home to a significant oil and gas production basin, where satellite data has identified at least 29 different emitters (Irakulis-Loitxate et al, 2022). In 2022 alone both fossil fuel fields in Turkmenistan leaked 4.4 million tons of methane (Carrington, 2023). Unless this issue is addressed very soon, Turkmenistan will struggle to meet its NDC target of a 20 percent reduction of GHG emissions by 2030.

3.1.5. Decarbonizing Uzbekistan: The late starter catching up fast

Uzbekistan announced its ambition to achieve carbon neutrality by 2050, with a strong focus on its low-carbon energy strategy. The country is prioritizing developing power sources with minimal carbon emissions, such as solar, hydro, wind, and nuclear energy.

Uzbekistan is set to reduce its dependence on thermal-power electricity generation to 50 percent by 2030. Thermal sources currently provide for over 80 percent of the country's energy requirements. Uzbekistan's updated NDC outlines ambitious targets of reducing GHG emissions and promoting sustainable development (Government of Uzbekistan, 2021). By 2030, Uzbekistan aims to decrease

GHG emissions per unit of GDP by 35 percent compared to 2010 levels. The NDC includes specific and measurable targets, such as doubling energy efficiency, reducing the carbon intensity of the GDP, increasing the share of renewable energy to 25 percent of total power generation, upgrading industrial infrastructure for enhanced energy efficiency, promoting efficient motor fuels and vehicles, developing electric transport, improving water use efficiency, implementing drip irrigation technologies, achieving land degradation neutrality, and increasing agricultural productivity.

Uzbekistan is also exploring the possibility of implementing a carbon tax mechanism. It strongly emphasizes economic development while focusing on improving energy efficiency and investing in renewable energy production. The NDC reflects the country's commitment to sustainable growth and a transition towards a low-carbon future.

3.2. Regional infrastructure projects and decarbonization initiatives

Recently, the region has witnessed the emergence of regional infrastructure projects that promote digitalization and decarbonization, such as Digital CASA and the Green Investment Principles (GIP) in the Belt and Road Initiative (BRI). If successful, the region will benefit from the implementation of these projects owing to improved connectivity and increased resource efficiency in infrastructure. One of the most recent strong indicators that the region is ready to act is the Regional Strategy for Adaptation to Climate Change in Central Asia, which was adopted at the UN Climate Summit in Dubai in 2023.[3]

Digital CASA

The World Bank has developed Digital CASA (Digital Central Asia–South Asia), a regional program with the aim of reducing the digital divide. This program focuses on improving broadband Internet connectivity and building integrated regional digital infrastructure. Kyrgyz Republic was the first country to join the project. Uzbekistan's Digital CASA–Uzbekistan project, which has an estimated budget of USD300 million, is awaiting approval, while Kazakhstan and Tajikistan are currently negotiating project terms. The Digital CASA projects generally consist of three components: expanding regional and domestic connectivity infrastructure; creating an enabling environment for digital transformation; and promoting digital entrepreneurship. With the support of the World Bank, the Central Asian countries aim to enhance their connectivity capacity, which will foster regional digital connectivity.

Green Investment Principles for the Belt and Road Initiative

China’s Belt and Road Initiative (BRI), one of the largest outbound infrastructure and investment initiatives, can help deliver low-carbon technologies to emerging market and developing economies (EMDEs). The Green Investment Principles (GIP) for the BRI, launched in 2018, call on signatories to set green investment targets, commit to phasing out carbon-intensive investment, and invest in the growing pipeline of green BRI projects. In 2021, the GIP Steering Committee expressed its endorsement of COP26 and restated its dedication to assisting economies along the Belt and Road in creating and executing ambitious climate objectives aligned with the Paris Agreement's goal of achieving net zero emissions. The GIP's Vision 2023 action plan mandates that signatories establish

[3] More on the Regional Strategy is available at https://centralasiaclimateportal.org/unfccc-cop28-central-asian-countries-adopt-regional-strategy-for-adaptation-to-climate-change/

ambitious green investment targets.[4] The China-led green transformation program was launched at the Asia and Pacific High-Level Conference on Belt and Road Cooperation on 23 June 2021. As a part of the BRI, the Initiative for the Belt and Road Partnership on Green Development (also known as the Green Belt) included all five Central Asian republics in the capacity of cooperation partner-countries.

4. Econometric model

Academic studies have prominently featured the intersection of digitalization and renewable energy, including microgrid systems, smart homes, and residential solar power generation systems (Kim & Park, 2021; Bellizio et al, 2022; Morell Dameto et al, 2020; Fouquet & Hippe, 2022; Helm, 2016; CAREC Institute, 2021b; Hao et al, 2023).

Most studies on the impact of digitalization on decarbonization in Central Asia have focused on the transport sector (Kalyuzhnova & Holzhacker, 2021; Komendantova et al, 2022; CAREC Institute, 2021a; CAREC Institute, 2021b). The objective of this section is to empirically investigate the relationship between digitalization and decarbonization in Central Asian countries—specifically Kazakhstan, Kyrgyz Republic, Tajikistan, Turkmenistan, and Uzbekistan—over the period from 1993 to 2017. The research methodology comprises two main components: data collection and empirical strategy.

4.1. Data compilation

This study uses World Development Indicators data from the World Bank, specifically CO_2 emissions as a decarbonization indicator. Logarithmic transformations are applied to ensure consistency. The dataset comprises 125 observations from the five Central Asian countries for 1993 to 2017. See Table 1 for definitions of the variables and descriptive statistics.

Table 1. Definition of variables and descriptive statistics

Variables	Definition	Descriptive Statistics			
		Mean	Max.	Min.	N
CO_2 emissions	*Carbon dioxide (metric tons per capita)*	5.5379	15.3411	0.3210	125
Fixed broadband subscriptions	*Fixed subscriptions (per 100 people) with high-speed access to the public Internet.*	1.1600	14.0657	0.0000	125
Mobile cellular subscriptions	*Subscriptions (per 100 people) for a public mobile telephone service*	43.9961	176.7856	0.0000	125
Digitalization index	*Index is calculated based on principal component analysis*	1.49E-16	3.4839	-0.9875	125
GDP per capita	*GDP per capita, PPP (constant 2017 international USD)*	6652.2530	24862.9700	1134.2310	125
Government expenditure	*General government final consumption expenditure (% of GDP)*	14.2944	37.2613	5.9410	125

Source: Authors' calculations based on World Development Indicators data

[4] See more at the WEF https://www3.weforum.org/docs/WEF_Advancing_the_Green_Development_of_the_Belt_and_Road_Initiative_2022.pdf

The study uses mobile cellular subscriptions and fixed broadband subscriptions as independent variables, selected for their relevance to digitalization based on existing literature (Ramos-Meza et al, 2021; Khan et al, 2022). A digitalization index for the region is constructed using principal component analysis (PCA), allowing the aggregation of these variables into a composite measure. The PCA estimation results are presented in Table 3 in the Appendix.

The control variables for this research are selected based on the study by Ramos-Meza et al (2021). They include real GDP per capita in PPP and general government final consumption expenditure as a percentage of GDP.

4.2. Empirical model

This study employs a panel autoregressive distributed lag model (ARDL) to examine the long-run and short-run connection between digitalization and decarbonization in Central Asia. The ARDL model captures dynamic adjustments, short-term impacts, and cross-sectional variations among countries, enhancing robustness and providing comprehensive insights into the relationship (Khan et al, 2022; Shahbaz et al, 2021; Addai et al, 2023; Fauzel, 2017). The ARDL panel model and panel error correction equations are as follows:

$$LnCO_{2_{i,t}} = \beta_i + \sum_{k=1}^{p-1} \lambda_{ik} LnCO_{2_{i,t-k}} + \sum_{k=0}^{q-1} \sigma_{ik} DI_{i,t-k} + \sum_{k=0}^{q-1} \alpha_{ik} C_{i,t-k} + \varepsilon_{i,t} \quad (1)$$

$$\Delta LnCO_{2_{i,t}} = \beta_i + \sum_{k=1}^{p-1} \lambda_{ik} \Delta LnCO_{2_{i,t-k}} + \sum_{k=0}^{q-1} \sigma_{ik} \Delta DI_{i,t-k} + \sum_{k=0}^{q-1} \alpha_{ik} \Delta C_{i,t-k} + \omega_1 LnCO_{2_{i,t-k}} + \omega_2 DI_{i,t-k} + \omega_3 C_{i,t-k} + \varepsilon_{i,t} \quad (2)$$

where $LnCO_{2_{i,t-k}}$ represents the lagged value of CO_2 emissions per capita for country i at time t-k; $DI_{i,t-k}$ is the lagged values of the digitalization index; $C_{i,t-k}$ represents the lagged value of control variables; $\varepsilon_{i,t}$ represents the error term capturing the unobserved factors.

The existing decarbonization literature offers diverse perspectives on the relationship between digitalization and its impact, giving rise to divergent arguments. Therefore, the expected impact of digitalization on decarbonization can be viewed from two distinct angles. Firstly, digitalization may increase energy consumption and subsequently raise CO_2 emissions. Conversely, it may facilitate sustainable practices, leading to emission reductions. A positive ω_2 suggests that the expansion and use of digital communication technologies in Central Asia are associated with higher carbon emissions per capita, while a negative ω_2 implies that digitalization in Central Asia will lead to lower CO_2 emissions.

4.3. Stationarity and Granger causality analysis

Prior to conducting the ARDL estimation, the stationarity properties of the data were assessed using the Levin–Lin–Chu (LLC) and Im–Pesaran–Shin (IPS) tests. The outcomes of these tests confirm that the variables exhibit stationarity in their first differences and do not require further differencing (Table 4 in Appendix). We also tested the data with Kao and Pedroni cointegration tests (Table 5 in Appendix), which shows that the variables are cointegrated and the ARDL model is appropriate for analysis of the long-run relationship between variables.

Despite the ARDL model's ability to handle endogeneity concerns in panel data by incorporating lagged values of both the dependent and explanatory variables (Fauzel, 2017) we further investigated the relationship between carbon emissions and digitalization variables by conducting a Granger causality test (as presented in Table 2). Although the significance level is at 10 percent, the results indicate a statistically significant one-way relationship from digitalization to decarbonization, meaning that digitalization impacts decarbonization in Central Asia.

Table 2. Pairwise Granger causality tests

	F-Statistic	**Prob.**	**N**
ΔDI does not Granger cause $\Delta LnCO_2$	2.5062	0.0864	110
$\Delta LnCO_2$ does not Granger cause ΔDI	0.6945	0.5016	110

Note: *p < 0.10, ** p < 0.05, *** p < 0.010
Source: Authors' calculations

4.4. Empirical findings

Table 3 displays the ARDL model results for carbon emissions per capita, with model selection based on the Akaike information criterion method. The long-run coefficient of the digitalization index demonstrates a statistically significant negative effect on carbon emissions, suggesting that increased digitalization leads to decreased carbon emissions in Central Asia. In terms of short-term dynamics, the error correction term is both statistically significant and negative, indicating mechanism moving towards long-term equilibrium.

Table 3. Panel ARDL estimates for CO2 emissions per capita

Variable	Coefficient	Std. Error	t-Statistic
	LONG-RUN EQUATION		
Digitalization index$_{i,t}$	-0.0697**	0.0307	-2.2659
Government expenditure$_{i,t}$	0.0919***	0.0315	2.9096
Log GPD per capita$_{i,t}$	0.7647***	0.1591	4.8047
	SHORT-RUN EQUATION		
Error correction term $_{t-1}$	-0.2895***	0.0864	-3.3505
ΔDigitalization index$_{i,t}$	-0.0219	0.0682	-0.3210
ΔDigitalization index$_{i,t-1}$	0.1005	0.0845	1.1905
ΔGovernment expenditure $_{i,t}$	-0.0234**	0.0117	-1.9987
ΔGovernment expenditure $_{i,t-1}$	-0.0200***	0.0049	-4.0866
ΔLog GPD per capita $_{i,t}$	0.0899	0.6712	0.1339
ΔLog GPD per capita $_{i,t-1}$	0.4349	0.7301	0.5957
Constant	-1.9918***	0.5659	-3.5199
Log likelihood	153.2642		
Included observations	105		
Selected model	ARDL(1,2,2,2)		

Note: *p < 0.10, ** p < 0.05, *** p < 0.010
Source: Authors' calculations

Overall findings indicate that digitalization can facilitate decarbonization in the Central Asian region. Adopting digital technologies and practices can offer promising prospects in reducing carbon emissions. These results are consistent with the existing literature, which supports the idea that digitalization contributes to a decrease in carbon dioxide emissions (Shan et al, 2021; Obobisa et al, 2022; Wang et al, 2022; Suki et al, 2022; Gao et al, 2022; Xu et al, 2022).

5. Survey results

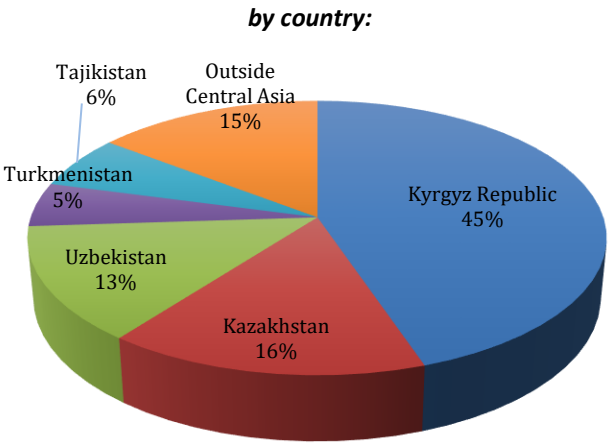
The survey gathered insights from diverse stakeholders involved in Central Asia's digitalization and decarbonization initiatives. The expert questionnaire covered aspects of the region's current status, challenges, opportunities, and policy measures. Conducted online in May 2023 in English and Russian, it employed purposive sampling for sector and regional representation.

The questionnaire had several sections focused on the past, challenges, opportunities, and policy recommendations regarding digitalization and decarbonization in Central Asia. Its goal was to offer a comprehensive understanding of the past context, guide policy recommendations, and pinpoint areas for further research.[5]

It is important to note potential limitations. Using an online platform may introduce selection bias, excluding individuals without Internet access. While the sample size provided insights, it may not fully represent the stakeholders in Central Asia's digitalization and decarbonization efforts. However, purposive sampling aimed for diversity. Despite these limitations, the survey's well-designed methodology aimed to capture crucial data on the current state, challenges, and prospects for the region's digitalization and decarbonization.

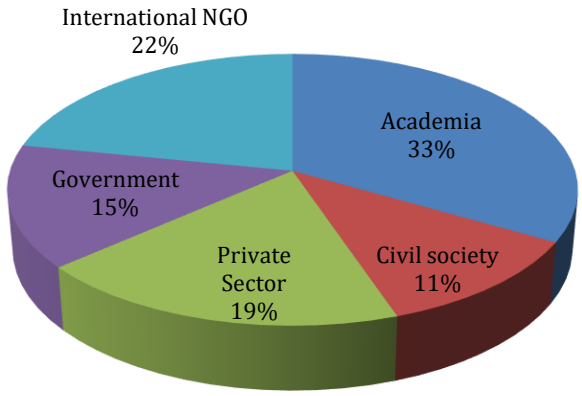
A total of 98 respondents participated in the survey (72 in English and 26 in Russian), offering valuable insights. After screening the data, two observations were removed because of missing values. Respondents were diverse in terms of demographics, representing all five Central Asian countries, with a majority from Kyrgyz Republic. About one-third identified as academics, and 22 percent as representatives of international organizations. The survey also included respondents with varying levels of experience, with roughly half having more than five years of relevant experience (Figure 7).

Figure 7. Distribution of respondents by country, affiliation and experience

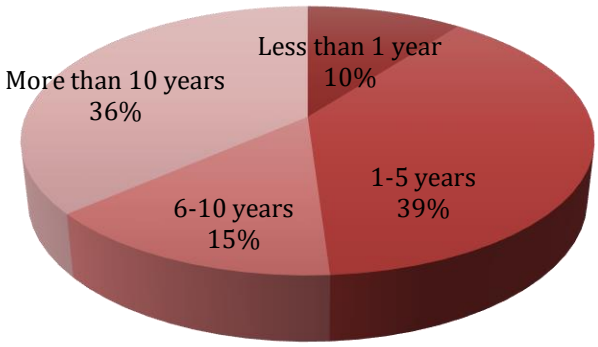


[5] A sample questionnaire is available upon request.

by affiliation:

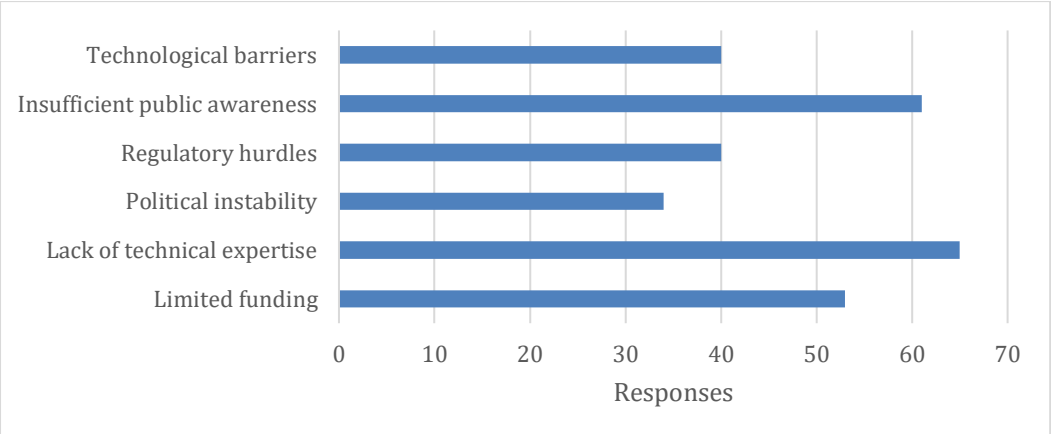


by experience:



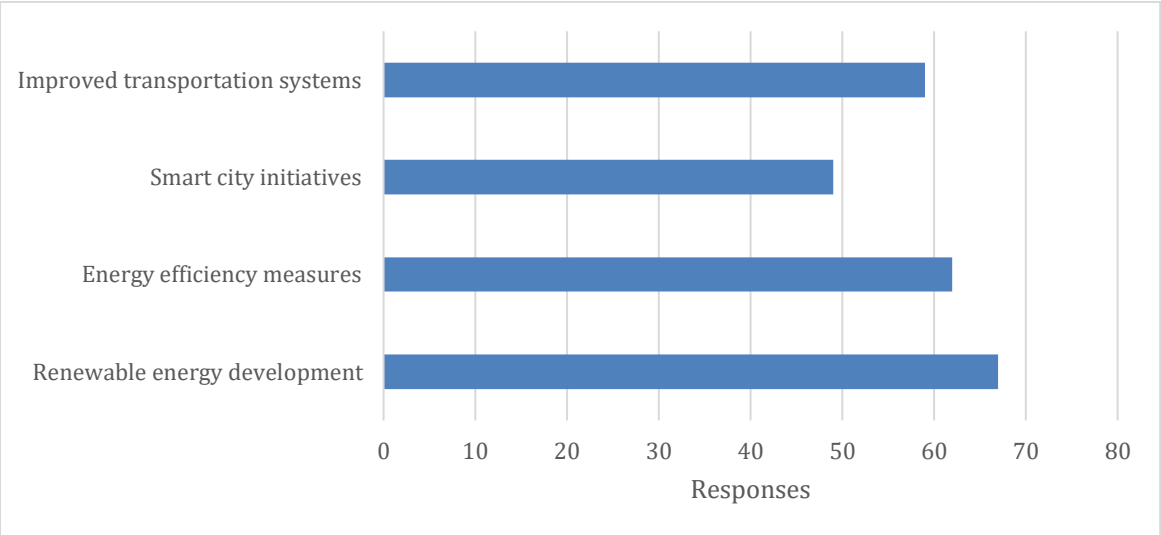
Respondents used a Likert scale to rate their responses from 1 to 10, with 1 representing the lowest level of agreement or proficiency and 10 representing the highest. Most respondents rated the level of digitalization and decarbonization in Central Asia as average or below average, around 4.3 out of 10. When asked about the major barriers to implementing digitalization and decarbonization projects in Central Asia, respondents identified insufficient public awareness, limited funding, and a lack of technical expertise (Figure 8).

Figure 8. Major challenges in the implementation of digitalization and decarbonization projects



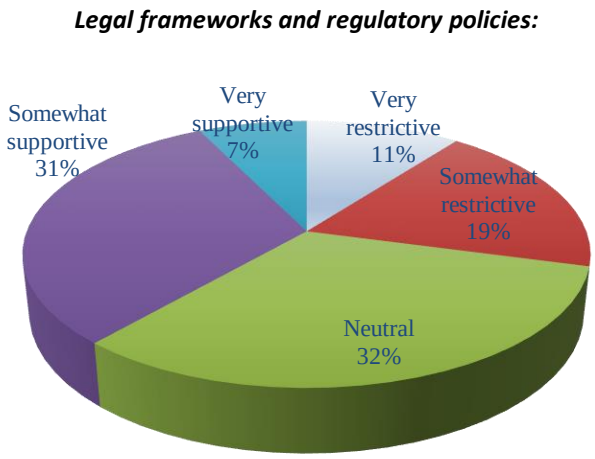
Respondents consider renewable energy development and energy efficiency measures as key for digitalizing infrastructure and promoting decarbonization in Central Asia (Figure 9).

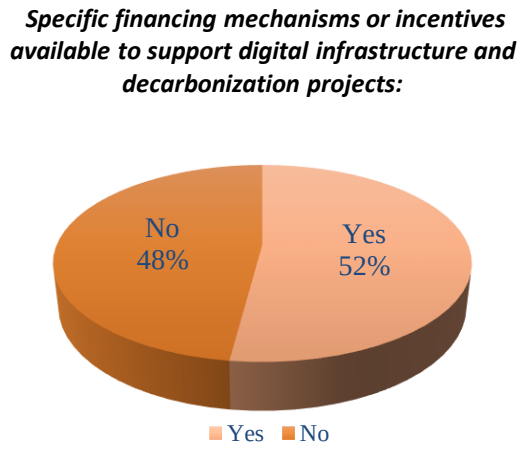
Figure 9. Key opportunities for digitalizing infrastructure and promoting decarbonization



Additionally, the majority of respondents highlight the presence of specific financing mechanisms or incentives to support digital infrastructure and decarbonization projects in Central Asia. However, only a third of them believe the current legal regulatory frameworks concerning digitalization and decarbonization provide adequate support (Figure 10).

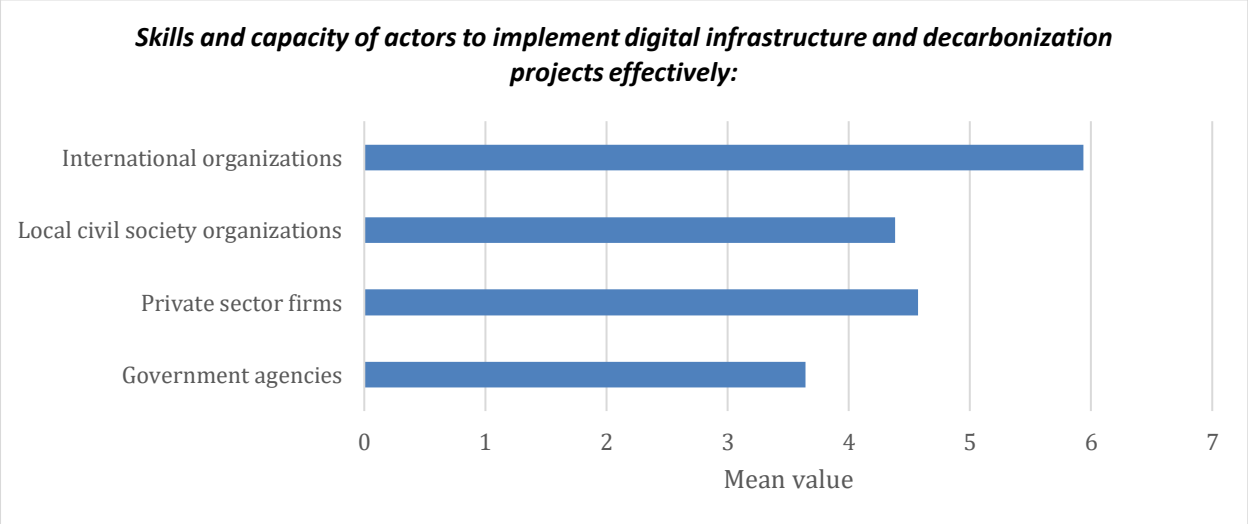
Figure 10. Assessment of legal frameworks for digitalization and decarbonization

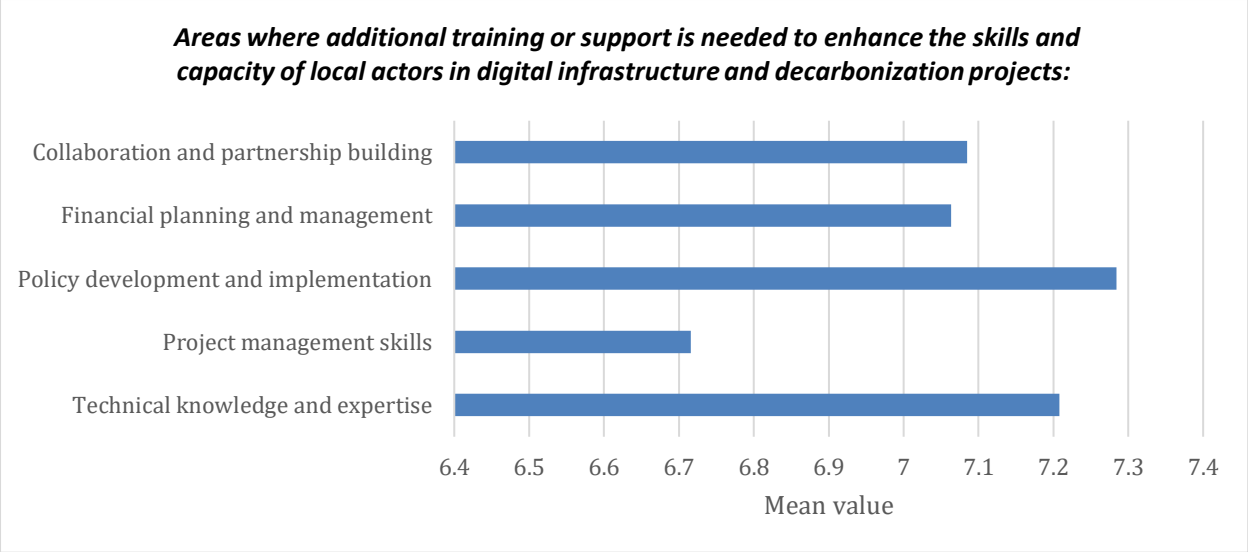




On the questions assessing the skills and abilities of various actors in effectively implementing digitalization and decarbonization projects on a scale of 1 to 10 (where 1 represents a very low level of skills and abilities and 10 represents a very high level), international organizations received the highest rating (Figure 11).

Figure 11. Rating of skills and training

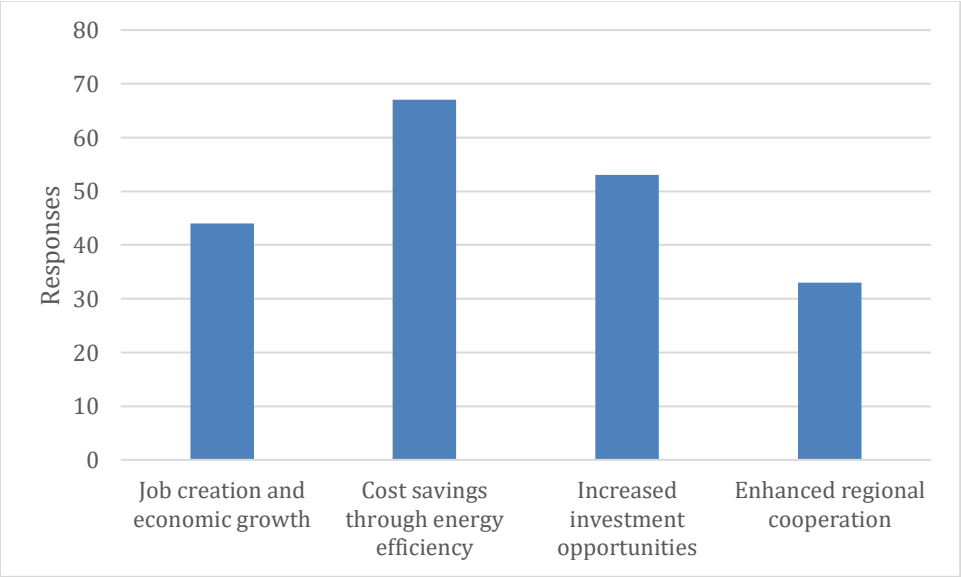




According to the experts, policy development and implementation are considered the most important skills to develop.

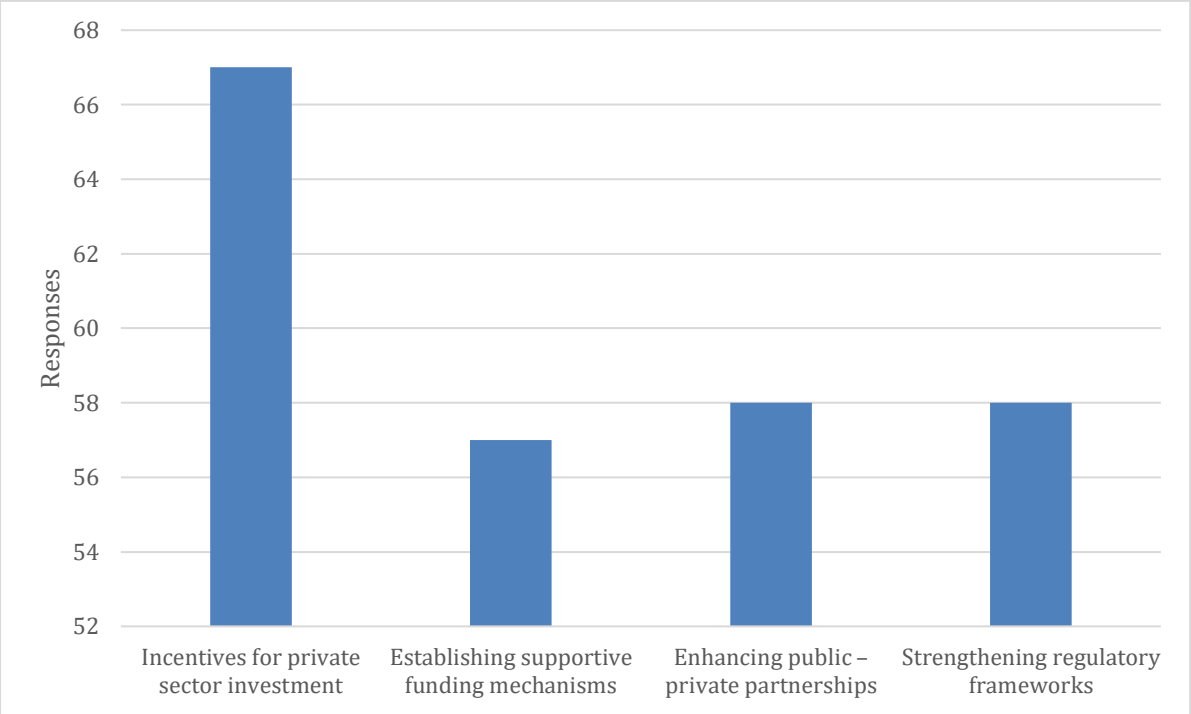
The potential economic benefits of digitalization and decarbonization in Central Asia, as perceived by respondents, can be summarized as follows: cost savings through energy efficiency as the primary benefit, followed by increased investment opportunities (Figure 12).

Figure 12. Perceived economic benefits of digitalizing infrastructure and promoting decarbonization in Central Asia



As per the survey, the main policy measures to promote the digitalization and decarbonization of infrastructure in Central Asia were identified as developing incentives for private sector investment (Figure 13). International cooperation and knowledge-sharing are viewed as highly significant for the successful digitalization and decarbonization with an average rating of 8.7 out of 10 points.

Figure 13. Policy measures for promoting digitalization of infrastructure and decarbonization



In summary, the survey highlights the current state of digitalization and decarbonization efforts in Central Asia. Most respondents perceive progress as average or below average, indicating a need for targeted interventions. Key barriers include a lack of technical expertise and limited public awareness. Opportunities lie in renewable energy and energy efficiency, requiring policy focus and investment.

6. Conclusion

The countries of Central Asia recognize the importance of digitalization and decarbonization in their infrastructure development. These efforts hold numerous advantages, primarily enhancing the efficiency of their economies through resource utilization and productivity. By adopting digital technologies, these nations can streamline processes, optimize resource allocation, and minimize waste, leading to a more sustainable and resource-efficient economy. Digitalization aligns with their international commitments to address climate change.

The region displays a diverse digitalization landscape. Kazakhstan leads the way in embracing digital transformation. Other countries in Central Asia pursue their national digitalization plans, acknowledging the transformative potential of technology. This collective drive toward digital advancement indicates a growing recognition of the benefits it can bring to their societies and economies.

Decarbonization is a shared objective for all countries in Central Asia, albeit with varying levels of prioritization. Each nation acknowledges the need to transition to a low-carbon future, reducing their GHG emissions, and mitigating the impacts of climate change under the Paris Agreement. While the specific focuses on decarbonization may differ, the overall commitment to address environmental concerns is evident across the region.

Regionally important projects that are implemented in cooperation with external partners (for example, Digital CASA, EBRD-funded projects, the Belt and Road Initiative) offer immense potential for introducing low-carbon technologies to Central Asia. These initiatives facilitate collaboration among countries, enabling the sharing of knowledge, resources, and expertise in sustainable development. Leveraging the opportunities presented by these regional projects, Central Asian nations can accelerate their decarbonization efforts and their implementation of low-carbon technologies that promote economic growth. The recent adoption of the Regional Strategy for Adaption to Climate Change in Central Asia at the 2023 United Nations Climate Change Conference in Dubai is an important step towards closer regional cooperation on addressing climate change.

Econometric modelling has provided valuable insights into the relationship between digitalization and decarbonization efforts in Central Asia. The findings reveal that an increase in digitalization leads to a reduction of carbon emissions in the Central Asian region, which means that digitalization can facilitate decarbonization in the Central Asian region.

The survey findings highlight the potential economic benefits of digitalizing infrastructure and promoting decarbonization in Central Asia. Policy measures such as incentives for private sector investment and regulatory strengthening are identified as crucial for promoting digitalization and decarbonization. The survey provides valuable insights for policymakers, researchers, and stakeholders, emphasizing the need for focused interventions to accelerate development, and addressing barriers such as the lack of technical expertise and insufficient public awareness and targeted interventions in sustainable energy development in Central Asia.

7. Policy recommendations for promoting the digitalization and decarbonization of infrastructure in Central Asia

This section provides key recommendations for taking advantage of technological advances in the transition to a low-carbon economy. These recommendations guide Central Asian countries in efforts to improve resource efficiency, reduce GHG emissions, and achieve the sustainable development goals.

1) Establish a policy framework for digitalization and decarbonization. Central Asian countries should develop a comprehensive policy framework that explicitly integrates digitalization and decarbonization goals into their national development plans. This framework should include specific targets, and regulations to encourage investments in digital infrastructure and renewable energy.

2) Enhance cross-border connectivity. Central Asian countries should improve cross-border connectivity and intra- and extra-regional cooperation. Regional cooperation platforms, such as the Central Asia Regional Economic Cooperation (CAREC) Program, should be leveraged to foster collaboration on digitalization and decarbonization initiatives. For example, the CAREC Institute can serve as a platform for knowledge-sharing and capacity building.

3) Promote renewable energy deployment and invest in smart grids and energy storage. Central Asian countries should prioritize the deployment of renewable energy and establish favourable regulatory frameworks to attract private investments in renewable energy projects. Central Asian countries should invest in smart grids and energy storage systems, such as batteries and pumped storage hydropower, which can address the variability of renewable energy generation and its reliability.

4) Foster digital infrastructure development and strengthen digital skills. Efforts should be directed towards expanding digital infrastructure, including broadband connectivity and data centres in

Central Asia. Private investments in high-speed Internet networks should be incentivized, particularly in rural and remote areas. Central Asian countries also should enhance digital skills and entrepreneurship to enhance the region's workforce to participate fully in the digital economy.

5) Develop resilient and sustainable urban infrastructure. Cities in Central Asia should prioritize the development of sustainable urban infrastructure by adopting smart city concepts and technologies, which may include deploying smart transportation systems and incorporating green building standards.

6) Strengthen international partnerships and establish monitoring mechanisms. Central Asian countries should engage in international partnerships and leverage multilateral financing mechanisms to facilitate knowledge exchange and the access to best practices. Also, Central Asian countries should establish robust monitoring and evaluation mechanisms to assess progress, and compare and monitor achievements easily.

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Appendix

Table 3. Principal component weighting factors of the digitalization index

	Component 1	Component 2
Fixed broadband subscriptions (per 100 people)	0.7071	0.7071
Mobile cellular subscriptions (per 100 people)	0.7071	-0.7071
Eigenvalue	1.6490	0.3509

Source: Authors' calculations

Table 4. Panel unit root tests

	LLC		IPS	
	I(0)	I(1)	I(0)	I(1)
Log CO_2	1.0316	-4.7044***	1.2135	-5.6718***
Digitalization index	1.9123	-2.0458**	3.7985	-2.6510***
Log GPD per capita	-0.5717	-3.7952***	1.7204	-6.2570***
Government expenditure (%)	-1.4732*	-4.0510***	-1.5845*	-6.3537***

Note: *p < 0.10, ** p < 0.05, *** p < 0.010

Source: Authors' calculations

Table 5. Cointegration tests

Pedroni residual cointegration test	
Null hypothesis: No cointegration	
Panel PP-Statistic	-2.1150**
Panel ADF-Statistic	-1.9395**
Kao residual cointegration test	
Null hypothesis: No cointegration	
ADF	-2.7815***

Note: *p < 0.10, ** p < 0.05, *** p < 0.010

Source: Authors' calculations

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