Energy Connectivity in Central Asia

Preliminary modeling results

Jason Veysey
Energy Modeling Program Director
Stockholm Environment Institute
jason.veysey@sei.org

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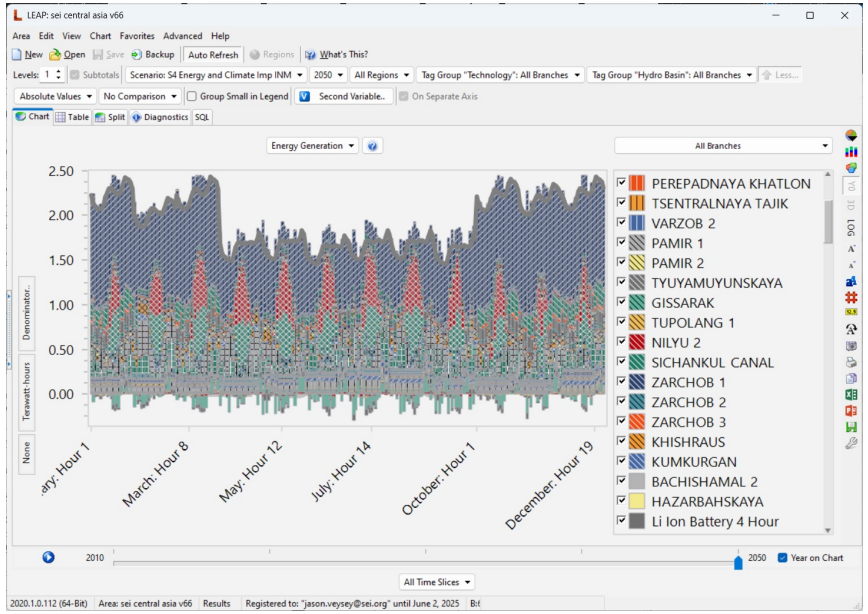
SEI Stockholm Environment Institute

Scope of scenario modeling

- Model energy systems of 5 Central Asian countries (KAZ, KGZ, TJK, TKM, UZB)
- Simulate three main scenarios
  - National energy self-sufficiency
  - Regional energy connectivity
  - Full connectivity (regional energy connectivity + connections to third countries)
- Analyze key model outputs
  - Energy endowments/reserves
  - Energy supply and demand
  - Deployment of low/zero-carbon technologies: renewable energy, nuclear, H_2, fossil with carbon capture
  - Electricity and gas grid expansion/integration
  - Deployment of energy storage
  - Costs of energy generation, transmission, and storage

Model enhancements since February 2024

- Added network modeling of electricity transmission
- Disaggregated electricity imports and exports, separately modeling electricity trade between countries/grids in Central Asia and with third countries
- Modeled hydropower availability in Amu Darya and Syr Darya Basins using results from SEI's integrated water-energy model for Central Asia
- Added grid-connected battery storage
- Updated renewable power targets in UZB and TJK
- Integrated latest available data on electricity production capacity and dispatch (including near-term capacity expansion plans)
- Revised capital costs and capacity credits for hydropower using locally sourced data
- Added hydrogen production
- Updated fossil fuel reserves
- Modeled National energy self-sufficiency, Regional energy connectivity, and Full connectivity scenarios, plus a fourth scenario with unlimited electricity transmission capacity



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Electricity transmission

- 7 network nodes: KAZ_North, KAZ_South, KAZ_West, KGZ, TJK, TKM, UZB
- High-voltage lines: >= 220 kV
- All existing and planned lines represented
- Various candidate lines (from World Bank grid modeling, plus extra lines for unlimited transmission scenario)
- Power flow simulation calibrated to historical line utilization
  - Minimum and maximum flow requirements between nodes to represent power purchase agreements and typical usage
  - Requirements are gradually lifted in projections

Modeled regions (nodes) for electricity supply and demand

Electricity transmission

- Assumptions about parallel operation with UES CA
  - TJK resumes parallel operation in 2024
  - TKM does not resume parallel operation (except in unlimited transmission scenario)

MW of transmission capacity among modeled nodes
(E = existing, P = planned, C = candidate)

Nodes		Self-sufficiency	Regional connectivity	Full connectivity	Unlimited transmission*
KAZ_North	KAZ_South	E: 2100	E: 2100	E: 2100	C: Unlimited
KAZ_North	KAZ_West	E: 1386	E: 1386	E: 1386	C: Unlimited
KAZ_South	KGZ	0	E: 3994 C: 3436	E: 3994 C: 3436	C: Unlimited
KAZ_South	UZB	E: 2034 C: 1718	E: 2034 C: 1718	E: 2034 C: 1718	C: Unlimited
KGZ	TJK	0	E: 240 P: 1715 C: 1718	E: 240 P: 1715 C: 1718	C: Unlimited
KGZ	UZB	0	E: 3741 C: 3436	E: 3741 C: 3436	C: Unlimited
TJK	UZB	0	P: 8562 C: 3436	P: 8562 C: 3436	C: Unlimited
TKM	UZB	0	E: 1653 C: 3436	E: 1653 C: 3436	C: Unlimited

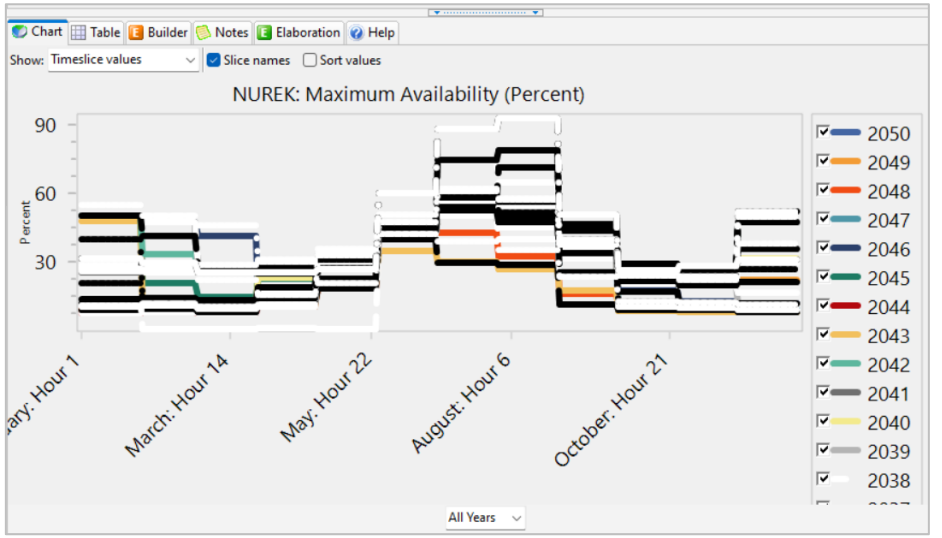
** Unlimited scenario includes all existing and planned capacity*

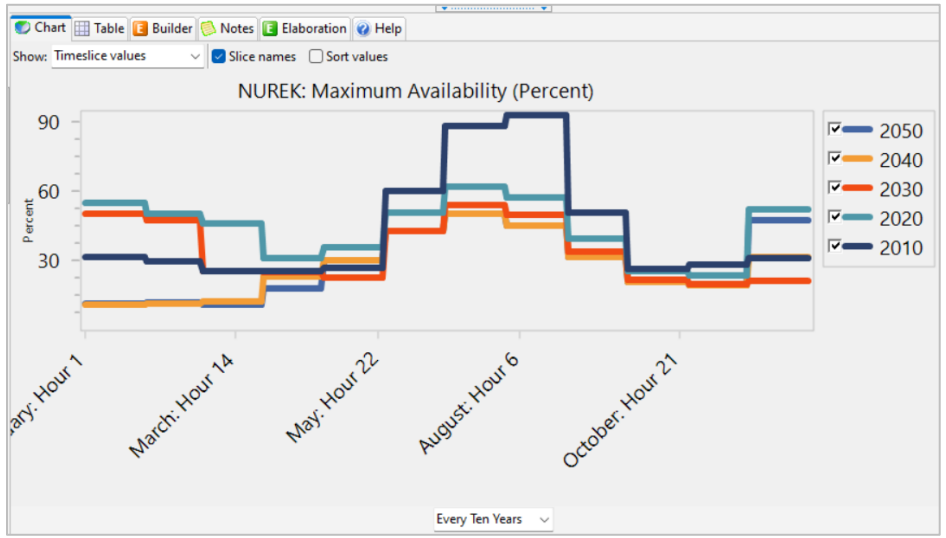
Electricity transmission

- Transmission connections with third countries
  - Only enabled in Full connectivity and Unlimited transmission scenarios
  - Afghanistan
    - Current and planned connections with TJK and UZB
    - Connections assumed to be for export only
    - Historical and projected exports reproduced in model
  - Russia
    - Connections with KAZ_North and KAZ_West
    - Two-way power trade
    - Historical trade reproduced in model and used to bound future line usage
  - Connections between TKM and Afghanistan (planned) and TKM and Iran (existing and planned) not modeled due to insufficient data on historical usage

Hydropower availability

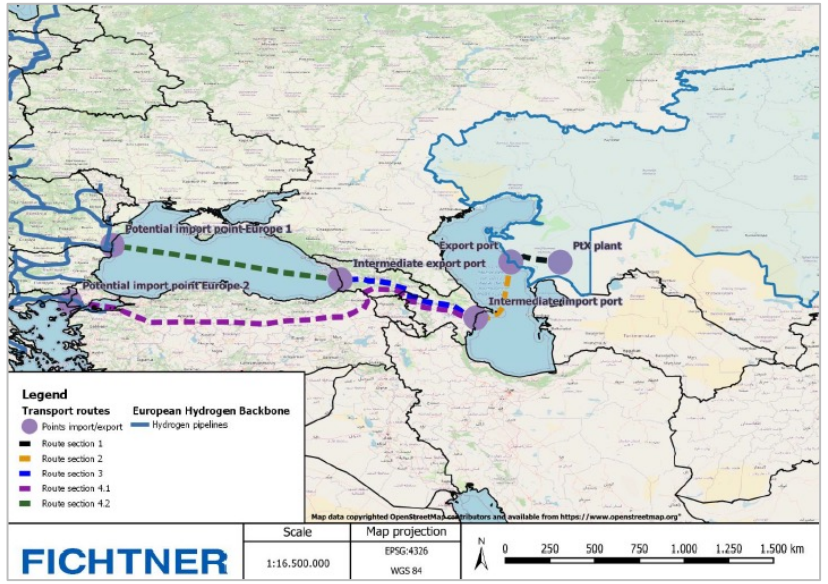
- Using results from integrated water-energy modeling allows a more realistic representation of:
  - Year-to-year variability
  - Competition with other water demands
  - Long-term impacts of climate change





Hydrogen production

- Multiple production pathways added to model
  - Alkaline and proton exchange membrane electrolysis
  - Steam methane reforming with and without CCS
  - Coal gasification with and without CCS
- Hydrogen demands not yet modeled
  - Domestic: need exogenous projections, appropriate data sources not yet identified
    - Key issue: level of decarbonization ambition in region
  - Exports: demand projections for KAZ available in GIZ *Green Hydrogen Transport Scenarios* report, export potential in other countries may be low



Source: GIZ (2023). Green Hydrogen Transport Scenarios: From Kazakhstan to Europe.

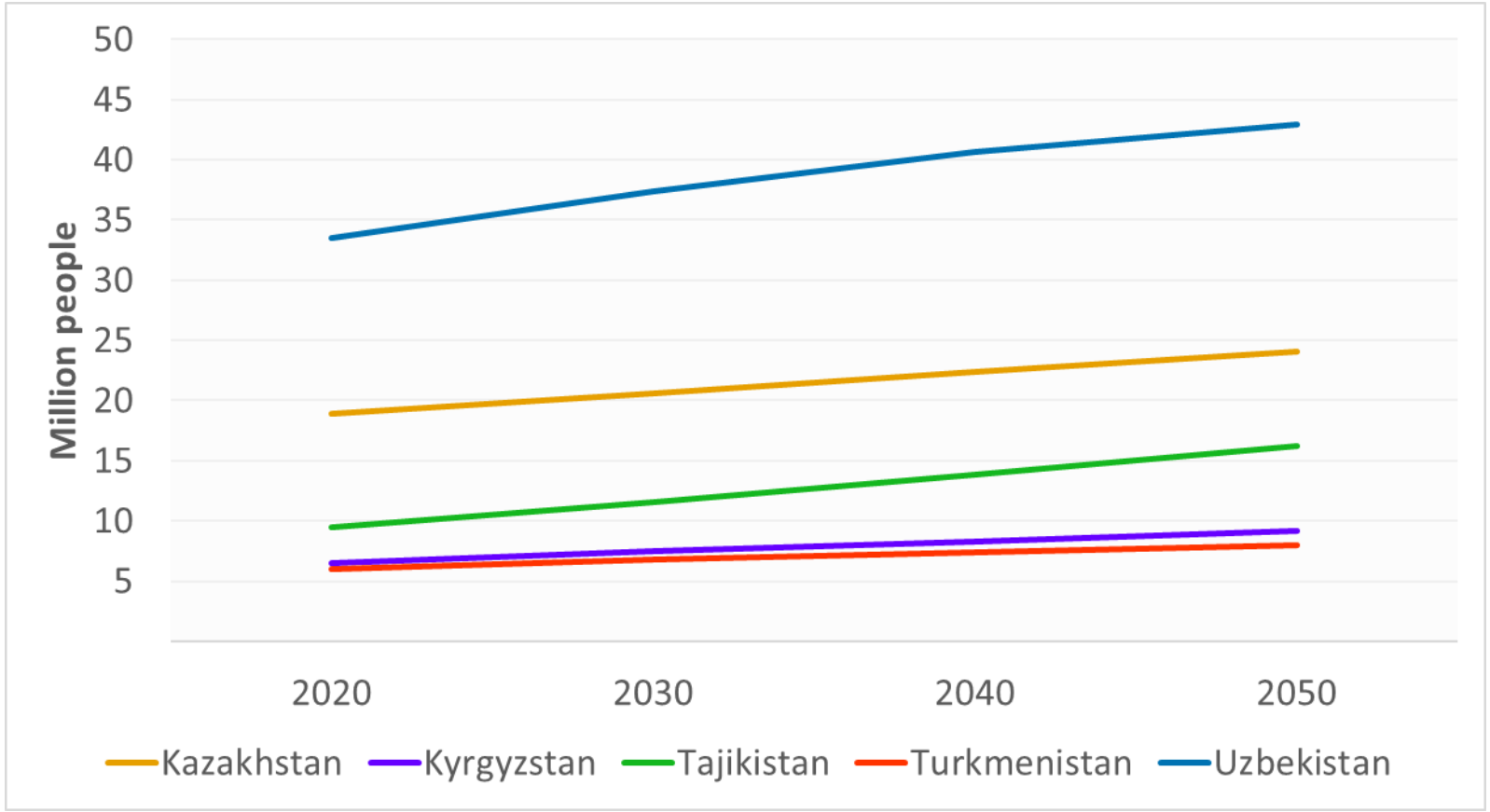
Preliminary results

- Results calculated for four connectivity scenarios
  - Self-sufficiency: electricity transmission within KAZ and between KAZ and UZB only
  - Regional: electricity transmission within Central Asia only
  - Full: electricity transmission within Central Asia and between Central Asia and third countries
  - Unlimited: unlimited electricity transmission within Central Asia, same assumptions as Full for transmission between Central Asia and third countries
- Key commonalities for all scenarios
  - Full realization of national plans for hydropower development and agricultural expansion
  - Implementation of unconditional NDCs and national clean energy plans (no net-zero in KAZ)
  - Adoption of national plans for water efficiency (including irrigation upgrades, new crops and cropping patterns, water-efficient equipment)
  - High climate change – hot, dry future climate (SSP5-8.5, INM-CM5 model's CMIP6 projection)
  - Population projections from UN *World Population Prospects*
  - GDP projections from IMF (TKM), World Bank (all other countries)

All results shown here are a draft and are subject to revision and enhancement.

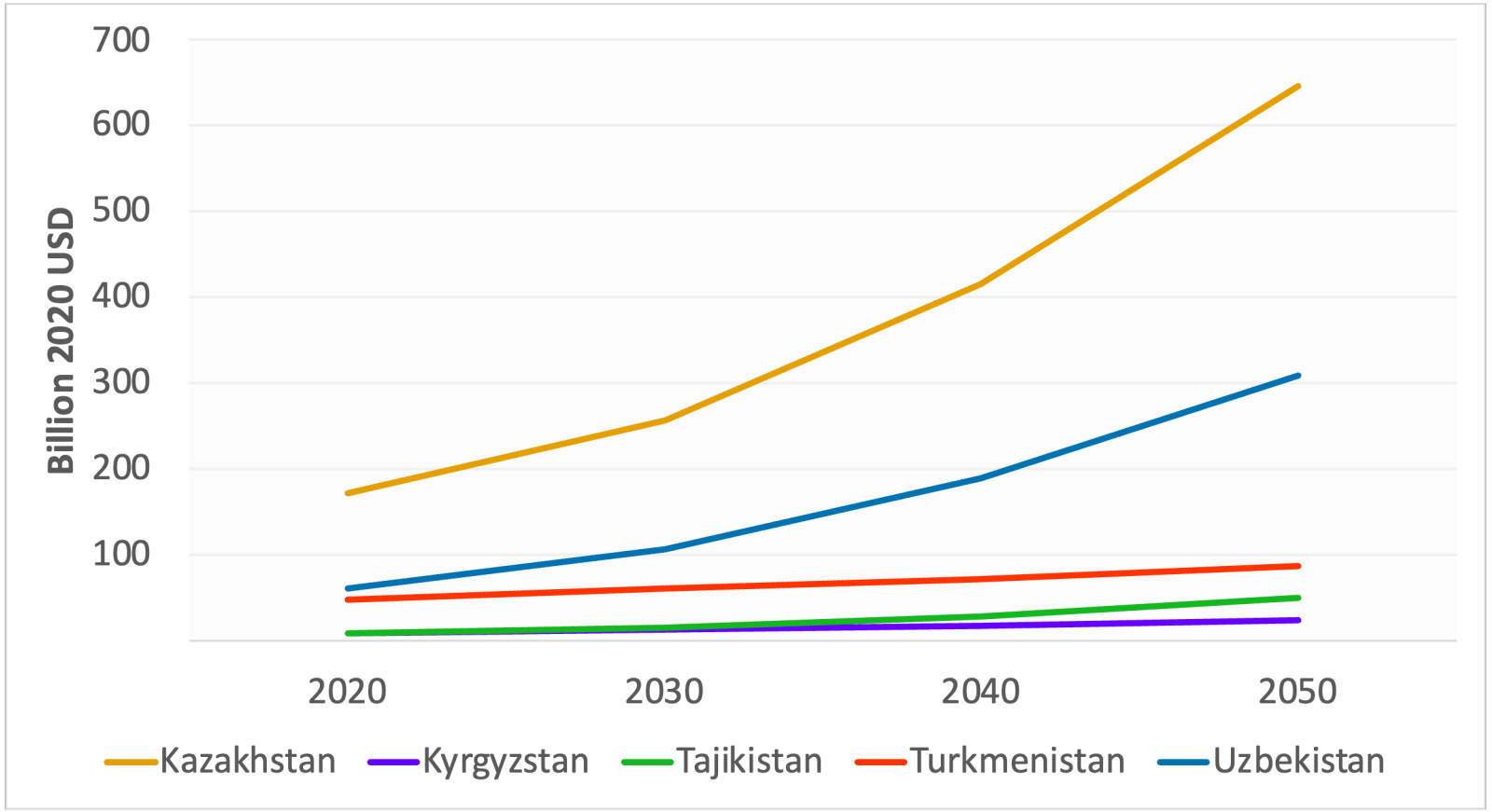
Additional results – and additional information on the model's inputs, assumptions, and methods – are available in the model itself, which can be shared on request.

Population



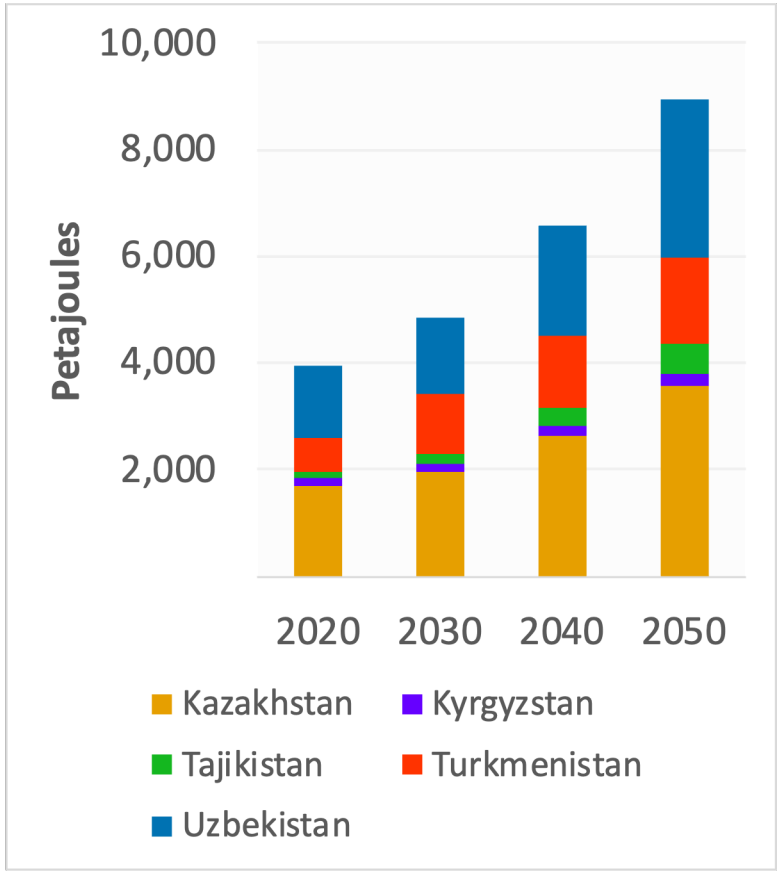
- 2020-2050 average annual growth rates:
  - TJK: 1.8%
  - KYG: 1.1%
  - TKM: 0.9%
  - KAZ, UZB: 0.8%

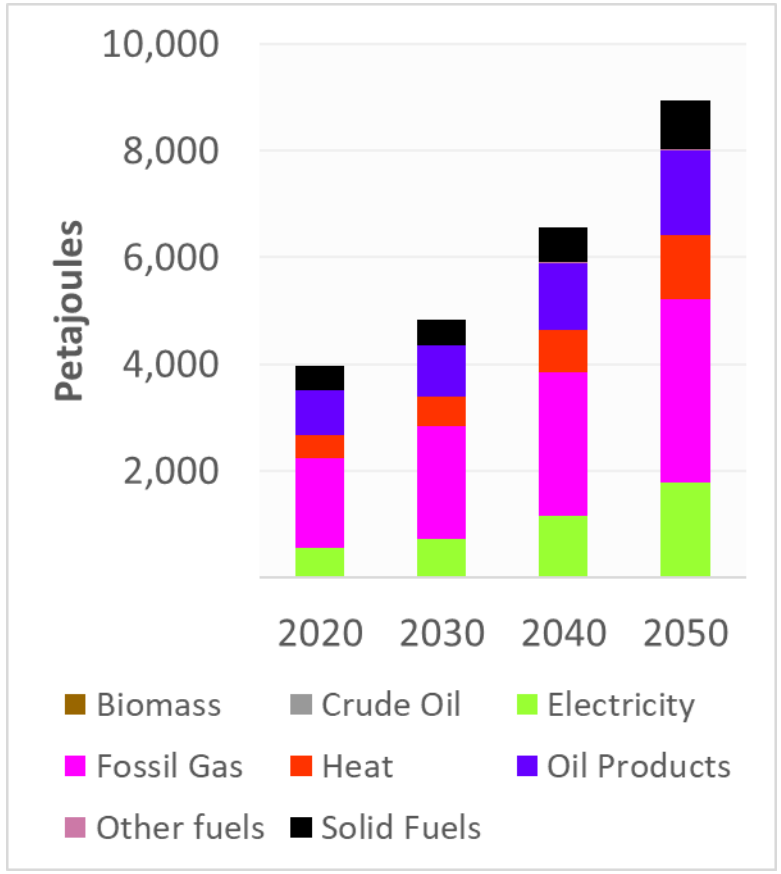
GDP



- 2020-2050 average annual growth rates:
  - TJK: 6.1%
  - UZB: 5.6%
  - KAZ: 4.5%
  - KYG: 3.6%
  - TKM: 2.0%

Final energy demand

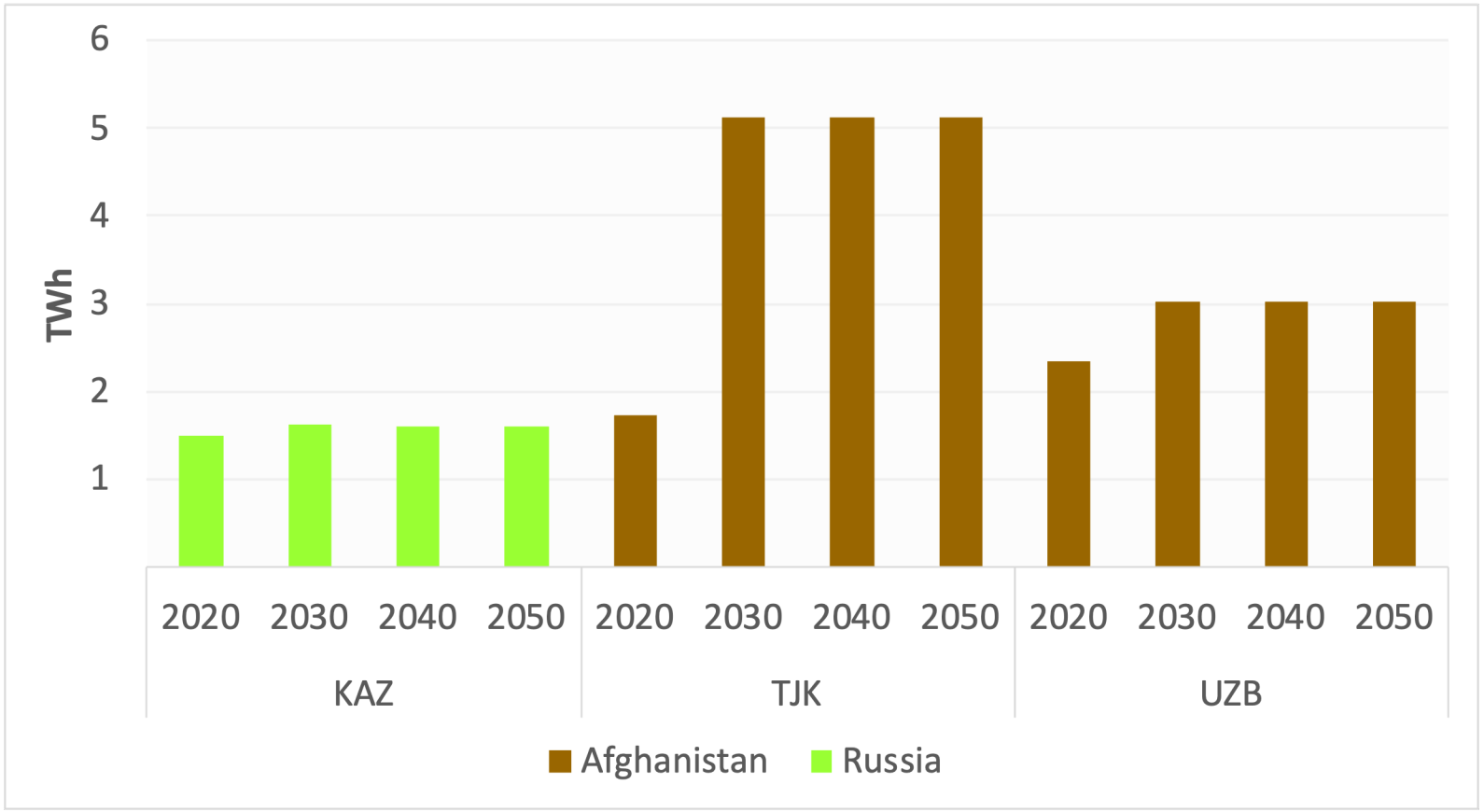




Excludes demand for electricity exports

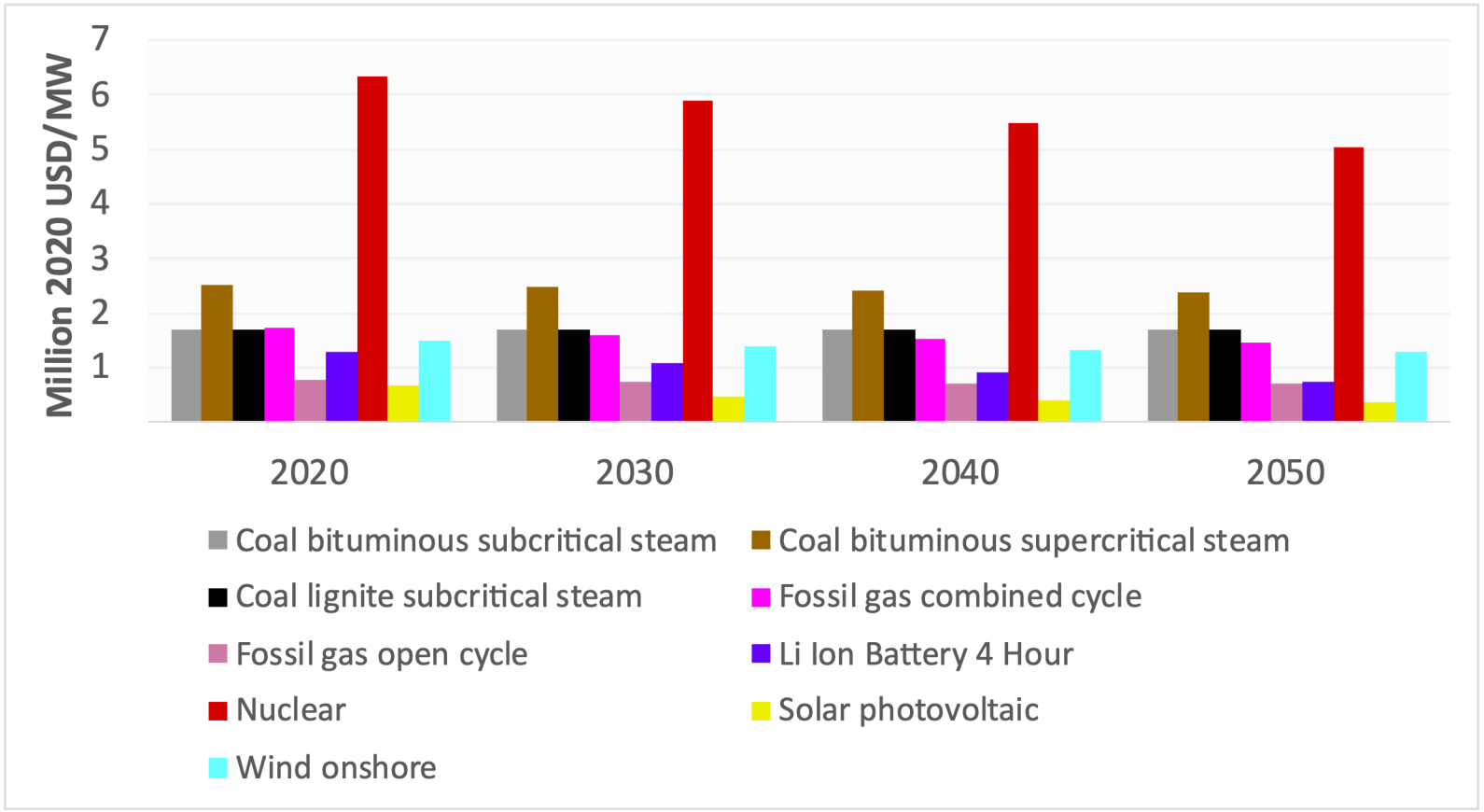
- Same final demand projection in all scenarios
- Significant demand growth in all countries: total demands more than double over projection period
- Increasing share for electricity: 4.0% annual growth between 2020 and 2050 across all countries
- Major roles for gas and oil

Electricity exports to third countries



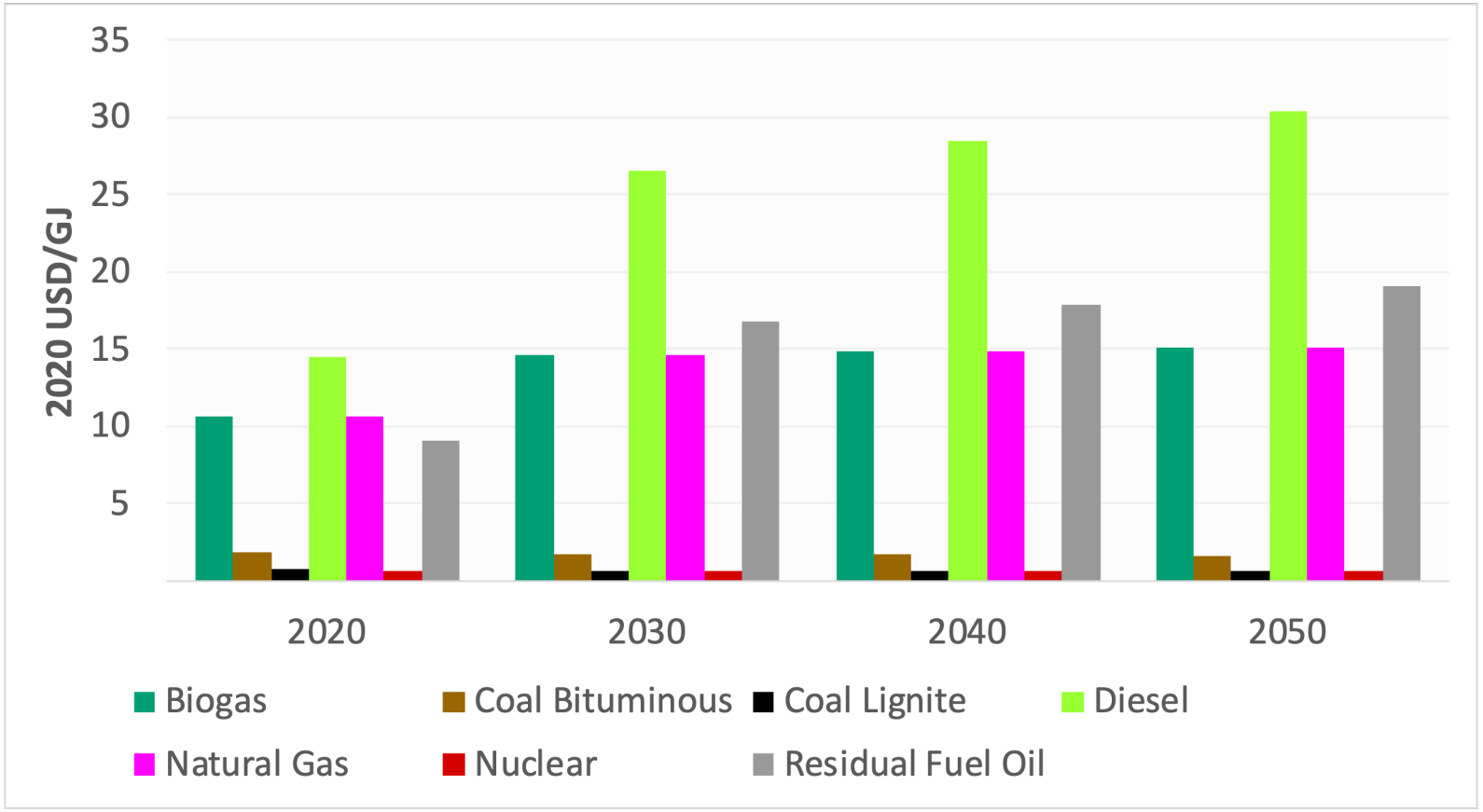
- Activated in Full connectivity and Unlimited transmission scenarios
- Long-run exports to Afghanistan based on projections in GIZ report *Conducting a country profile analysis and inventory of existing national energy systems* (Katyshev, 2023)
- Exports from TKM to Afghanistan and Iran not modeled due to a lack of data

Overnight capital costs – selected electricity production technologies



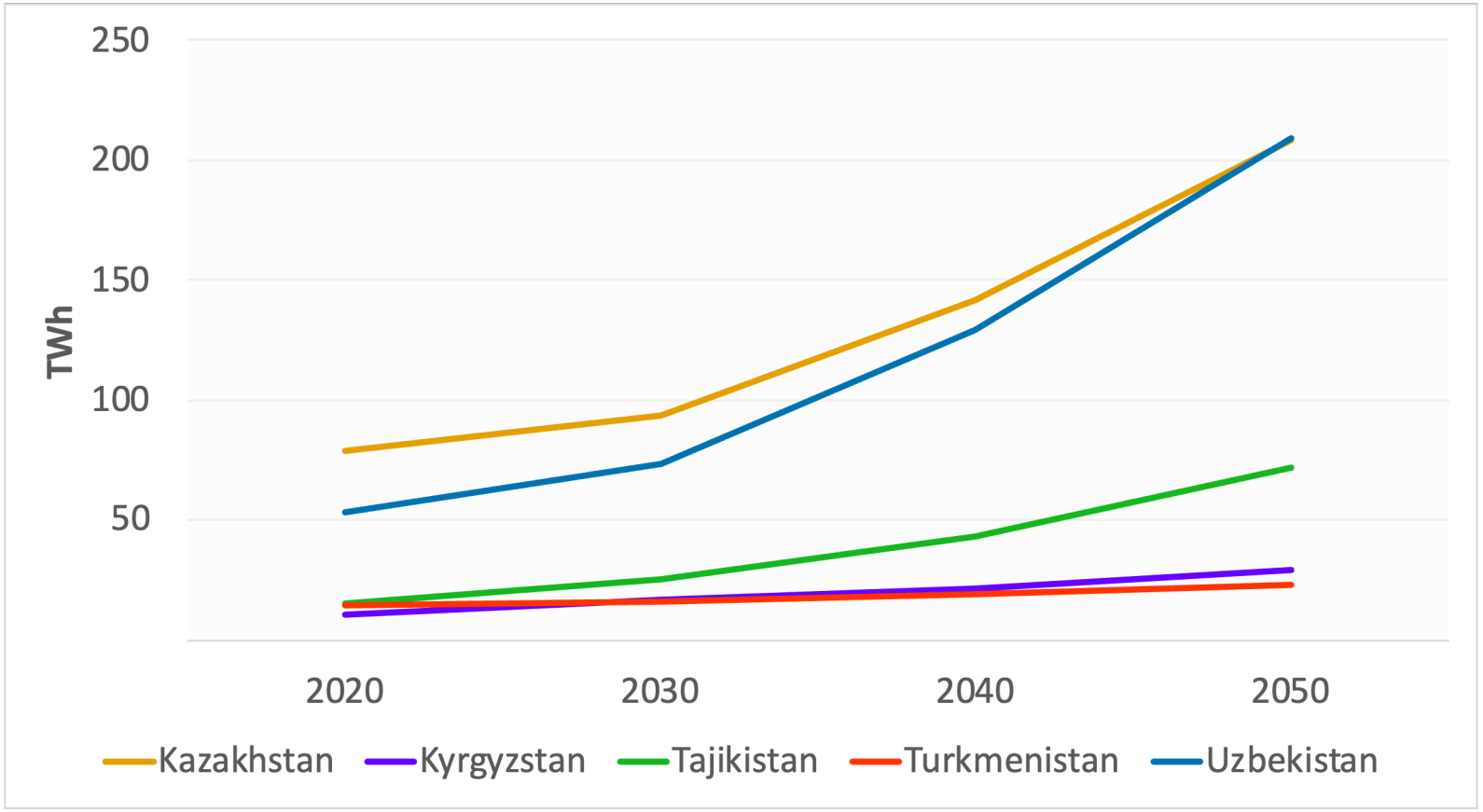
- Decreasing costs for solar, batteries, nuclear, gas, and wind
- Coal costs essentially stable
- Solar PV's low costs pair with good capacity factors in Central Asia
- Same electricity production technology costs used in all scenarios
- Except for hydropower, same technology costs used in all regions

Fuel prices for electricity production



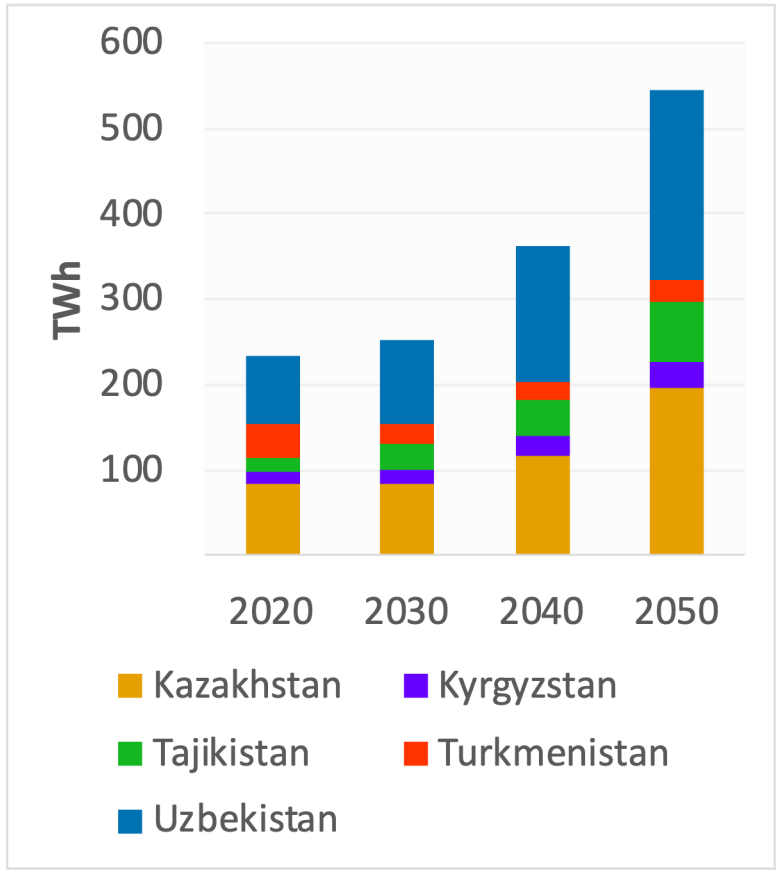
- Significant price advantage for coal over natural gas
- Same fuel prices used in all scenarios and regions

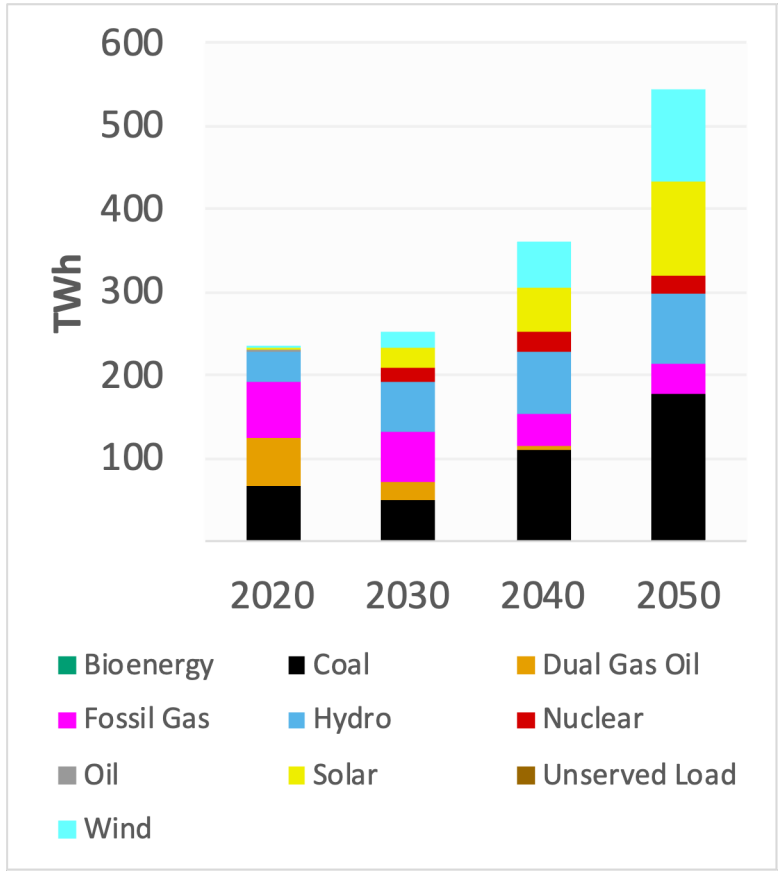
Electricity production requirements



- Requirements excluding third-country exports shown
- In long run, requirements in UZB match those in KAZ
- Large relative and absolute growth in requirements in TJK (57 TWh between 2020 and 2050)

Electricity generation: Self-sufficiency

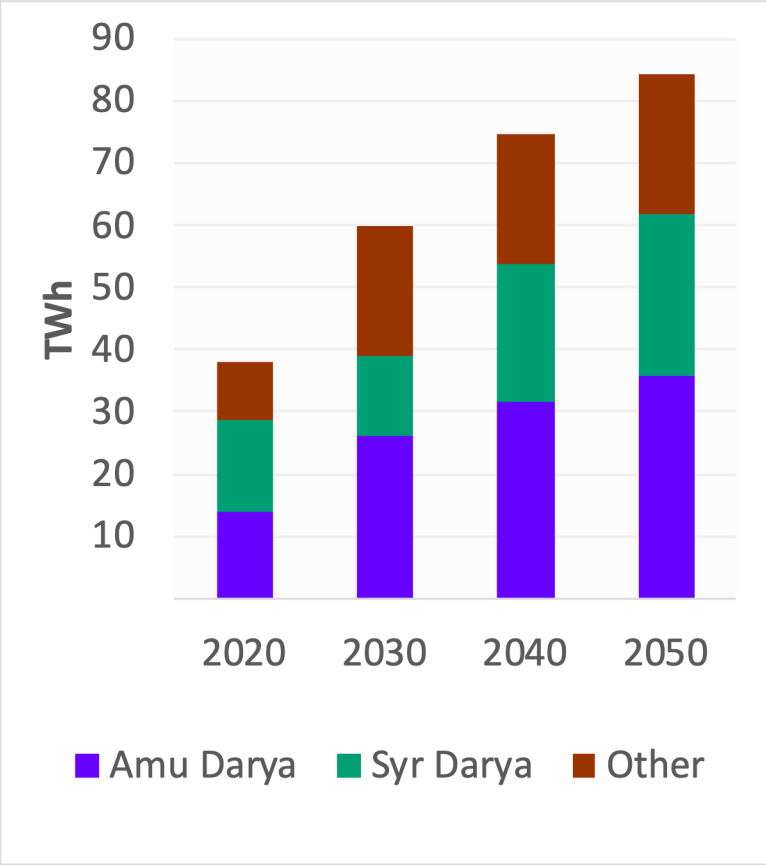


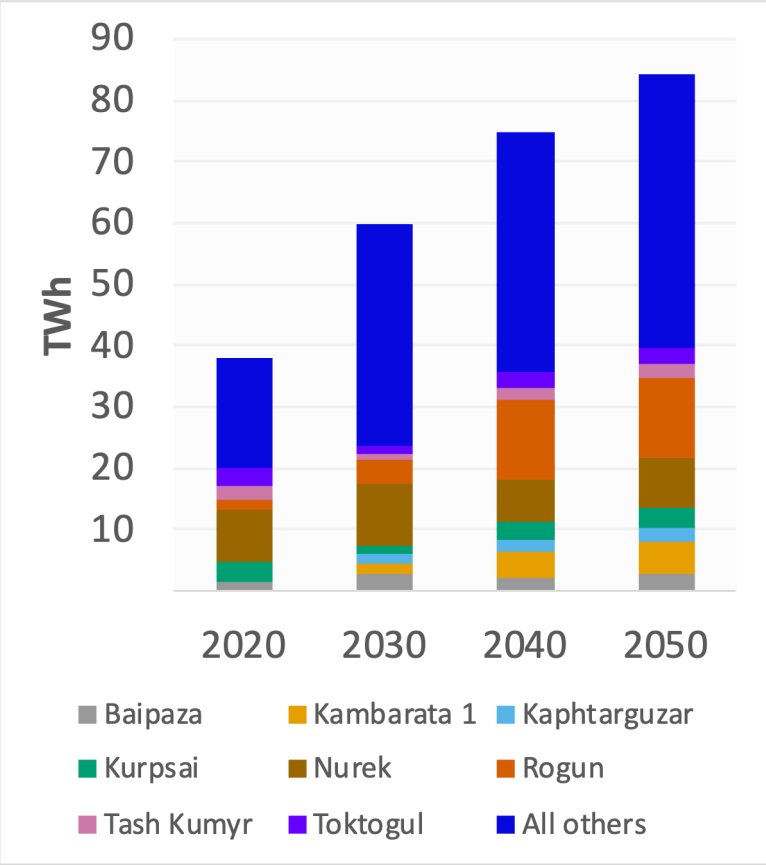


Excludes generation by battery storage

- Generation by country aligns with national electricity demand / production requirements
- Marked increase in low-carbon generation in long run – solar, wind, hydro, and nuclear
- Coal generation also grows (2.7x by 2050) because most countries do not have stringent long-term decarbonization targets
- Exception: KAZ, where renewables + nuclear + gas must account for 55% of generation by 2030, 100% by 2050 (Concept for Transition to Green Economy)

Hydro generation: Self-sufficiency

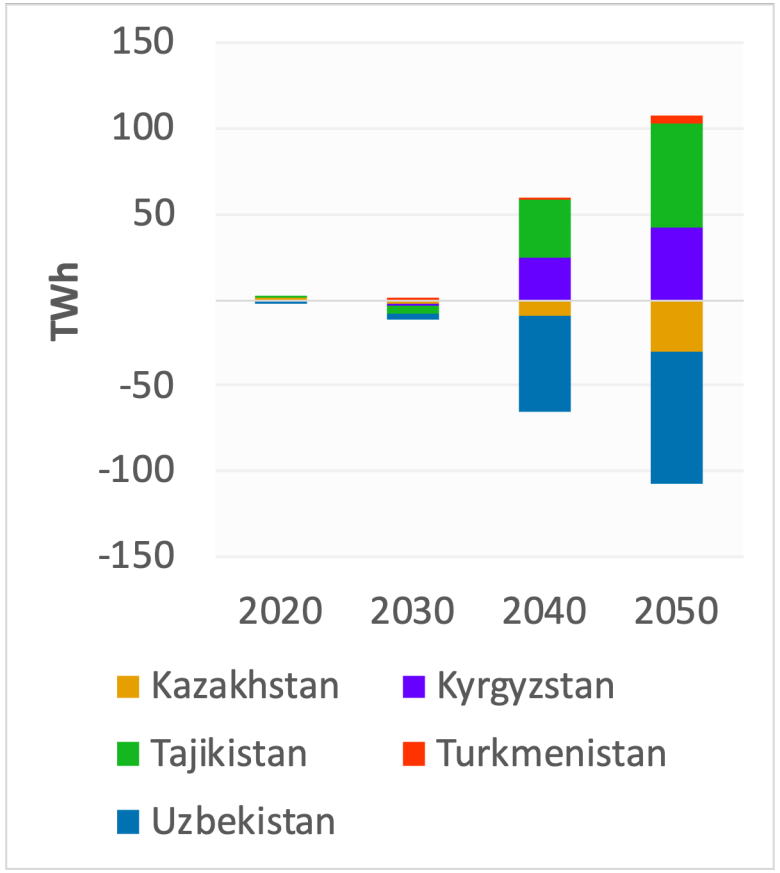


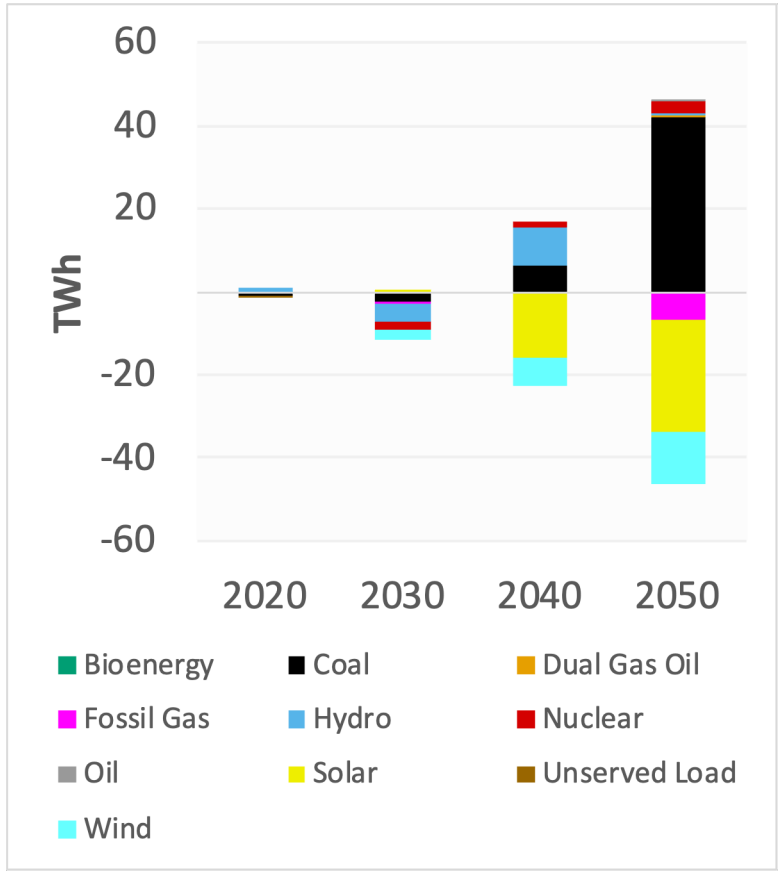


- Availabilities from integrated water-energy modeling cover more than 70% of hydro generation in most years
- Several significant plants (e.g., Rogun, Nurek), but total generation includes contributions from dozens of facilities of different sizes
- Hot, dry climate impedes hydropower production, particularly in Amu Darya Basin

Electricity generation: Regional connectivity

Results for Regional connectivity - results for Self-sufficiency



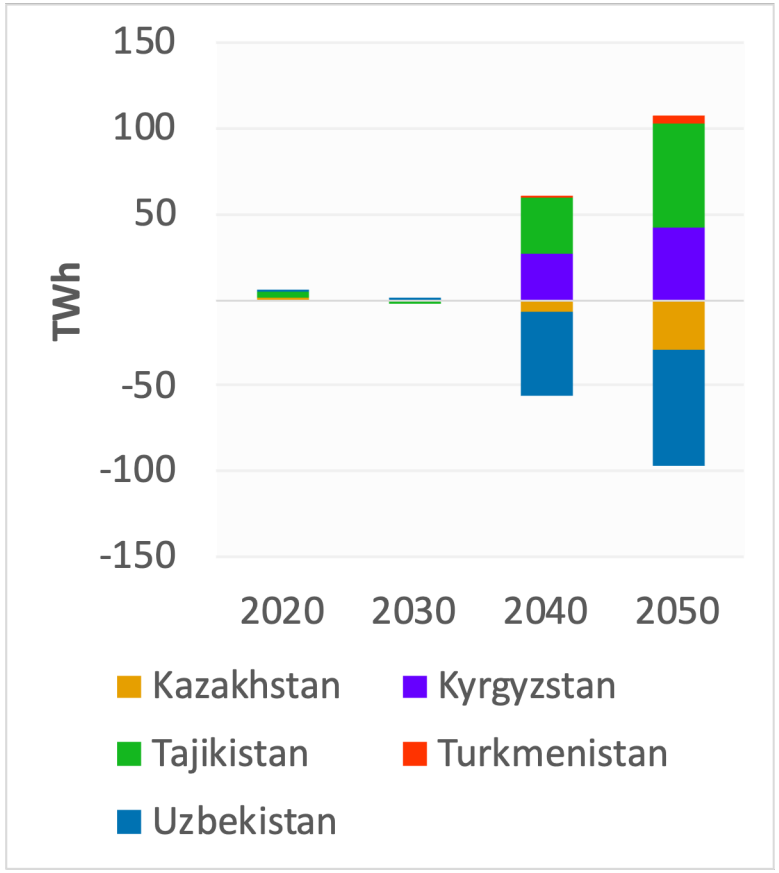


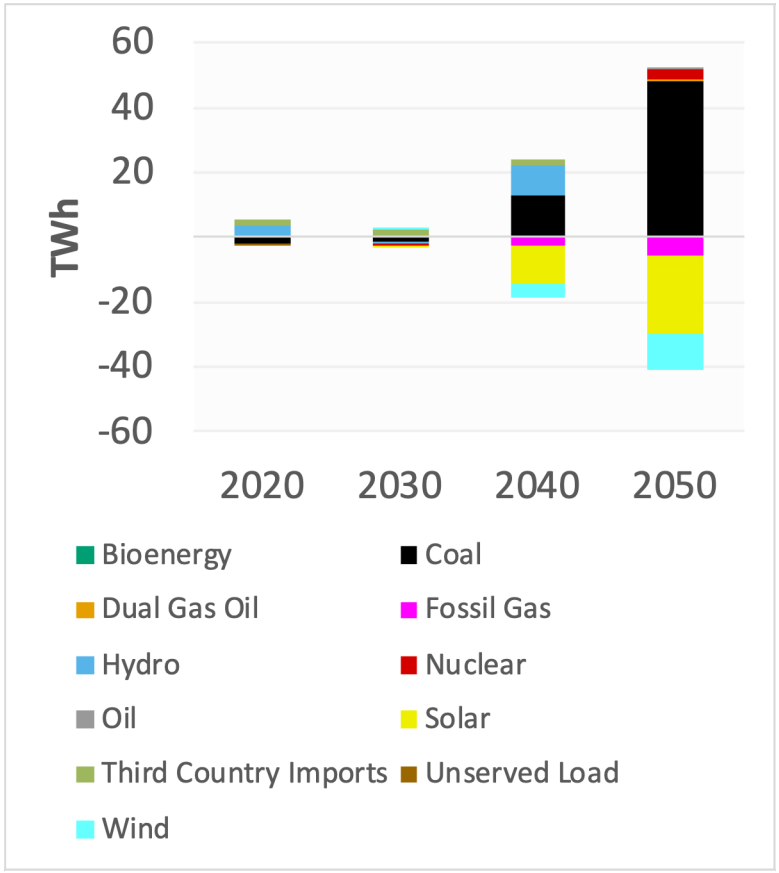
Excludes generation by battery storage

- Some regional efficiencies in near term (reductions in curtailment, better utilization of hydro)
- In longer run, however, carbon leakage becomes a significant problem – growth in coal generation in TJK and KYG, which do not have deep decarbonization requirements

Electricity generation: Full connectivity

Results for Full connectivity - results for Self-sufficiency



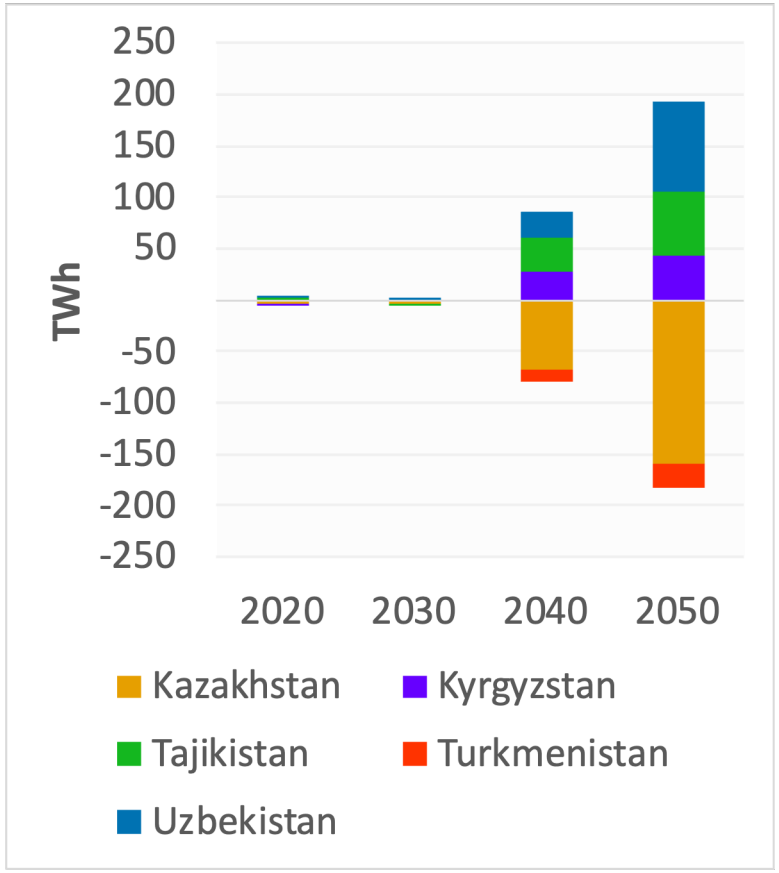


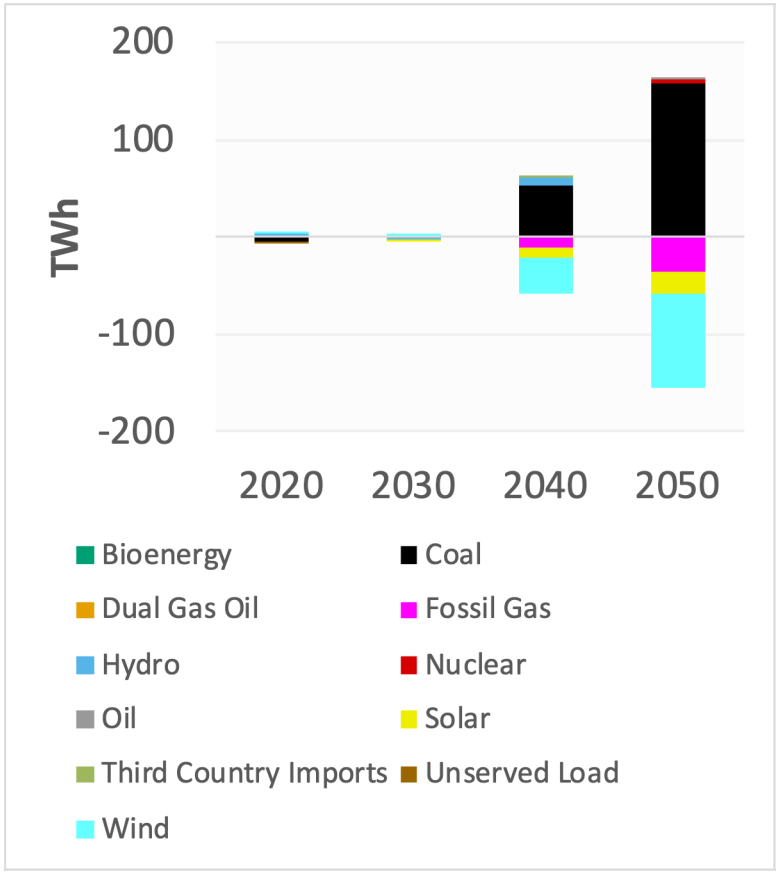
- Similar picture as for Regional connectivity
- Increased generation overall compared to Regional connectivity due to exports to third countries

Excludes generation by battery storage

Electricity generation: Unlimited transmission

Results for Unlimited transmission - results for Self-sufficiency



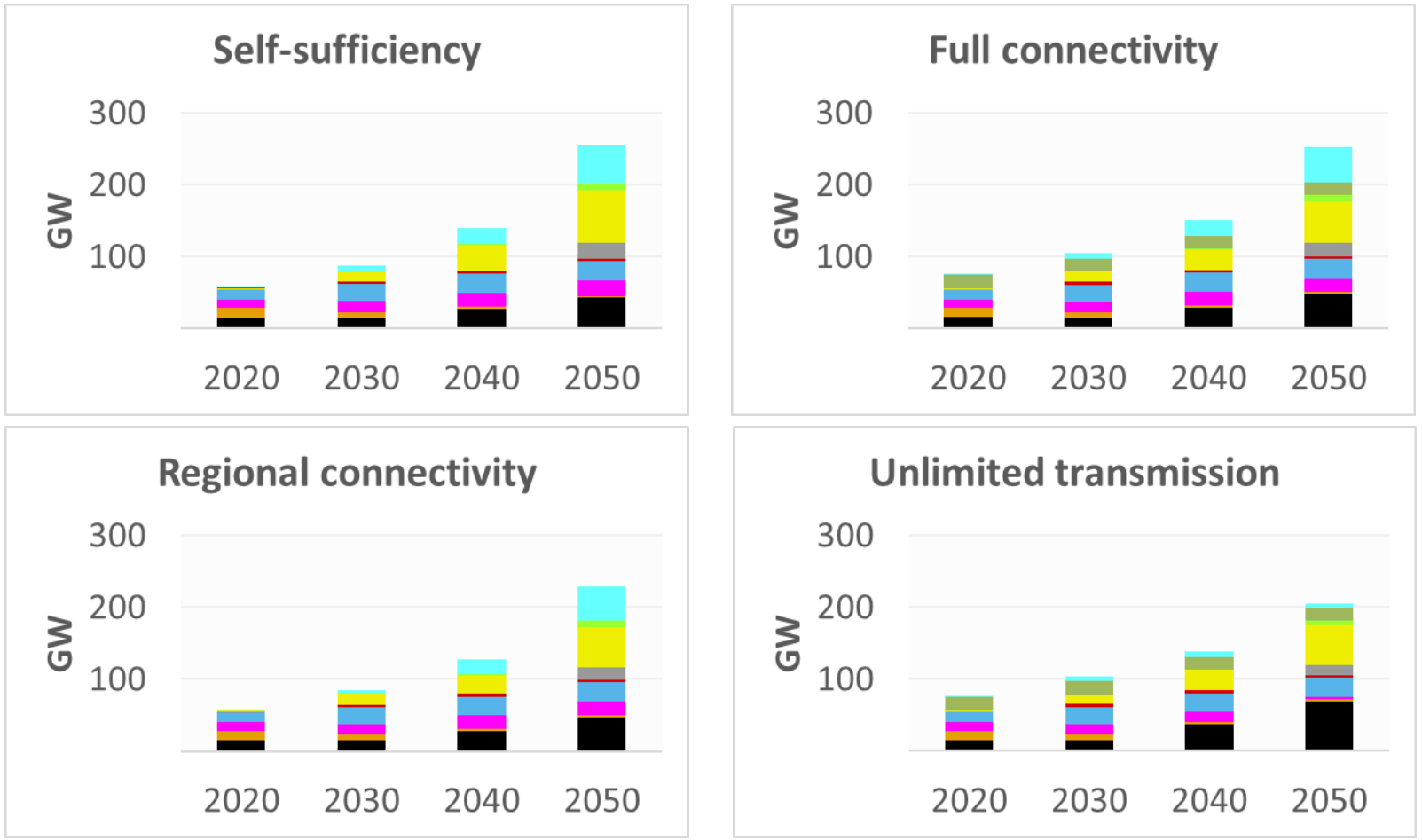


- Even greater carbon leakage than in other transmission scenarios
- Significant decrease in generation in TKM due to price differential between gas and coal
- Additional coal and solar generation in UZB for export to TKM

Excludes generation by battery storage

Discussion

Electricity production capacity (all regions)

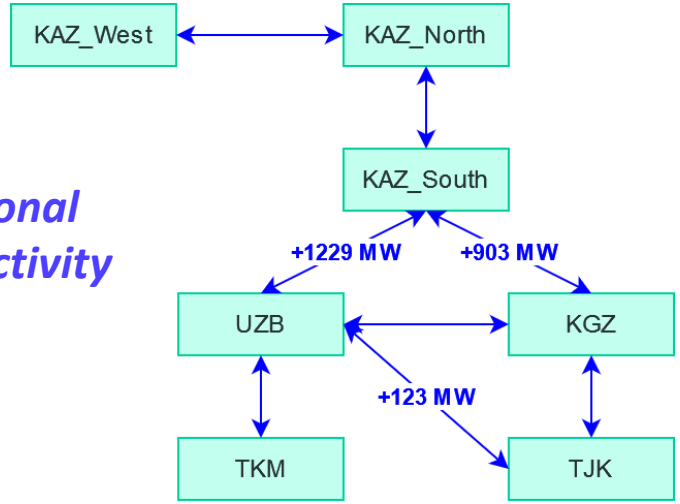


- All scenarios foresee considerable growth in renewables – solar, hydro, and wind (averages in 2050: 60 GW, 26 GW, and 39 GW respectively)
- Some adoption of batteries despite reservoir hydro assets (9 GW of batteries on average in 2050, mainly in KAZ, TKM, UZB)
- Nuclear added in KAZ and UZB to meet national targets (3.4 GW, no endogenously selected nuclear)
- Inter-scenario comparisons show relationship between increased transmission and carbon leakage – more coal in enhanced connectivity scenarios, less wind, gas, solar, and storage

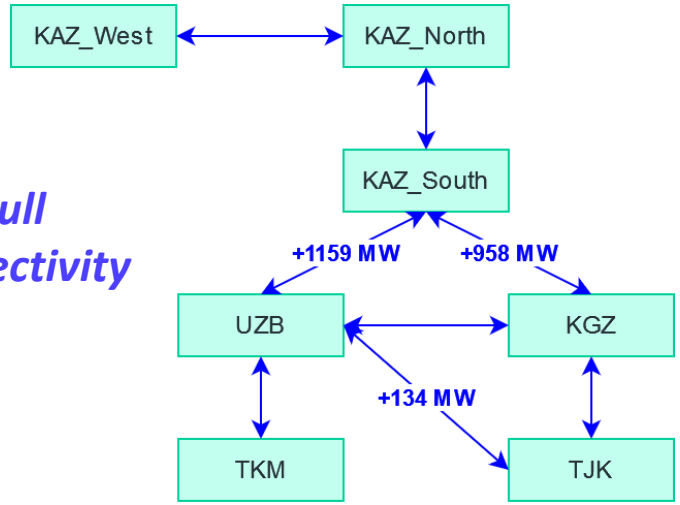
Electricity transmission capacity

Candidate capacity added

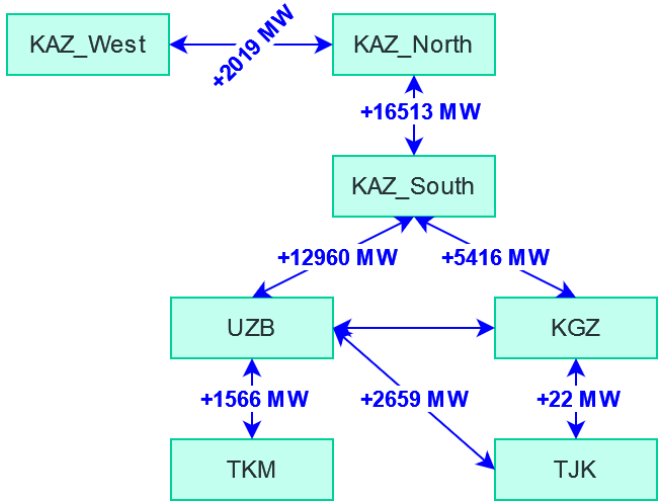
Regional connectivity



Full connectivity

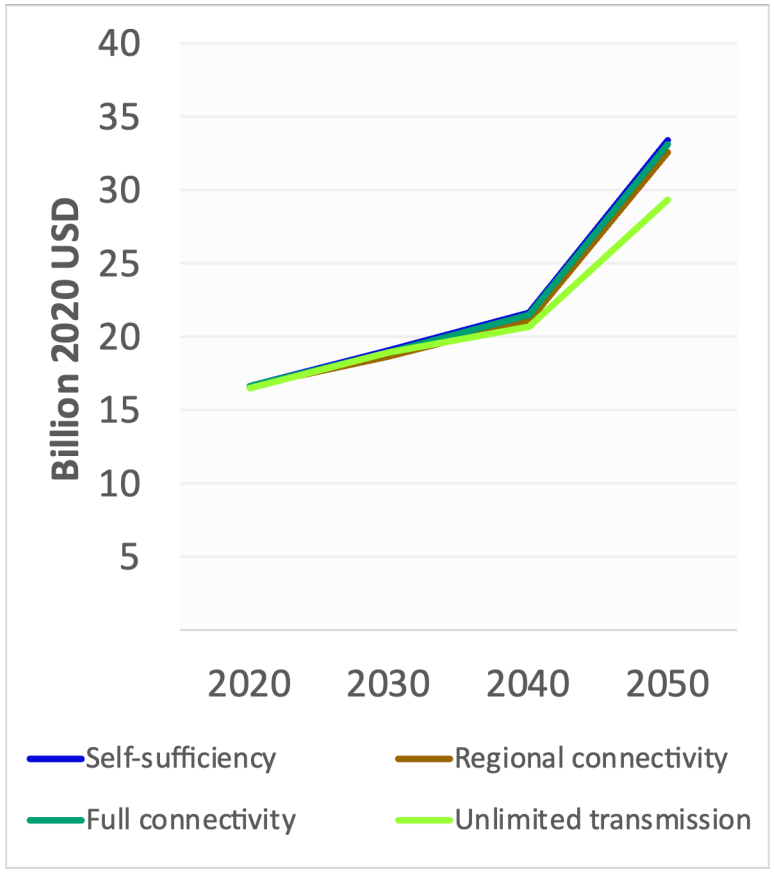


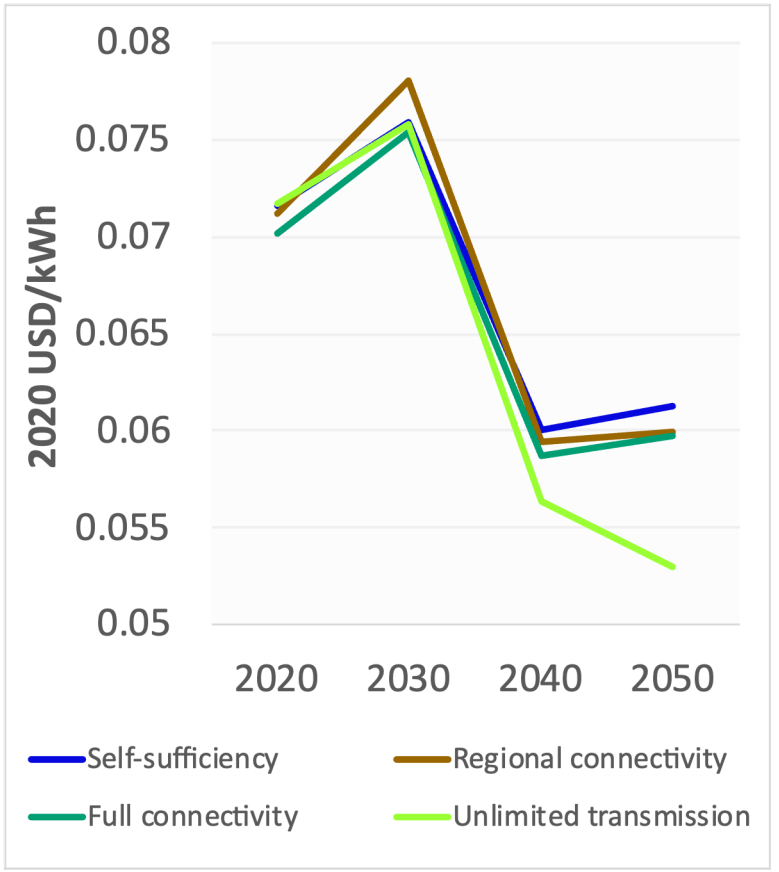
Unlimited transmission



- Similar results in Regional connectivity and Full connectivity scenarios, which have same options for candidate lines
  - Enhanced connections between KAZ_South and rest of UES CA
- Much higher additions in Unlimited transmission scenario, which unlocks potential for trade through better integration within KAZ and two-way exchange between UZB and TKM

Electricity production costs (all regions)

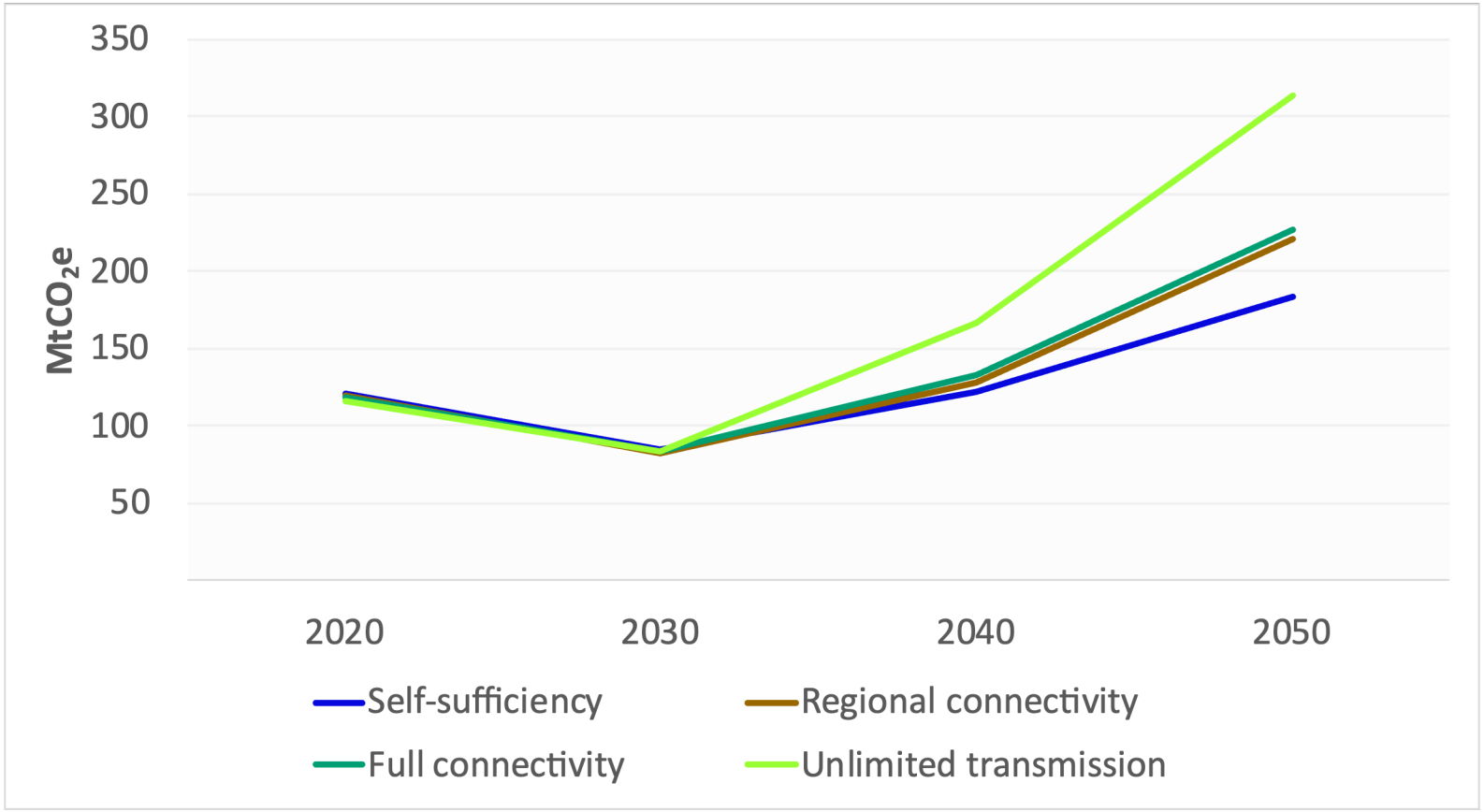




- Improved connectivity lowers electricity production costs
- Compared to Self-sufficiency scenario, Unlimited transmission reduces costs 12-14% in long run – a savings of $4 billion per year across all five countries

Includes capital, operations and maintenance, and fuel costs of electricity generation and storage; capital costs of candidate transmission capacity

GHG emissions from electricity production (all regions)



- Carbon leakage in enhanced transmission scenarios increases annual emissions by as much as 130 $MtCO_2e$ by 2050 (19% of total energy system emissions in 2050 in Self-sufficiency scenario)

Key take-aways from preliminary modeling

- Driven by cost advantages, new renewable power (in particular, solar, wind, and hydro) is likely to play a major role in meeting the region's growing demands for electricity
- Although hydro is the dominant source of renewable power in the region today, in the long run it will likely provide a smaller share of electricity generation than solar (and wind, depending on assumptions)
- Increased solar and wind power can be integrated by leveraging energy storage (reservoir hydro, batteries), transmission, and flexible thermal generation, among other options
- Enhanced electricity transmission connectivity has the potential to lower electricity system costs, but it also risks carbon leakage if decarbonization plans are uneven across the region
- Additional electricity transmission connections to and within KAZ appear to be highly cost-effective
- Unlike renewables, nuclear power's potential in the region appears more limited due to its relatively high costs

Potential model improvements

Improvement	Critical data needs
Explore scenarios with harmonized decarbonization assumptions – e.g., carbon price, renewable power share, % emission reductions	Assumptions validated by stakeholders
Refine peak load projections in electricity simulation	Nationally or regionally specific hourly load curves
Explicitly model gas transmission	Data on current, planned, and potential gas transmission – capacities, costs, historical usage
Localize fuel prices and technology costs in electricity modeling	Locally sourced price/cost data
Add pumped hydro storage – e.g., Khojikent and VerkhnePskemskaya in UZB?	Estimates of pumped hydro potential in region, information on current and planned pumped hydro projects
Model H_2 demand and H_2 technologies for electricity production	Projections of domestic H_2 demand
Add carbon capture for power generation	—
Improve representation of power purchase agreements and limitations	Terms of power purchase agreements/expected power trade, particularly with Russia, Iran, and Afghanistan

Discussion

Disclaimer

The views expressed herein are those of Jason Veysey and do not necessarily reflect the views of the United Nations.