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Modelling a Resilient and Integrated Energy System for Central Asia: a Roadmap for Regional Interconnectivity

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I. Introduction

Enhancing regional energy connectivity, integration and coordination of energy infrastructure, resources, and markets across regions, is critical to strengthening energy security and energy system resilience in Central Asia. An integrated and interconnected energy system, that encompasses both the electricity and gas grids, and which is also compatible for the transport and trade of low-carbon hydrogen, can help create a more reliable, affordable and sustainable energy supply. Additionally, energy interconnectivity allows for deep decarbonization as well as a more effective integration of scaled renewable energy capacity into the energy system.

Central Asia is a diverse region rich in natural resources and with vast potential to develop large scale renewable energy projects. However, despite a positive trend and increasing renewable energy capacity, the region still heavily depends on fossil fuels. Coal and natural gas still dominate the regional electricity generation mix and will continue meeting increasing regional energy demand for the foreseeable future. Nevertheless, the forecasted increase in regional electricity demand (Figure 1 below) presents a significant challenge to the region, particularly in light of the strain it places on fossil fuel reserves.

Uzbekistan's significant dependence on gas, accounting for 82 per cent of electricity production, and for 83 per cent of total energy supply in 2022,[1] underscores the urgency for diversification. This is especially the case given that Uzbek natural gas reserves are predicted to be depleted before 2040.[2] Investing in renewable energy sources can therefore provide a sustainable solution to bolster energy security by alleviating natural gas demand whilst also mitigating the environmental impact associated with fossil fuel consumption.

In Kazakhstan, coal constitutes the most significant energy source accounting for 51 per cent of total energy supply and 62 per cent of total electricity generation in 2022.[3] Consequently, given Kazakhstan's ambitious nationally determined contribution (NDC) aiming to achieve a 25 per cent reduction in greenhouse gas (GHG) emissions by 2030 and carbon neutrality by 2060, the Kazakh government aims to reduce coal-based power and heat generation by 50 per cent by 2030.[4][5] Nevertheless, electricity demand is expected to increase by roughly 75 per cent by 2035, meaning that alternative energy sources, notably renewables, must be scaled up to fill the gap.[6] Thus, by effectively scaling renewable energy the region can not only meet its growing energy needs but also reduce its dependence on carbon intensive fossil fuel resources.

Kyrgyzstan and Tajikistan have a significant, still vastly untapped, potential of hydropower resources amounting to 158 and 527 TWh of annual electricity production, respectively.[7] Sustainable long-term management of these water resources is not only a prerequisite for domestic electricity supply but can also be a source of green energy in Uzbekistan and Turkmenistan, as well as across South Asia.

Kazakhstan's rich domestic natural resources, such as its vast uranium reserves, the second largest in the world, and uninhabitable land that provides space for large scale wind and solar power projects could make the country a green and low carbon energy powerhouse and drive the regional energy transition.[8] [9]

Uzbekistan is also endowed with significant uranium reserves, the thirteenth largest in the world, which are planned to be leveraged to build a 2.4 GW nuclear power plant.[10] Additionally, Uzbekistan has approved the construction of 10 solar power plants with a capacity totalling 2.0 GW and has taken preliminary steps to develop an additional 1.0 GW of wind power capacity.[11]

In addition to Turkmenistan's extensive gas resources, amounting to over 7.2 per cent of global proven reserves, which if coupled with carbon capture use and storage (CCUS) can provide low carbon baseload electricity to the

[1] IEA, 2021. International Energy Agency Countries & Regions: Uzbekistan.
Available at: https://www.iea.org/countries/uzbekistan.
[2] bp, 2022. bp Statistical Review 71st Edition, London: bp.
[3] IEA, 2021. International Energy Agency Countries & Regions: Kazakhstan.
Available at: https://www.iea.org/countries/kazakhstan
[4] Kazenergy, 2023. The National Energy Report 2023, Astana: Kazenergy.
[5] IEA, 2022. Kazakhstan 2022 Energy Sector Review, Paris: International Energy Agency.
[6] UNECE, 2023. Sustainable Hydrogen Production Pathways in Eastern Europe, the Caucasus and Central Asia, Geneva: United Nations Publications.
[7] UNECE, 2023. Sustainable Hydrogen Production Pathways in Eastern Europe, the Caucasus and Central Asia, Geneva: United Nations Publications.
[8] IAEA, 2021. Country Nuclear Power Profiles: Kazakhstan. [Online]
Available at: https://www-pub.iaea.org/mtcd/publications/pdf/cnpp-2021/countryprofiles/kazakhstan/Kazakhstan.htm
[9] IEA, 2022. Kazakhstan 2022 Energy Sector Review, Paris: International Energy Agency.
[10] IEA, 2022. Uzbekistan 2022 Energy Policy Overview, Paris: International Energy Agency.
[11] UNECE, 2023. Sustainable Hydrogen Production Pathways in Eastern Europe, the Caucasus and Central Asia, Geneva: United Nations Publications.

region, Turkmenistan's climatic conditions also favor the production of solar power.[12] [13] It is estimated that Turkmenistan's solar potential amounts to 4.4KWh/m, meaning that it would require 0.025 per cent of the country's territory to supply the nation's current electricity demand.[14]

[12] bp, 2022. bp Statistical Review 71st Edition, London: bp.
[13] UNECE, 2023. Sustainable Hydrogen Production Pathways in Eastern Europe, the Caucasus and Central Asia, Geneva: United Nations Publications.
[14] UNECE, 2023. Sustainable Hydrogen Production Pathways in Eastern Europe, the Caucasus and Central Asia, Geneva: United Nations Publications.

II. Benefits of Energy Connectivity for Central Asia

The regional energy system in Central Asia is connected and largely a legacy of Soviet time planning. In the late 1990s, Kazakhstan, Kyrgyzstan, Uzbekistan, Tajikistan, and Turkmenistan signed a multilateral agreement to operate their national energy systems in parallel, leading to the establishment of the Central Asian Power System (CAPS). After Turkmenistan's withdrawal from CAPS in 2003 and Tajikistan's reconnection in June 2024, following its disconnection from Uzbekistan in 2009, the CAPS is now operating with the energy systems of four Central Asian countries. In addition, several initiatives have been launched to expand regional cross-border electricity trade, including the CASA-1000 project, the Turkmenistan-Uzbekistan-Tajikistan-Afghanistan-Pakistan (TUTAP) project, and the Turkmenistan-Afghanistan-Pakistan (TAP) project. [15]

However, despite the existing infrastructure, the current system is not ready for integration of large-scale renewable energy capacity and real-time power trading. The average electricity transmission losses for the region amount to 12.8 per cent, and intra-regional blackouts, such as those of 2022 where a system malfunction induced a blackout in southern Kazakhstan consequently leading to power outages in Kyrgyzstan and Uzbekistan, have threatened regional energy security. Consequently, in order to enhance the reliability of the regional electricity grids, significant investments are required to refurbish existing power lines and install new high-voltage power lines capable of enabling multilateral regional power trading and significant influxes of variable renewable energy.

In addition, the countries in the region are prone to developing their national energy strategies in isolation of each other, despite their energy systems already operating bilaterally with each other. This is problematic as not only do their strategies fail to consider current mutual interdependencies shaping energy discourse, especially in the case of hydropower, where water resources are shared between Kazakhstan, Uzbekistan, Kyrgyzstan and Tajikistan, but also because their strategies can fail to consider the economic and environmental benefits associated with regional energy cooperation and integration.

In 2024, UNECE in cooperation with the Stockholm Environment Institute (SEI), conducted an analysis of economic benefits and possible losses of increased interconnectivity in the region versus self-sufficiency of each of the countries. The results of the modelling described more in detail in the following chapter of this report prove the following:

1. Enabling an integrated energy system capable of multilateral real time power trading would grant each Central Asian country *access to a wider variety and increased share of renewable and low carbon energy sources*, that, if operating in isolation of each other, they would not have access to.

2. This, in turn, is extremely beneficial to the region's *energy security and decarbonization efforts*, not only because it would maximize the consumption of renewable energy, but it would also enable regions facing power shortages or disruptions to receive power in real time from regions with power surpluses. Thus, Central Asia's power system will benefit *from increased flexibility and redundancy planning* which, in turn, will translate to *a more stable and reliable power grid*.

3. An interconnected power system would also lighten the implications to energy security associated with the *intermittent nature of renewable energy, such as wind and solar power, by providing scalable baseload low-carbon power*, to the Central Asian region. Turkmenistan and Kazakhstan's extensive gas resources, if coupled with effective CCUS systems can provide flexible low-carbon baseload power. Kazakhstan and Uzbekistan's uranium resources can soon be leveraged to produce nuclear energy and, if their respective nuclear energy economies develop, will be capable of providing baseload nuclear power to the region in the future. Plans to substantial scale up hydropower capacity in Tajikistan and Kyrgyzstan by 2030 would enable Tajikistan and Kyrgyzstan to provide large quantities of baseload hydropower to the region.

4. An integrated power system could align each *country's water management strategies, balancing national irrigation needs while maximizing hydropower output*.

[15] Power market road map for Central and West Asia: Promoting cross-border electricity connectivity for sustainable development | ESCAP [Online] Available at: https://www.unescap.org/kp/2024/power-market-roadmap-central-and-west-asia-promoting-cross-border-electricity-connectivity

5. Moreover, an interconnected Central Asian power system *would facilitate the development of electricity markets in the region.* A common integrated power market would enable efficient resource allocation and promote market competition, which is currently lacking due to the monopolistic structure of Central Asia's power sectors. In the long run, market integration could lead to lower electricity tariffs for end consumers and boost efficiency in power production, transmission and distribution.

6. Achieving regional energy connectivity can henceforth enhance the availability and affordability of low-carbon energy and accelerate the utilization of renewable energy over time through the economies of scale of large green infrastructure projects, resulting in lower overall system investment and operating costs.

7. It is also expected that interconnectivity will serve as a driver for the Central Asian economic growth and social justice, generating new jobs and improving gender parity.

III. Modelling of Energy Connectivity in Central Asia

The research conducted by UNECE and SEI included a modelling exercise simulating four main scenarios from now through 2050, which are the National Energy Self-sufficiency Scenario, Regional Connectivity Scenario, Full Connectivity Scenario and Unlimited Connectivity Scenario.

The assumptions behind each scenario are shown in the table below:

TABLE 1

Modelling scenarios assumptions

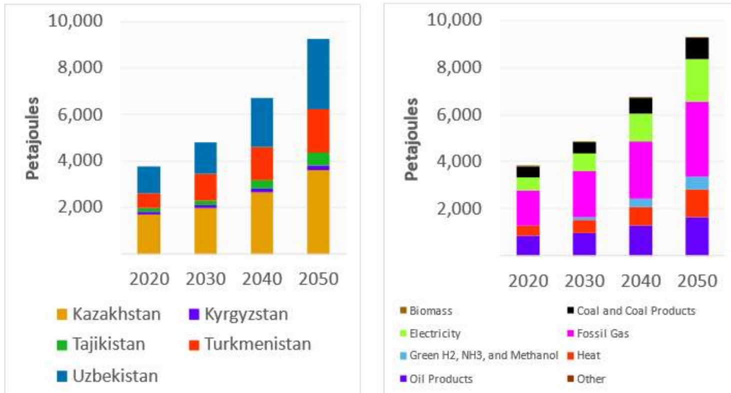
	Trading of Electricity and Hydrogen	Trading of Fossil Fuels Between CA Countries and with Rest of World	Electricity Transmission Capacity
National Energy Self-sufficiency scenario	No	Yes	Limited by current and planned transmission grid
Regional Connectivity Scenario	Yes (only between CA countries)		
Full Connectivity Scenario	Yes (between CA countries and with rest of world)		
Unlimited Connectivity Scenario	Yes (between CA countries and with rest of world)		Unlimited

All the four scenarios are modelled based on:

- Ambitious decarbonization, including the implementation of unconditional NDCs and national clean energy plans;
- 2060 carbon neutrality in Kazakhstan;
- Adoption of national plans for hydropower development, agricultural expansion, and water efficiency;
- High impact of climate change (hot, dry future climate – SSP5-8.5)[16];
- Population projections from UN World Population Prospects;
- GDP projections from IMF (Turkmenistan), World Bank (all other countries);
- The price of CO2 is harmonized across all the countries, in order to avoid carbon leakage inside the region.

[16] SSP5-8.5.15 refers to a specific scenario used in climate change research, particularly in the context of the Shared Socioeconomic Pathways (SSPs) and Representative Concentration Pathways (RCPs) developed by the Intergovernmental Panel on Climate Change (IPCC)

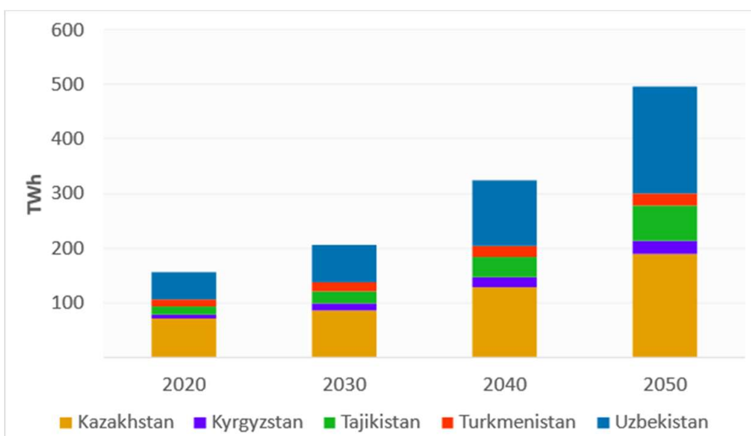
FIGURE 1



Central Asian countries are poised for substantial growth in energy demand, with Tajikistan, Turkmenistan, and Uzbekistan experiencing the highest growth rates. Electricity is expected to play an increasingly important role in the region's energy mix, with its share projected to rise from approximately 15% today to 19% by 2050. Despite this shift, gas and oil will continue to be major contributors to the energy landscape. However, the region is also embracing cleaner energy sources, with green hydrogen, ammonia, and methanol anticipated to account for 6% of total demand by mid-century.

FIGURE 2

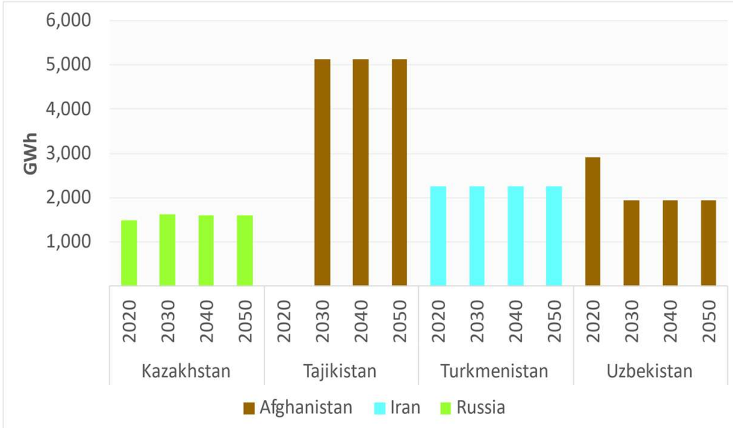
Final Electricity Demand in National Energy Sufficiency Scenario, TWh



The transition to cleaner energy sources is reflected in the dramatic increase in final electricity demand, which is projected to more than triple between 2020 and 2050, underscoring the need for significant infrastructure development and regional cooperation to meet these growing energy needs.

FIGURE 3

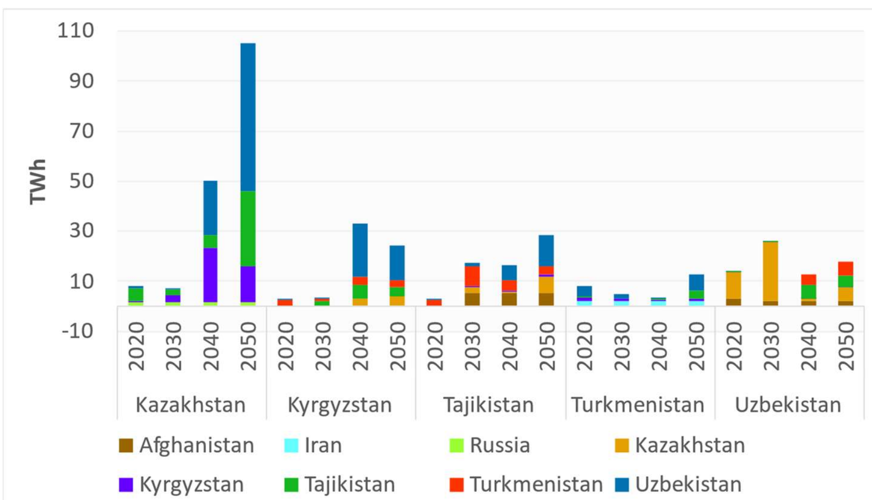
Electricity exports to third countries (Full Connectivity and Unlimited Transmission Scenarios), GWh



In the Full Connectivity and Unlimited Transmission Scenarios for Central Asian energy integration, the potential for increased third-country electricity exports becomes a reality. However, these exports generally represent only a small fraction of total electricity demand across most countries in the region. This suggests that while enhanced connectivity opens up new opportunities for cross-border energy trade, the primary focus remains on meeting domestic energy needs and intra-regional exchanges.

FIGURE 4

Electricity exports to third countries and intra-regional (Unlimited Transmission Scenarios, exports from countries on x-axis to countries in legend), TWh

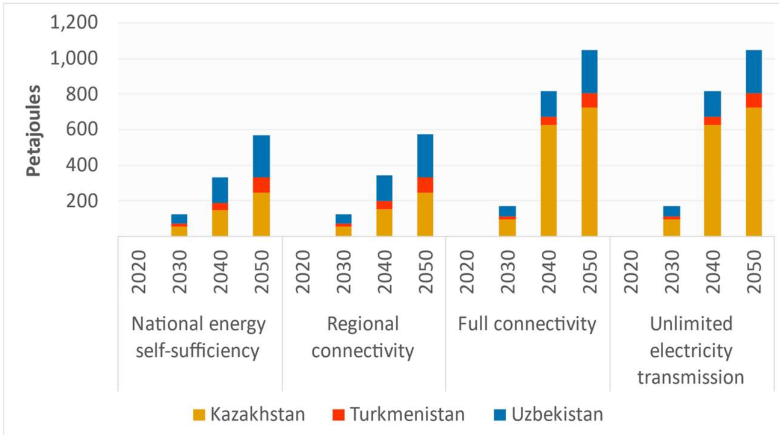


However Tajikistan's situation is quite notable, particularly in the early years of the simulation. Its higher export potential likely stems from its significant hydropower resources, which could be leveraged to supply neighbouring countries, especially during periods of excess generation. This figure highlights the diverse roles different Central Asian countries might play in a more interconnected regional energy system, with some potentially emerging as key exporters while others focus on domestic consumption and regional trade.

Hydrogen production and exports to Europe are projected to drive a significant increase in production in Kazakhstan, particularly in the Full energy connectivity and Unlimited electricity transmission scenarios.

FIGURE 5

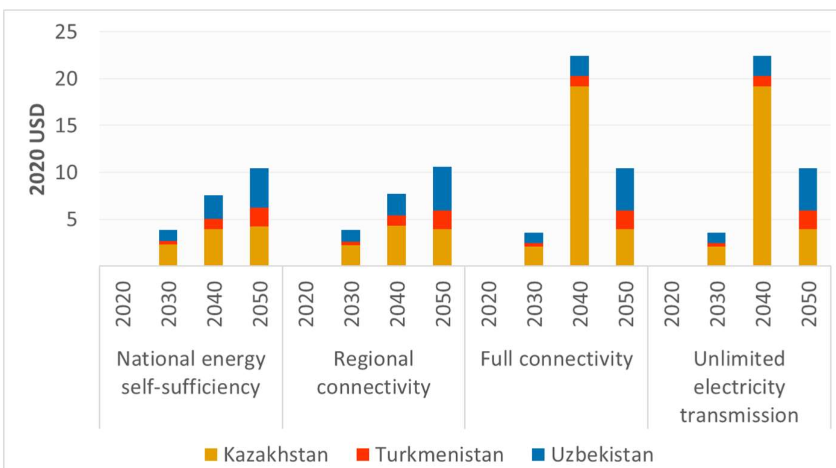
Hydrogen production – scenario comparison



These scenarios highlight the potential for Kazakhstan to become a major player in the emerging hydrogen market. However, despite the country's ambitions for green hydrogen production, steam methane reforming (SMR) with carbon capture and storage (CCS) emerges as the most cost-effective technology across all scenarios (so-called "blue" hydrogen). This suggests that while Kazakhstan has substantial renewable energy potential, particularly in wind and solar resources, the economics of hydrogen production currently favour gas-based methods. The preference for SMR with CCS indicates that Kazakhstan may need to balance its green hydrogen ambitions with practical economic considerations in the near term, potentially focusing on "blue" hydrogen as a transitional solution while developing its renewable hydrogen capabilities.

FIGURE 6

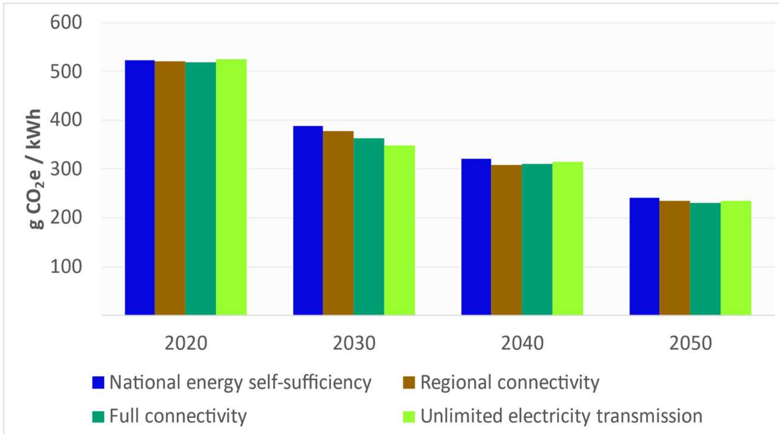
Investment in low-carbon hydrogen production – undiscounted decadal totals, billion USD



Improved regional energy connectivity in Central Asia is projected to have a significant positive impact on greenhouse gas (GHG) emissions from electricity production. Enhanced connectivity scenarios facilitate a greater uptake of renewable energy sources across the region, leading to a lower GHG emissions intensity in electricity generation. The long-term benefits are particularly noteworthy, with models suggesting that in an "Unlimited transmission" scenario, the emissions intensity could be approximately 3% lower compared to a "National energy self-sufficiency" scenario.

FIGURE 7

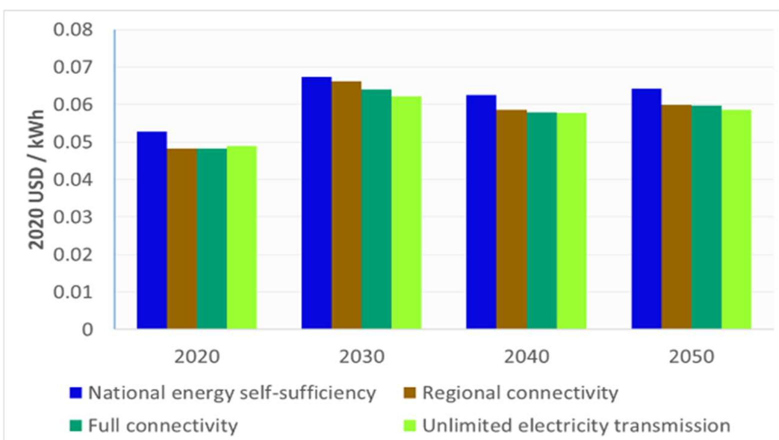
Emissions intensity of electricity production scenario comparison



This underscores the potential of regional energy connectivity to not only improve energy security and efficiency but also to play a crucial role in the region's efforts to mitigate climate change and transition to cleaner energy systems. The annual savings in electricity production costs by 2050 could be 1.4 billion USD if we compare the Unlimited Transmission vs National Energy Self-Sufficiency scenarios.

FIGURE 8

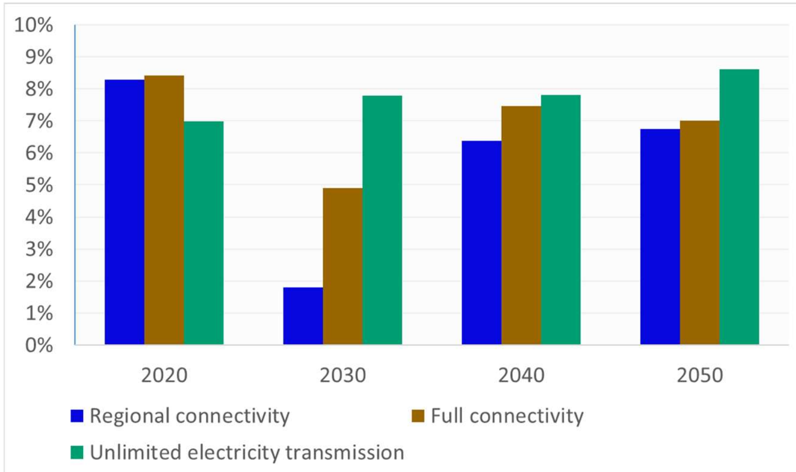
Cost of electricity production – scenario comparison



Regional electricity markets spanning large geographic areas offer numerous benefits that contribute to a more efficient, sustainable, and cost-effective energy system. Improved efficiency is a key advantage, as these interconnected grids can significantly lower power supply costs while enhancing security of supply. Furthermore, expanded connectivity facilitates better integration of renewable energy sources, particularly wind and solar power, allowing for a more cost-efficient deployment of these technologies. The ability to share resources across regions is another crucial benefit, as it enables better utilization of generation assets and potentially reduces the need for redundant capacity. Enhanced competition is also fostered in larger, more connected markets, which can lead to lower electricity prices for final consumers.

FIGURE 9

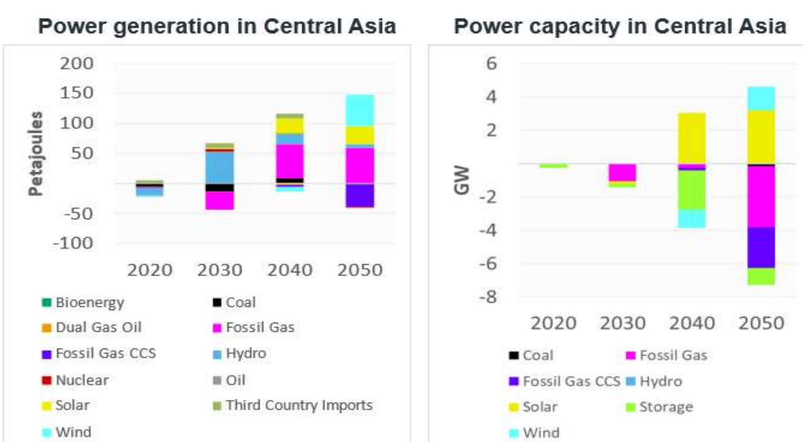
Savings in annualized costs of electricity production (generation, storage and transmission) relative to National Self Sufficiency Scenario



While decarbonization efforts may modestly increase electricity production costs (Figure 8) in the long-term perspective, it's important to note that greater connectivity consistently leads to lower electricity production costs, which the comparison of scenarios demonstrates on Figure 9. This underscores the value of regional energy connectivity in supporting both economic and environmental goals in the transition to cleaner energy systems.

FIGURE 10

Comparison of power generation and power capacity (results from Unlimited Connectivity Scenario minus results from National Energy Self-sufficiency Scenario)

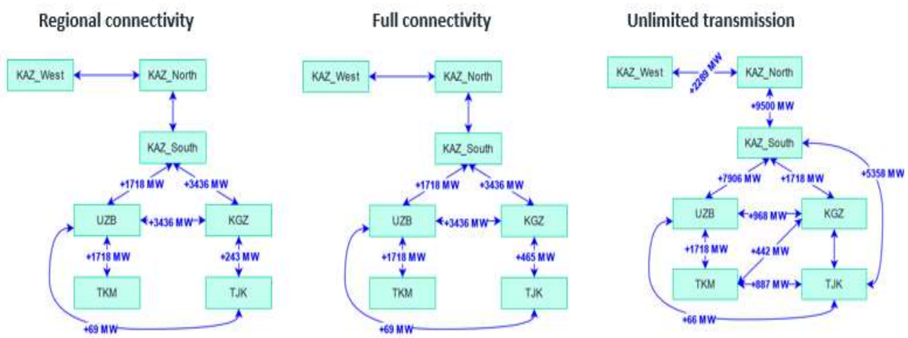


This figure proves how improved connectivity drives adoption of low-cost clean power sources (i.e. wind, solar, hydro) and pushes away from fossil fuels like gas and coal. It excludes battery storage and third country imports in power capacity simulation. The power generation chart shows the additional electricity requirements are met with hydropower in the short-term and gas, wind, and solar power in the longer term. The use of hydropower in the short-term reflects spare/slack hydro capacity in the short-term. In the long-term, this situation changes due to climate change and the fact that national electricity demands rise significantly as per Unlimited Connectivity Scenario (due to hydrogen, ammonia and electricity exports to third countries). The reduction in gas generation in the short-term reflects the substitution of more expensive gas by low-cost hydro power; this substitution is possible due to intra-regional connectivity.

In the power capacity chart, the reductions in storage and gas show how enhanced transmission allows countries to effectively share reserve capacity, in comparison with the National Self-Sufficiency Scenario, where each country has to build its own, separate reserves, leading to some overbuilding of reserves across the region as a whole.

FIGURE 11

Candidate electricity transmission capacity added by 2050 – scenario comparison[17]



The most ambitious scenario for regional energy integration unlocks significant potential for electricity trade within Kazakhstan and strengthens connections across the Unified Energy System of Central Asia (UES CA). Similar outcomes are observed in the Regional Connectivity and Full Connectivity Scenarios, which share options for candidate transmission lines. However, the Unlimited Transmission Scenario stands out, proposing substantially higher economically efficient (cost-minimizing) additions to transmission infrastructure. For example, the Unified Power System of Kazakhstan could be advanced by adding another 2289 MW to its West-North connection, and 9500 MW to its North-South connection. The transmission capacity of Kazakhstan-Uzbekistan connection could also be raised from 1718 MW to a significant 7906 MW. These efficiency improvements in Kazakhstan's national transmission capacity could help promote the country's energy trade both domestically and regionally. As in the regional transmission capacity, the Unlimited Scenario unlocks potential for electricity trade across UES CA by enhancing the connectivity between more countries in the area. Precisely, Turkmenistan could enlarge its regional connectivity cooperation through 442 MW and 887 MW transmission lines connecting to Kyrgyzstan and Tajikistan. Tajikistan could connect with Kazakhstan with additional transmission capacity of 5358 MW.

Such extensive grid expansion would facilitate greater power trading opportunities, potentially leading to more efficient resource utilization, improved integration of renewable energy sources, and enhanced energy security across the region. It should be noted that the model calculated approximately the economically efficient (cost-minimizing) amounts of transmission capacity given the available input data on average costs of the currently planned transmission projects in the region. The model considers the projected generation capacity, resource potentials, and the projections of electricity demand, but does not include an analysis of line siting or the political requirements for routing lines through intermediate countries (e.g., for connections between Tajikistan and Kazakhstan). While those approximations may affect the feasibility of the modelled outcomes, this figure can serve as a starting point to more advanced planning of interconnectivity projects.

[17] The graphic only shows the construction of additional transmission capacities. The renovation needs for the existing transmission infrastructure are not reflected.

FIGURE 12

Electricity trade (possible physical flows) in Full Connectivity Scenario in 2030, TWh

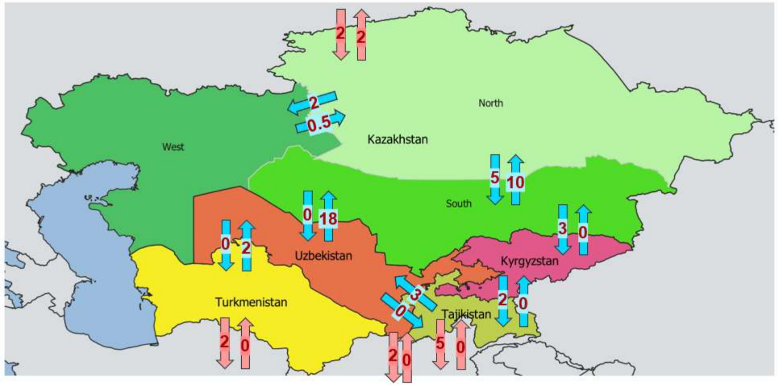
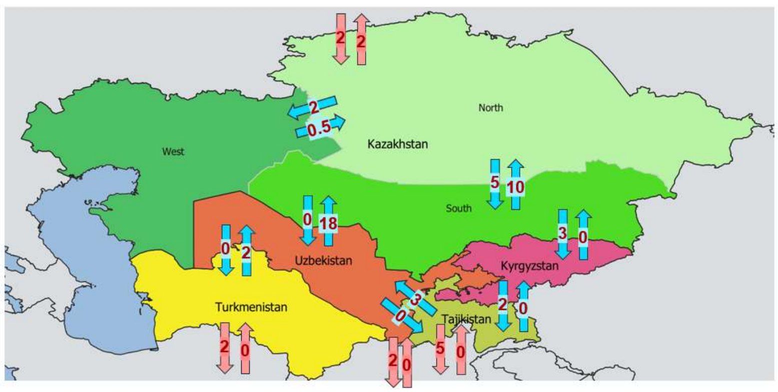


FIGURE 13

Electricity trade (possible physical flows) in Full Connectivity Scenario in 2050, TWh



In 2050, the Full Connectivity Scenario envisages no electricity import to the region (pink arrows on Figures 12 and 13), meaning that enhanced connectivity would help zero out Central Asia's dependence on energy import, therefore contributing to regional energy security. Within Kazakhstan, the electricity trade from West to North could greatly increase from 0.5 TWh to 9 TWh, indicating the contribution made by the effective integration of the natural gas resources in the West into the Unified Power System of Kazakhstan. The country's electricity export to Kyrgyzstan could strongly increase from 3 TWh to 43 TWh as well, supporting Kazakhstan's more active participation in the Central Asia Regional Electricity Market including through the CASA-1000 project via the planned North-South HVDC lines.

For Uzbekistan, enhanced energy connectivity could help ease the pressure from the drastically rising domestic energy need by introducing more electricity imports from neighbouring countries, 40 TWh from Kyrgyzstan, 26 TWh from Kazakhstan (0 TWh in 2030), and 8 TWh from Tajikistan (8 TWh) and Turkmenistan (2 TWh). It also allows Uzbekistan to flexibly arrange its electricity stocks by exporting electricity to Kyrgyzstan and Tajikistan in winter for their energy shortages.

The modelling exercise allowed to simulate the most economically efficient power flows when the transmission is enhanced. This envisages multiple modes of electricity trading:

- bidirectional - for example, as in case of Tajikistan and Uzbekistan, where annual power flows have close values,
- export-oriented flows – as is the case of Kyrgyzstan and Uzbekistan
- power wheeling – when electricity is exported from one country to second one through the interconnectors of the third country – for example, as is the case of the CASA-1000 project, which allows Kyrgyzstan to export electricity to Tajikistan and Afghanistan).

FIGURE 14

Electricity trade (possible physical flows) in Unlimited Connectivity Scenario in 2030, TWh

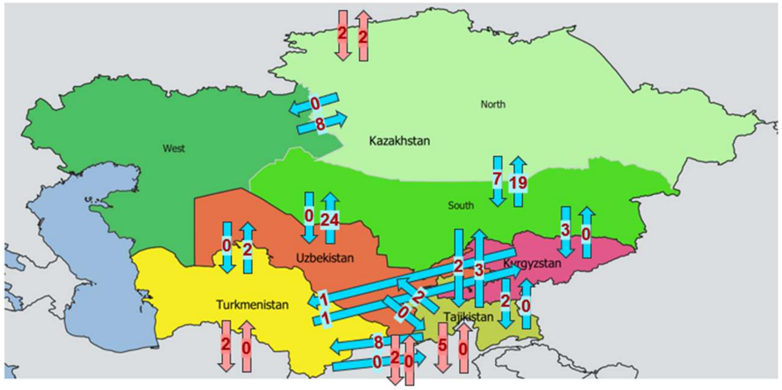
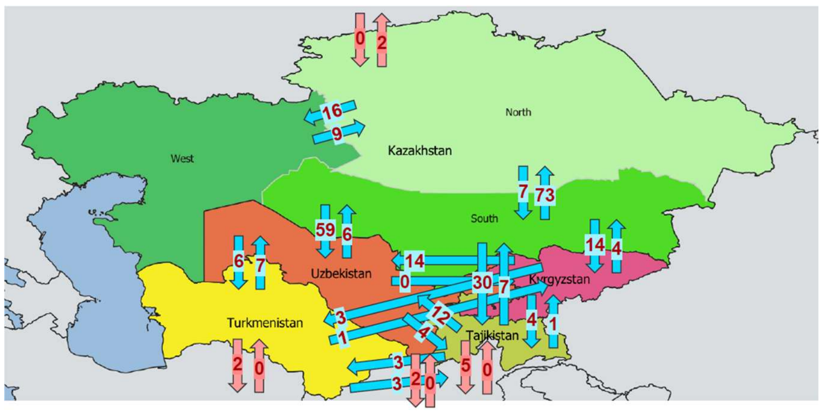


FIGURE 15

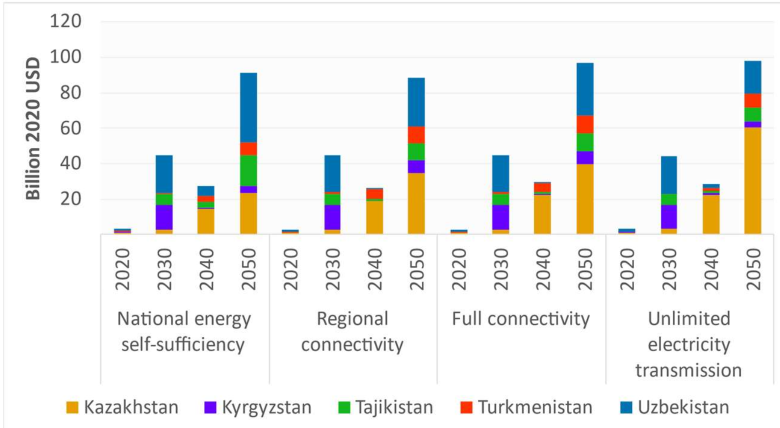
Electricity trade (possible physical flows) in Unlimited Connectivity Scenario in 2050, TWh



This modelling scenario demonstrates the electricity traded potential of connected Tajikistan for all the other four Central Asian countries in 2030 and 2050. Electricity trade is the most active in the Tajikistan and Kyrgyzstan region. The rationale behind it is among others the significance of Rogun project, which aims to add another 3780 MW to Tajikistan's national electricity generation capacity by 2032. This will not only guarantee Tajikistan's national energy security but will also be able to offer additional energy stock for energy shortages in other Central Asian countries via energy trade. Also, the CASA-1000 project builds up the benefits for regional energy trade between Central Asia and South Asia. The strategic geographic position of Tajikistan and Kyrgyzstan makes them serve as transport hubs for electricity trade between Central Asia and South Asia.

FIGURE 16

Investments needed in electricity sector[18] – scenario comparison



Enhanced connectivity scenarios in Central Asia primarily influence the location of energy investments rather than significantly altering their overall level. This trend is particularly evident in the electricity sector, where investments in generation, storage, and transmission consistently account for an average of 84% of total investments across various years and scenarios. This substantial proportion underscores the critical role of electricity infrastructure in the region's energy development plans.

[18] The depicted investment needs only reflect the construction of additional transmission capacities. The renovation needs for the existing transmission infrastructure are not reflected.

IV. Elements to Shape the Roadmap on Energy Connectivity – A Multidimensional Approach

To maximize the potential discussed in the previous chapters, as well as building upon ESCAP's approach to interconnectivity in the region,[19] the integration and coordination of energy infrastructure, resources and markets across the Central Asian region requires a multidimensional approach which integrates and aligns technical, political, organisational and financial considerations. By proactively aligning these elements through sustained stakeholder engagement, Central Asian nations can create an enabling environment for realizing the economic, environmental and energy security benefits associated with regional cross-border energy cooperation.

A successful regional strategy aiming to enhance regional energy connectivity should include the following elements:

(a) Technical Considerations:

- (i) Research, analysis and interconnectivity scenarios;
- (ii) Technical preparations (feasibility studies for proposed projects, project management plan- timeline, milestones, risk management);
- (iii) Capacity building (training programs for technical personnel and stakeholders, sharing information and best practices among countries, R&D and innovation on technologies).

(b) Political Considerations:

- (i) Assessment of stakeholder engagement (government, private sector, international organizations);
- (ii) Current activities and initiatives in this area (by governments, international organizations, other stakeholders).

(c) Financial Considerations:

- (i) Financial planning (cost estimation, funding sources, impact analysis).

(d) Organizational Considerations:

- (i) Harmonization of policies and regulatory framework across the region (energy regulations and standards, incentives for investment, cross-border agreements);
- (ii) Implementation and monitoring framework (various tools for implementation - data analytics, mapping tools, GIS, modelling software, etc).

A. Technical Considerations

A detailed assessment of the existing energy infrastructure across Central Asia is crucial, with a particular focus on the UES CA. ECE's report on Energy Connectivity in Central Asia[20] showcases an inventory of existing national energy systems. It includes a map and an evaluation of the current energy system dynamics, such as power generation, consumption and trade, as well as the state of power generation assets, such as hydropower, fossil fuel resources including gas and coal, and other renewable energy technologies. Additionally, this report also expansively illustrates the existing and planned transmission and distribution networks, interconnections and grid operations within each country in the region, consequently highlighting the infrastructure bottlenecks, constraints and investment needs for power system modernization, expansion and regional integration.

Technical infrastructure and systems-dynamics assessments, such as the report mentioned above, can be

[19] Regional road map on power system connectivity: promoting cross-border electricity connectivity for sustainable development | ESCAP [Online] Available at: https://www.unescap.org/our-work/energy/energy-connectivity/roadmap
[20] Energy Connectivity in Central Asia: an Inventory of Existing National Energy Systems [Online] Available at: https://unece.org/sed/documents/2024/02/energy-connectivity-central-asia-inventory-existing-national-energy-systems

capitalized upon to conduct models illustrating interconnectivity scenarios to evaluate different pathways for enhancing regional energy connectivity, like the ones presented in this report. Such an exercise allows stakeholders to gain insight on the impacts of scaling up renewable energy sources on grid integration requirements.

Implementing a regional connectivity strategy will require significant capacity building to ensure that the required technical expertise is available. Stakeholders will require training programs on subjects such as advanced grid planning, systems operations and renewable energy integration, amongst others. Consequently, international organizations involved can enable the sharing of knowledge regarding the best practices for regional interconnectivity as well as the standards and protocols which will be required. This can be done through the creation of regional knowledge hubs and centers of excellence regarding energy connectivity. With the help of such bodies, institutional capacity must be built for regional coordination bodies such as CDC "Energia", the coordinating dispatch centre of the UES CA.

By combining a rigorous assessment of existing infrastructure, detailed technical studies to chart an evidence-based roadmap, and capacity building initiatives, Central Asian countries can develop a comprehensive regional strategy underpinned by strong technical foundations. This will enable the optimized investments and coordinated operations to realize the full benefits of enhanced energy connectivity. Stakeholder engagement, open communication and information sharing is imperative for the entire duration of this process as national and regional energy developments, policies and dynamics must be incorporated into technical considerations.

B. Political Considerations

Developing a successful regional strategy to enhance energy connectivity in Central Asia requires addressing key political considerations alongside the technical aspects. Indeed, technical capacity cannot be developed without stakeholder engagement, collaboration and mutual trust. Political commitment provides an enabling environment for countries to collaborate on the technical aspects of grid integration and energy trade.

The Stakeholder Consultations conducted regularly within UNECE activities on energy connectivity in Central Asia, serve a vital role for fostering alignment and a shared vision among diverse stakeholders regarding regional energy interconnectivity initiatives.

The current state of the UES CA enables only limited energy connectivity and electricity trade between Kazakhstan, Uzbekistan, Tajikistan and Kyrgyzstan compared to all the opportunities lying ahead. International agencies have been working on a plethora of projects aimed at enhancing energy connectivity in Central Asia and can therefore leverage their expertise to guide other national stakeholders during the process.

C. Financial Considerations

Financial considerations are critical enablers for catalysing energy interconnectivity and regional integration in Central Asia. Insufficient financial resources or misaligned fiscal policies like energy pricing can disincentivize the political prioritization of regional connectivity projects. However, innovative financing models that improve project economics can incentivize greater political buy-in from the governments.

Comprehensive cost estimation studies will be required to estimate the capital, operational and lifecycle costs for proposed interconnectivity projects such as cross-border transmission line expansion, grid refurbishments as well as maintenance and replacement. Costs should also be assessed not solely for physical infrastructure but also for institutional strengthening, capacity building, and regulatory harmonization.

Financing can be mobilized through diverse streams, including national budgets but also financial institutions such as development banks, public-private partnership and, in the case of bankable projects, private financers. Institutional frameworks are required to mobilize such financing. Concessional lending from development partners can improve project bankability and attract private capital. Consequently, international development agencies and financial institutions can provide technical capacity building to reform existing regulatory financial structures and enable further financing. Currently, development banks such as the Asian Development Bank have significantly invested in energy connectivity, providing financing and technical assistance to Central Asia under the CAREC program.

Cost-benefits analyses must quantify the financial impacts from energy trade, optimized resource allocation, reduced technical losses and all factors of interconnectivity. These should also evaluate the distributional impacts across all stakeholder groups to be able to assess equitable risk allocation. Financial modelling can evaluate different pricing/tariff scenarios and revenue streams to ensure cost recovery.

Stakeholders should also incorporate comprehensive risk assessments which cover technical, commercial, political and foreign exchange risk. Risk mitigation tools including guarantees, insurance and legal frameworks for investor protection are required in this case.

D. Organizational Considerations

Weak institutional capacity and fragmented regulatory frameworks hinder effective technical coordination on issues like cross-border power trading and grid operations. On the other hand, strengthening regional institutions through capacity building initiatives enables harmonization of technical standards and practices. Additionally, limited institutional mechanisms for joint investment planning and risk mitigation tools increase financial risks, deterring capital for connectivity infrastructure. Establishing strong governance frameworks and investment protection provisions can help mobilize financing from diverse sources.

Policy and regulatory framework harmonization is crucial towards enabling energy interconnectivity across Central Asia. Stakeholders should come together and align national energy policies, strategies, regulations, regulatory market dynamics, pricing mechanisms and technical standards.

Strengthening regional institutions in Central Asia and knowledge sharing platforms will enable coordinated policymaking, operations monitoring and progress tracking towards connectivity goals.

Overall, these technical, political, financial and organizational considerations for regional energy connectivity are intricately coupled. Siloed approaches focusing solely on one dimension will face barriers from deficiencies in the other areas. An integrated strategy that proactively aligns all four elements in a coherent manner is important for overcoming barriers and realizing the full benefits of enhanced cross-border energy cooperation. This multi-dimensional approach would provide the comprehensive enabling environment for regional connectivity in Central Asia to take root and thrive.