Kazakhstan’s power system 2035: options for development

Insights from in-house modelling of Kazakhstan’s power sector

May 2025

Agora Energiewende

About Agora Energiewende

Who we are

Agora Energiewende is a think tank, policy lab, and part of the Agora Think Tanks

What we do

We develop scientifically sound and politically feasible strategies for a successful pathway to climate-neutral industry – in Germany, Europe and internationally

How we work

We are independent and non-partisan, with a diverse financing structure – our only commitment is to climate action

Where we take action

Agora Energiewende has offices in Berlin, Brussels, Beijing and Bangkok, and cooperates internationally with more than 20 partner organisations

Key Findings

1 **Kazakhstan is at a critical juncture where decisive policy action could unlock its significant clean energy potential.** Coal powers 66 percent of Kazakhstan's electricity and is responsible for 40 percent of its emissions, yet current plans to grow renewables to 25 percent by 2035 would cut power sector emissions by just 1 percent. Expanding renewables like solar and wind more rapidly is necessary to meet the country's 2060 carbon neutrality target.

2 **Ramping up renewables, avoiding new coal capacity and boosting the operational flexibility of existing fossil assets can accelerate a cost-effective transformation of the power sector.** By increasing the share of renewables to 35 percent by 2035, Kazakhstan could reduce power sector emissions by 4 percent compared to 2023 while lowering system costs by 40 percent compared to current plans. The ongoing update to the country's nationally determined contribution (NDC) under the Paris Agreement framework provides a timely opportunity to reflect these more ambitious measures.

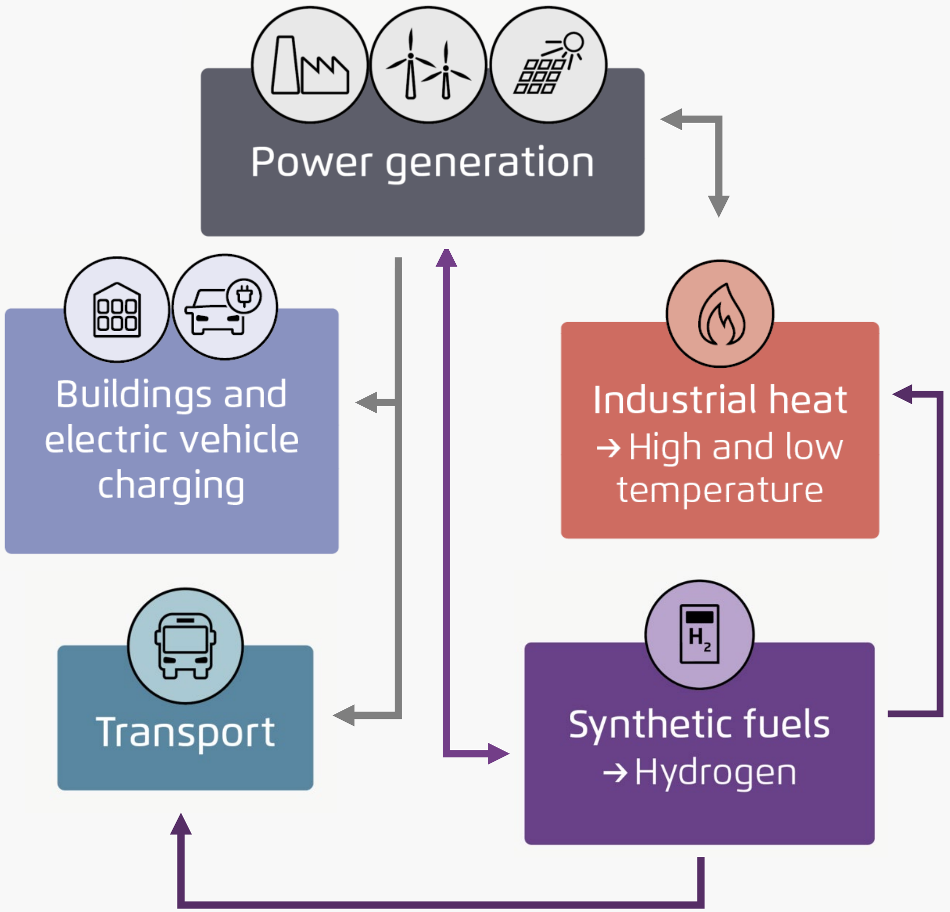
3 **Significant power system emissions reductions are achievable with higher domestic carbon prices.** A carbon price of around USD 40 per tonne by 2035 would increase renewables' share in power generation up to 47 percent and reduce power sector emissions by 44 percent compared to 2023, while lowering system costs by 1 percent versus current plans. A robust domestic carbon price would also reduce upcoming EU carbon border adjustment mechanism payments for Kazakh exporters, keeping revenues in-country which could then be reinvested in renewables and grids.

4 **Kazakhstan's vast and cost-efficient wind energy potential offers a particularly strong foundation for scaling up renewable energy capacity.** The country could increase its wind power capacity to 10 gigawatts by 2035, twice as much as the government is currently planning – or even more. Unlocking this potential would support deeper emission reductions and enable more ambitious national climate targets.

Contents

Agora’s suite of power system models

An Agora in-house PyPSA[1]-based model developed for multi-sector cost optimisation, with a focus on the power sector



- → **Multi-sector cost optimisation possible,** but only power sector modelled for this analysis
- → Over **40 technology options** for power generation and industrial heat supply, including emerging technologies, such as Power-to-X, carbon capture and storage and battery storage
- → **Optimised power sector** investment and generation
- → Buildings with prosumers and optimised electric vehicle charging
- → **Transport demand** met by conventional fuels, synthetic fuels and electricity
- → **Industrial heat demand** represented as two different temperature levels (high and low). Heat demand met through a mix of boilers and electrification

Agora's in-house PyPSA-based model (2025); [1] PyPSA: Python for Power System Analysis (https://pypsa.org/)

Model-based analysis of Kazakhstan’s power system

Cost optimisation modelling used for analysis, with local data where possible

Inputs

→ Techno-economic parameters of various technologies, including CAPEX, [1] OPEX, [2] efficiency, ramp limits, fuel use, emission factors

→ Other macro-economic parameters, including fuel costs and interest rates

→ Time series and capacity factors per region for wind and solar from ERA5[3] datasets

→ Electricity demand time series per region

→ …

Modelling

→ Total system cost minimization (using PyPSA[4] framework)

- Techno-economic constraints
- Hourly resolution
- Full-year co-optimisation of generation and capacity (myopic)
- Kazakhstan represented by 3 regions

Outputs

→ Optimised investments by region for each technology

→ Average and hourly prices by region

→ Optimised hourly dispatch for the entire year

→ Net electricity flows between each region

→ Capacity factors for each technology by region

→ Carbon dioxide emissions from each technology by region

→ …

Agora's in-house PyPSA-based model (2025); [1] CAPEX: annualised capital expenditure; [2] OPEX: operational expenditure (fuel, operation and maintenance); [3] Hersbach, H., et al. (2023): ERA5 hourly data on single levels from 1940 to present. Copernicus Climate Change Service Climate Data Store (https://doi.org/10.24381/cds.adbb2d47); [4] PyPSA: Python for Power System Analysis (https://pypsa.org/)
Note: Kazakhstan is represented by 3 regions: North (NR), WEST (WS) and South (SO). Transmission capacities across regions are kept constant due to a lack of information on grid development planning

Three pathways modelled for the power sector* up to 2035

	Reference (REF)	Reference Plus (REF+)	Renewables (RES)
Narrative	Investigating cost-optimal dispatch under national planned capacities	Power system under cost-optimal dispatch and capacity expansion	Exploring higher ambition of minimum renewable generation with **30% in 2030** and **35% in 2035**
Capacity	Following national plan	• **Endogenous capacity expansion**[1] based on least-cost optimisation • **Coal decommissioning** following **national plan**	
Fuel costs	**Domestic cost assumptions**		
Power plant retrofit	All power plants older than their technical lifetime are assumed to continue operating and pay annualised retrofit capital expenditure (e.g., **71%** of CAPEX for coal-fired power plants)		
Generation	Least-cost optimal dispatch with following constraints: • With **full load hour (FLH) restrictions** for coal (at base year level of max **67%**) and hydropower (at max **43%**) • Other renewable generations are restricted by resource availabilities		
Emission constraint	Carbon price at USD 1 per tonne of carbon dioxide (CO_2)**		
Demand	• Using existing total generation assumptions as demand and assuming zero transmission loss • Demand pattern per region based on 2017 profiles		
Interconnection	Only between the **domestic regions –** imports/exports from the neighbouring countries not considered		
Interest rate	**10%** for main scenarios		

* Sector coverage of the model: only power sector is included, hence no district heating assumption. Combined heat and power (CHP) plants only serve for power generation; **With sensitivity conducted ranging from USD 1-40 per tonne of CO_2; [1] Except hydropower, which follows the national plan; [2] Source: Global Energy Monitor (2025) (https://globalenergymonitor.org/projects/global-coal-plant-tracker/)

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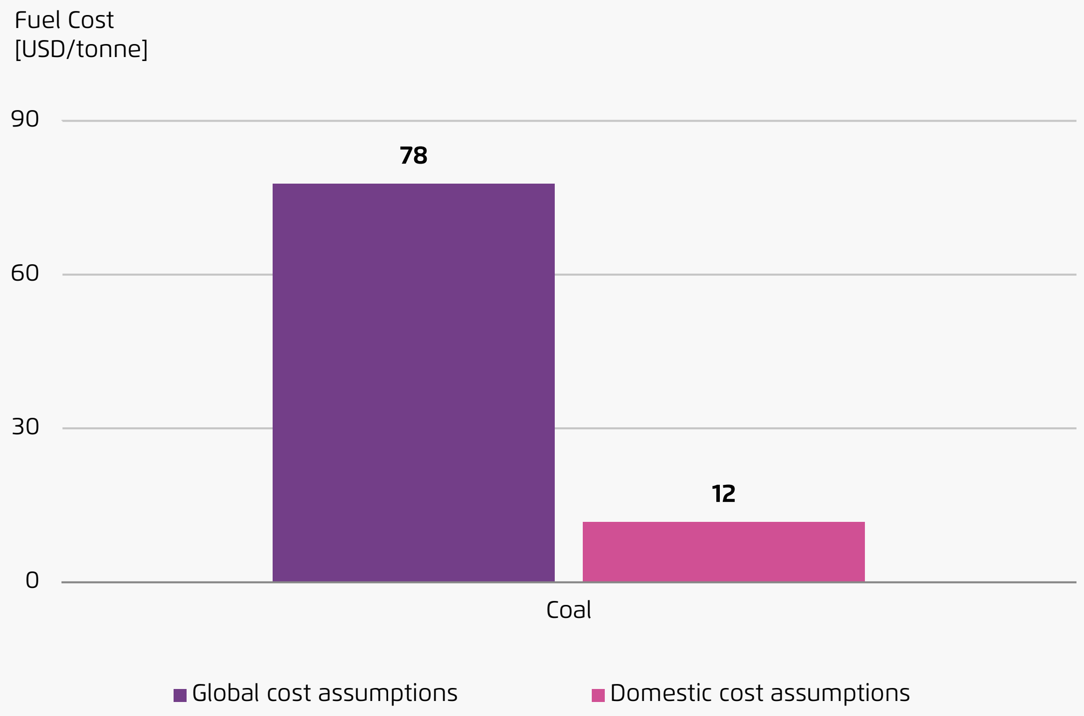
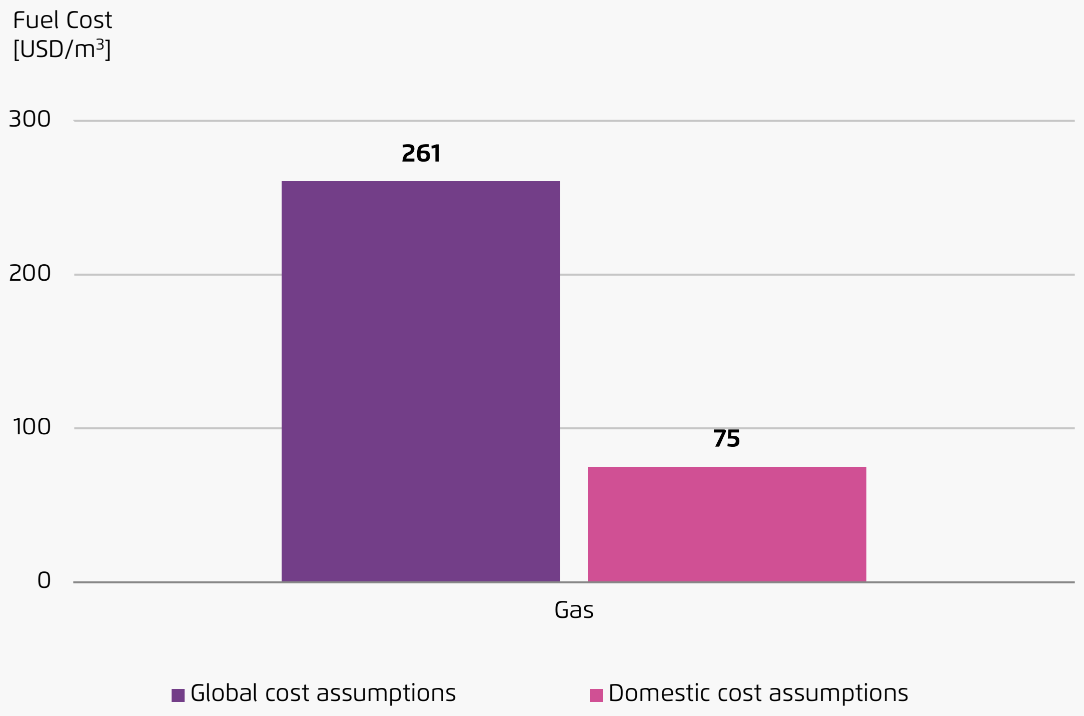
For the purposes of the analysis, coal and gas prices set to domestic levels; future reliance on gas could yield higher costs due to scarcity

Input fuel cost for coal-fired power plants in 2023



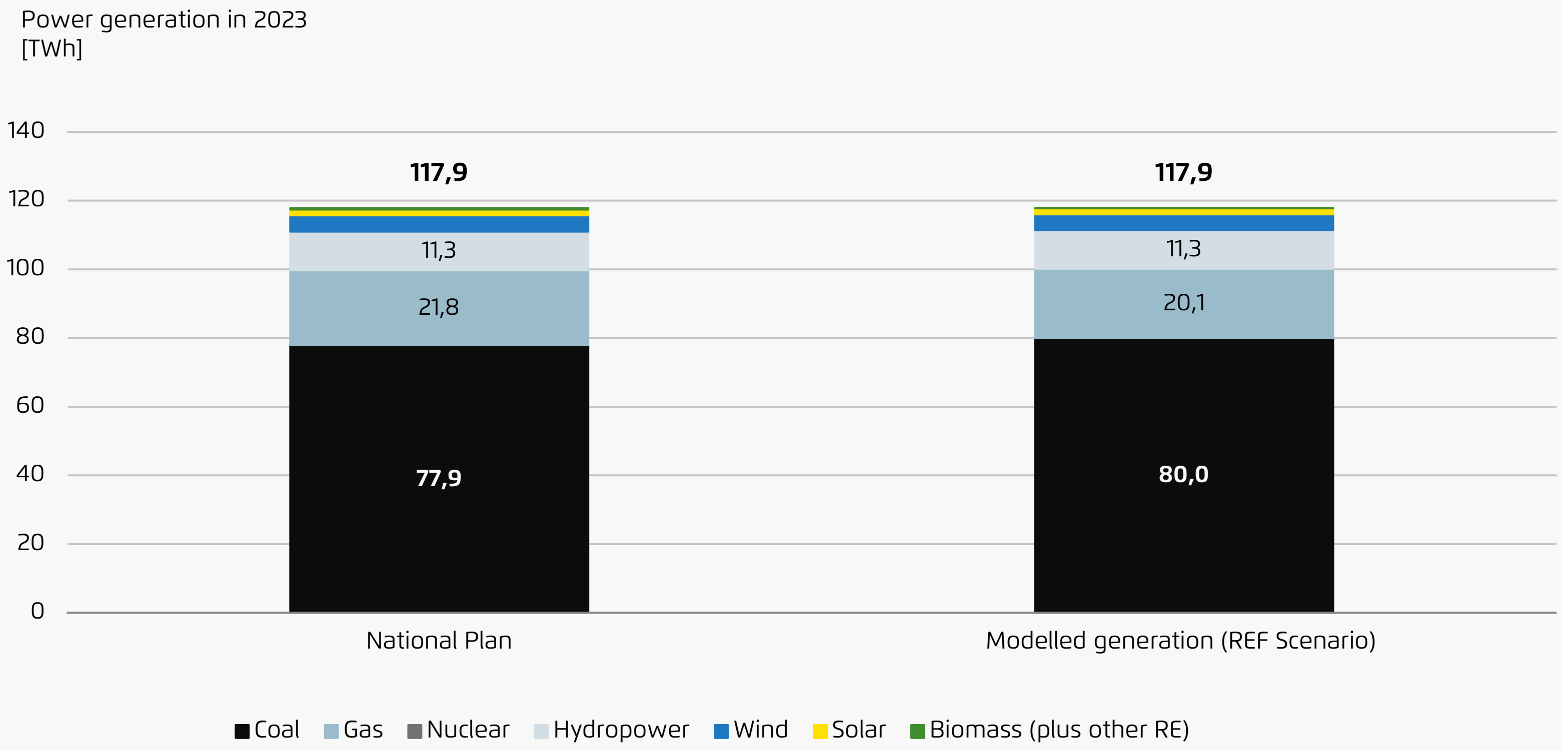
Input fuel cost for gas-fired power plants in 2023



DIW (2013). Current and prospective costs of electricity generation until 2050; Inbusiness.kz (2023). Capital thermal power plants to increase heating tariffs in midwinter; Information and legal system of regulatory legal acts of the Republic of Kazakhstan (2023). On approval of maximum prices for wholesale sales of commercial gas on the domestic market of the Republic of Kazakhstan; with Agora's own calculations.

Model calibrated using data from national sources to enhance accuracy and alignment with the national plan

Power generation in 2023 – comparison of model results and data from the national plan



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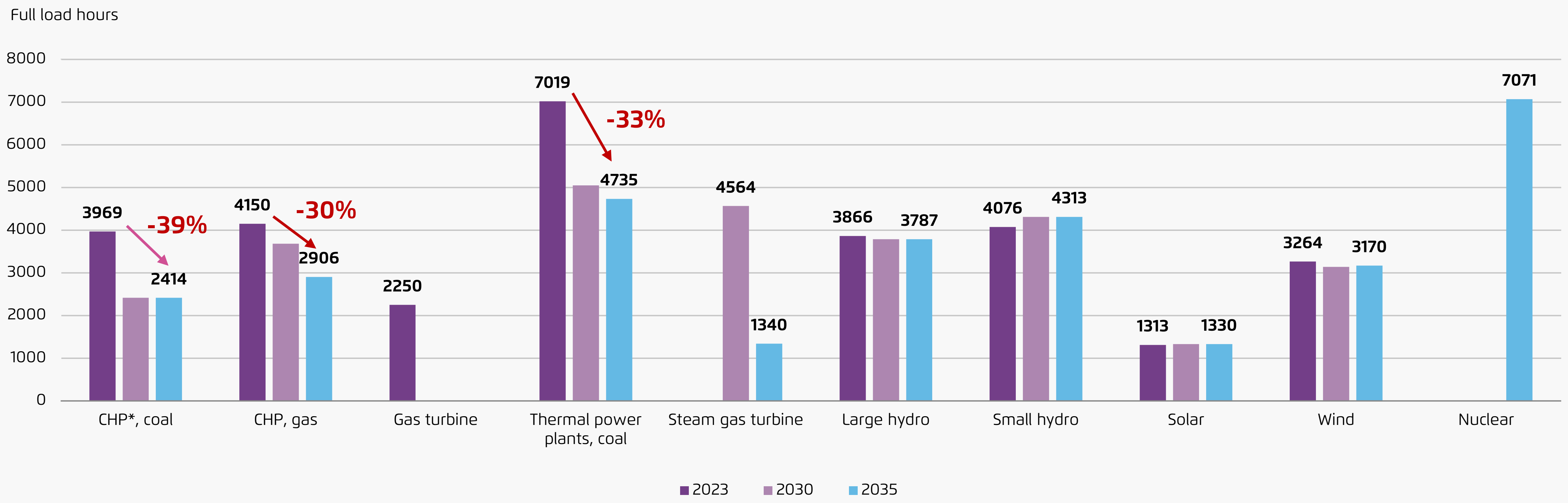
National plan foresees reduced utilisation of coal and gas power plants, raising risk of financial losses and stranded assets

Utilisation (in full load hours) of various power generation technology in the **national plan** from 2023–2035



 Order of the Minister of Energy of the Republic of Kazakhstan dated March 24, 2022 No. 104 "On approval of the Energy Balance of the Republic of Kazakhstan until 2035";
* CHP: combined heat and power

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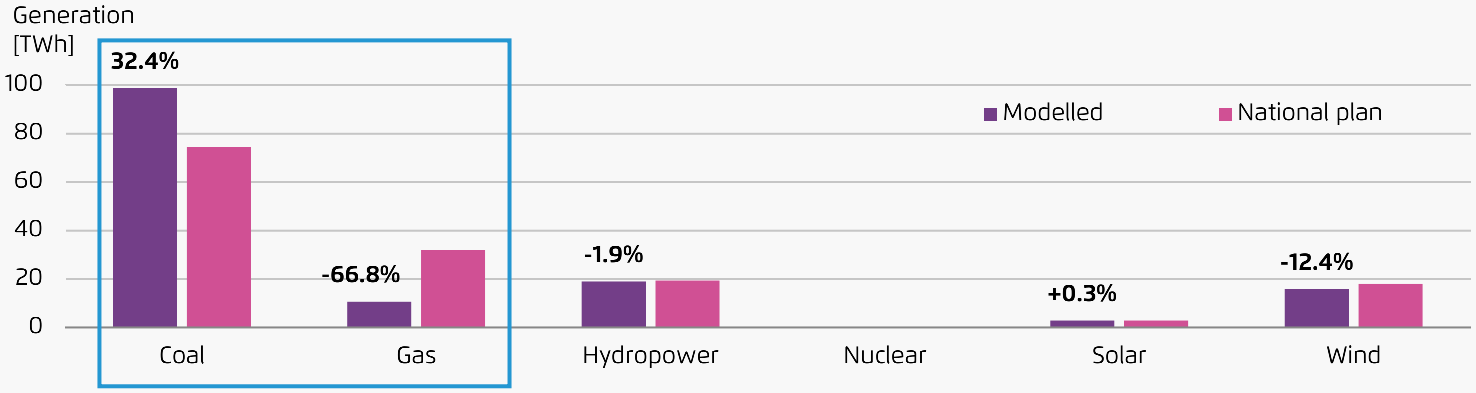
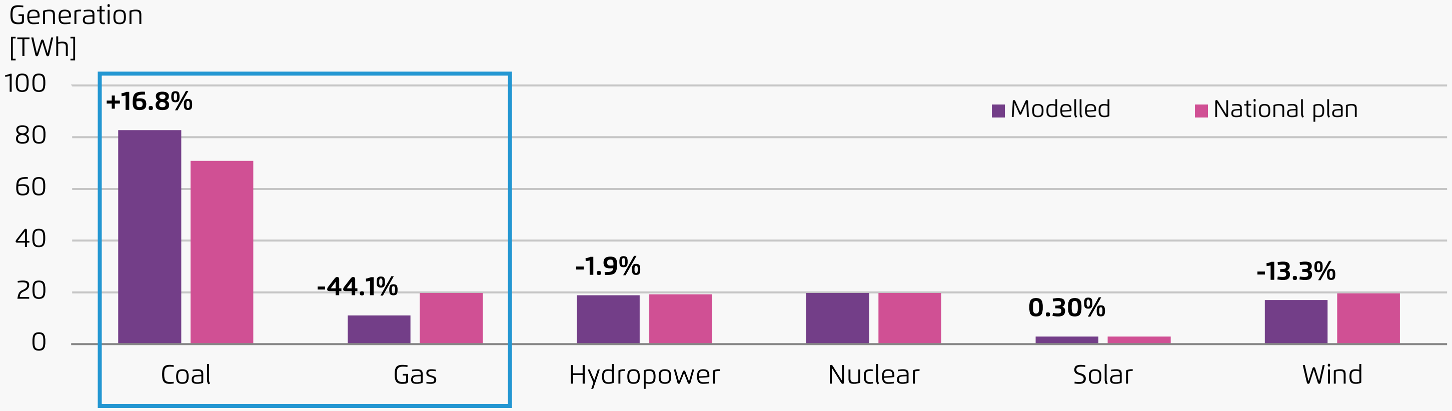
Model shows higher generation coming from coal than the national plan, suggesting unknown constraints in national estimates

Modelled power generation (REF) vs national plan in 2030



Modelled power generation (REF) vs national plan in 2035



Possible explanations:

→ Restriction on coal supply in the future

→ National plan's assumption for lower FLHs of coal power plants due to ageing coal fleets

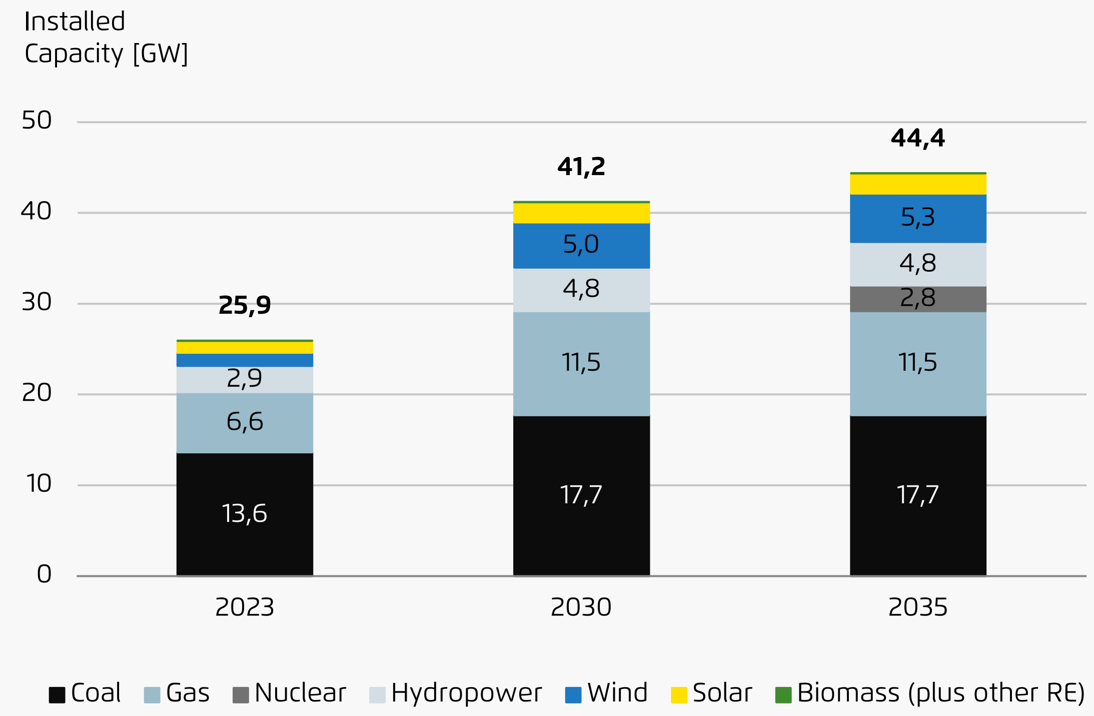
→ Unknown emission constraints from estimation of the national plan

→ Gas must-run hours due to power purchase agreements (PPAs)

Insights from scenario-based analysis

Cost-optimal power system transformation up to 2035 (REF+) requires no new coal or gas; added wind with existing gas capacity meet projected demand

Capacity expansion pathway under national plan (**REF scenario**)



Capacity expansion pathway in **REF+ scenario**

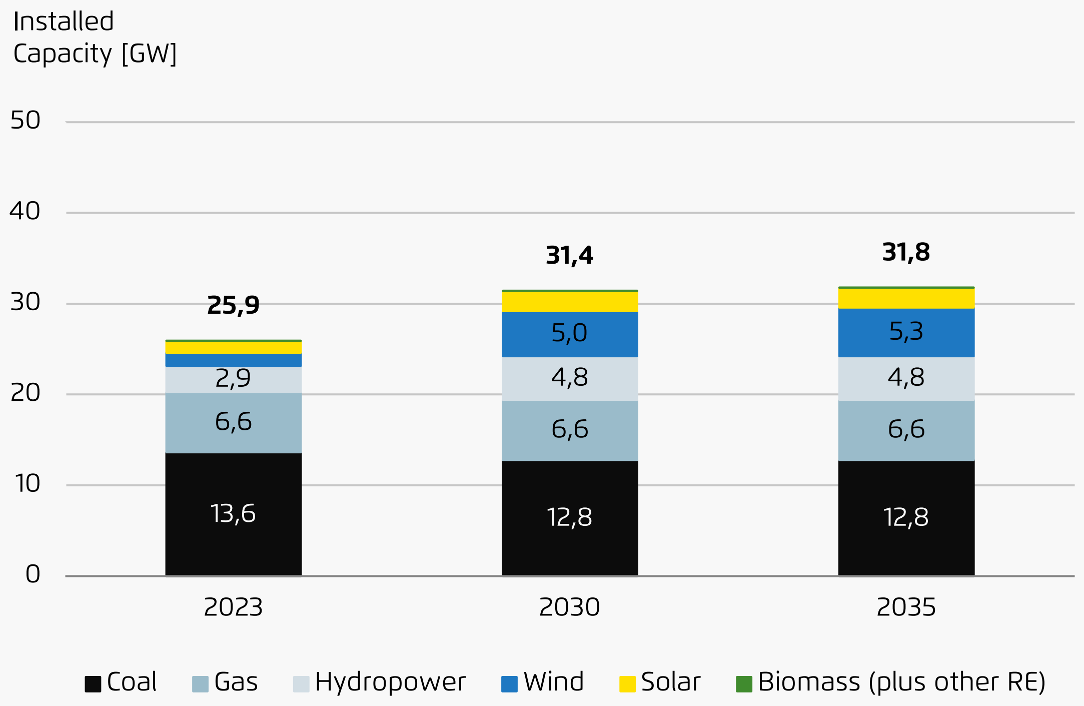


 Figure left: KEGOC's plan in combination with Agora's own calculation using GEM dataset (2025); Figure right: Agora's in-house PyPSA-based model (2025)

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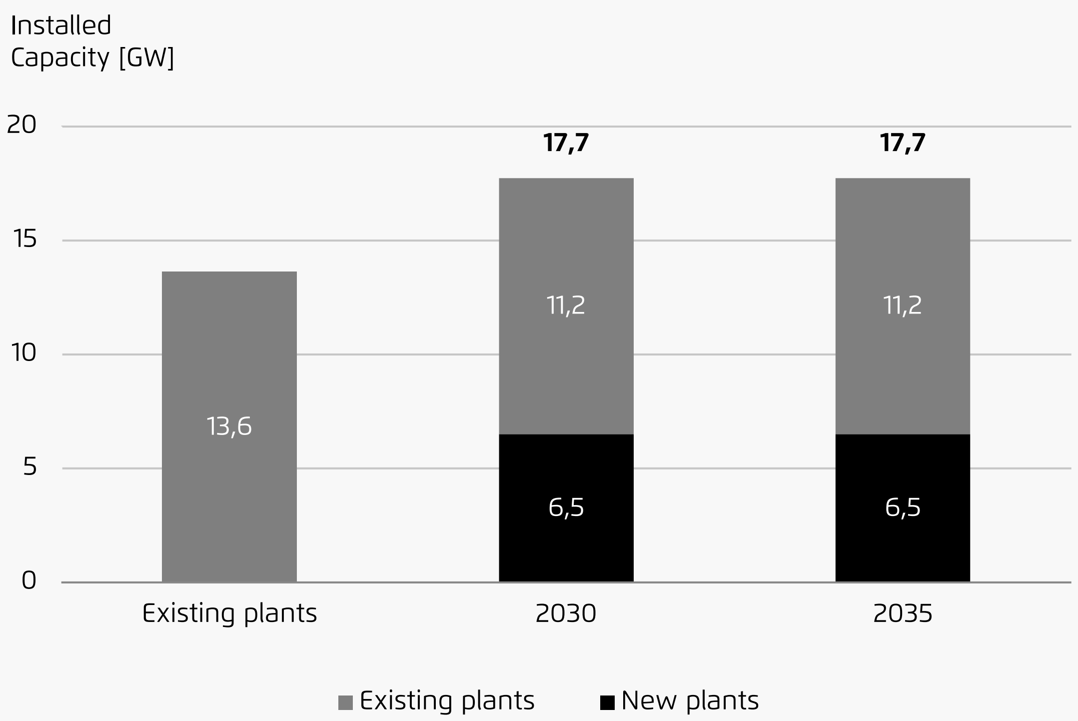
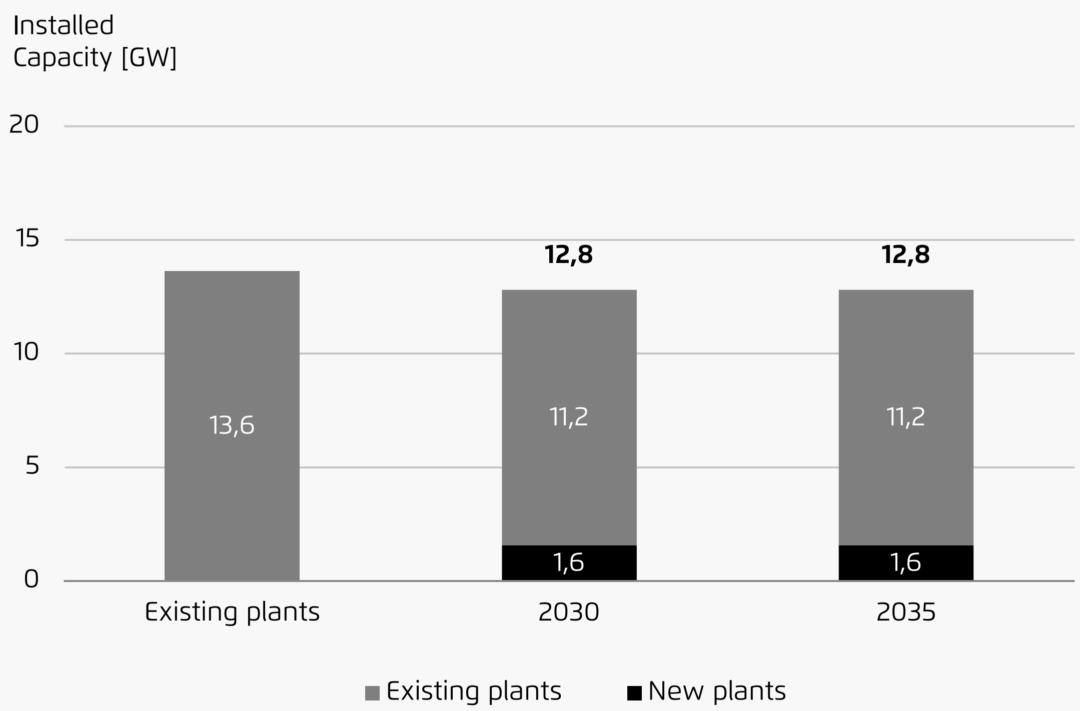
While national plan foresees 6.5 GW of new plants by 2030, REF+ scenario does not build additional new coal plants for cost reasons

Coal capacity under national plan (REF scenario)



→ Approximately 5 GW of new coal-fired power plants are planned to be operational by 2030.

Coal capacity in the REF+ scenario

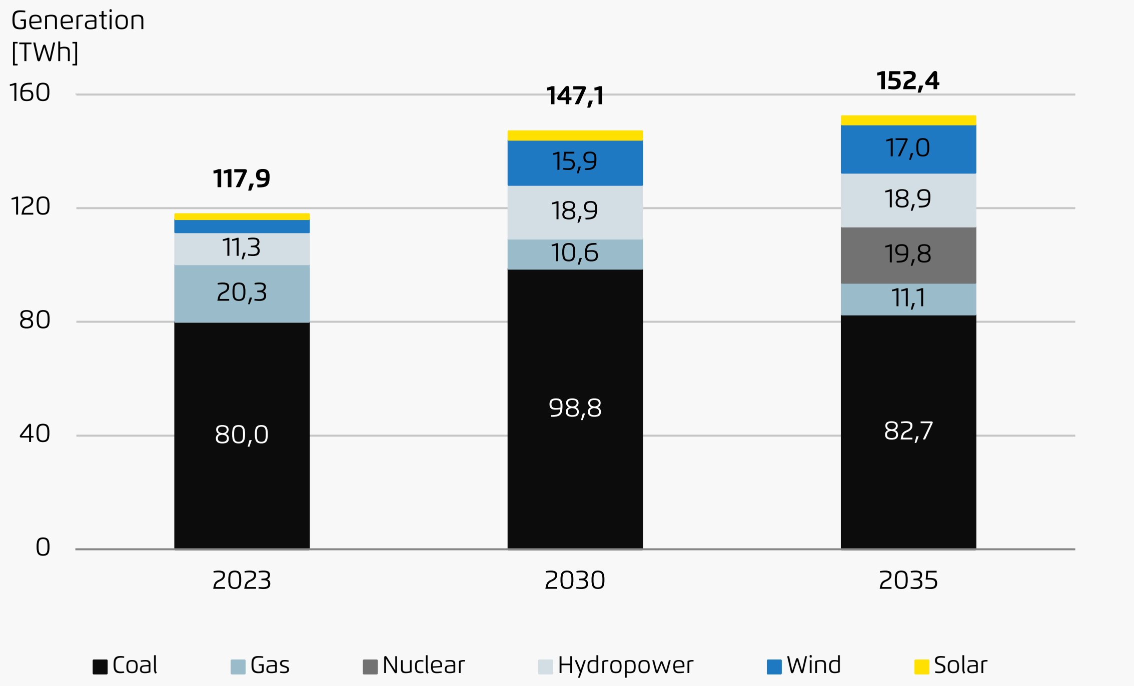


→ Existing coal assets are utilised while additional coal investment are halted compared to the national plan.

 Figure left: KEGOC's plan in combination with Agora's own calculation using GEM dataset (2025); Figure right: Agora's inhouse PyPSA-based model (2025)

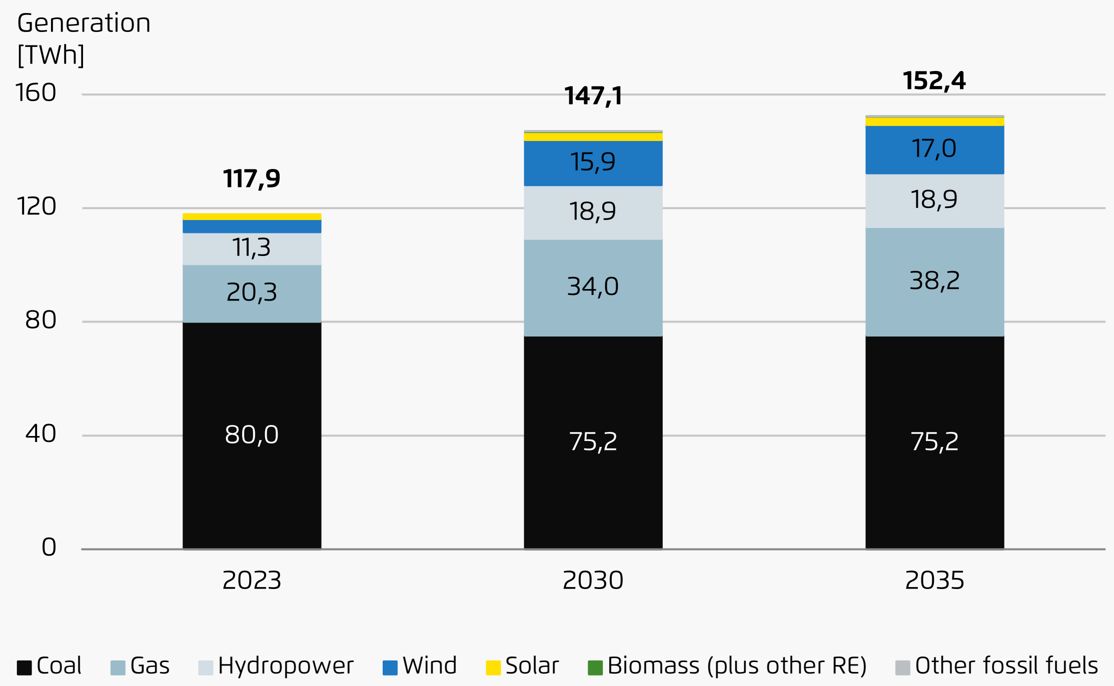
Planned national capacity shows more coal-fired & less gas-fired power generation, potentially risking climate targets & stranded investments in new gas power plants

Power generation under national plan (REF scenario)



→ Gas-based generation is cut by half in 2030 compared to 2023, offset by a 2.2-fold increase in wind+hydro power generation over the same period.

Power generation in REF+ scenario

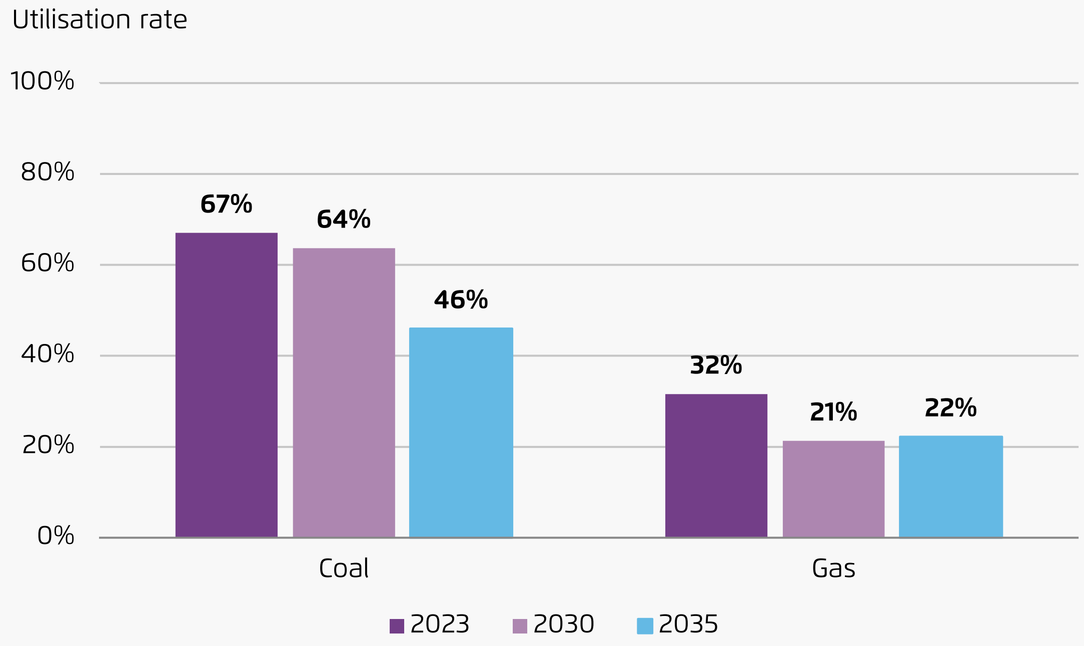


→ Gas generation increase from 20.3 TWh to 38.2 TWh with more wind+hydro expansions.

 Figure left: KEGOC's plan in combination with Agora's own calculation using GEM dataset (2025); Figure right: Agora's inhouse PyPSA-based model (2025)

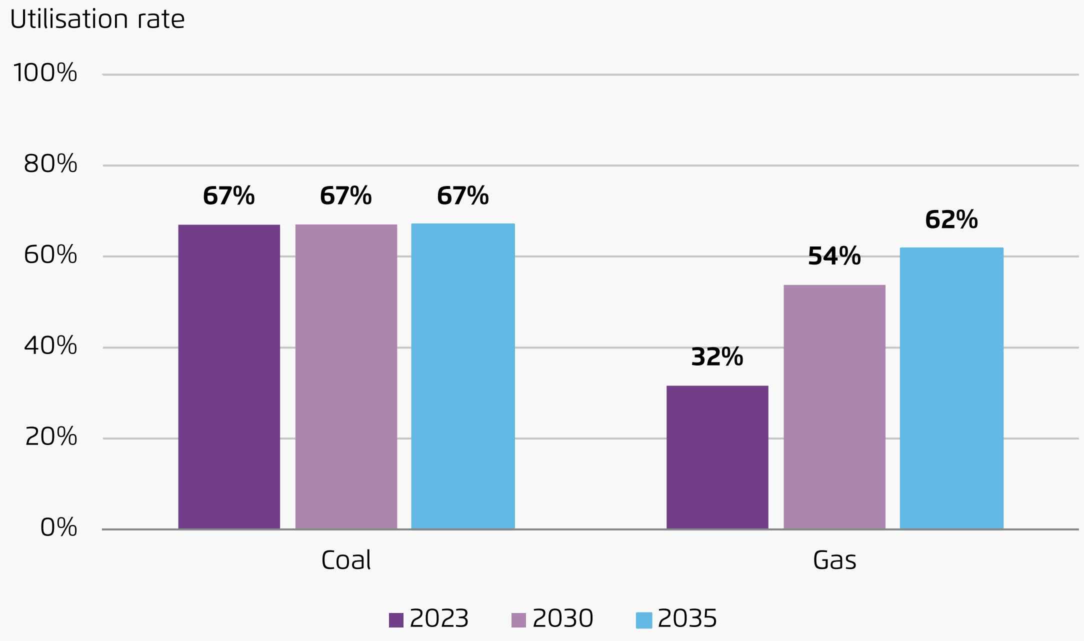
In contrast to the REF scenario, the REF+ scenario increases gas utilisation

Utilization rate of coal and gas power plants under national plan (REF scenario)



→ Low utilisation rate of gas power hints a risk of stranded assets for new gas plants.

Utilization rate of coal and gas power plants in REF+ scenario

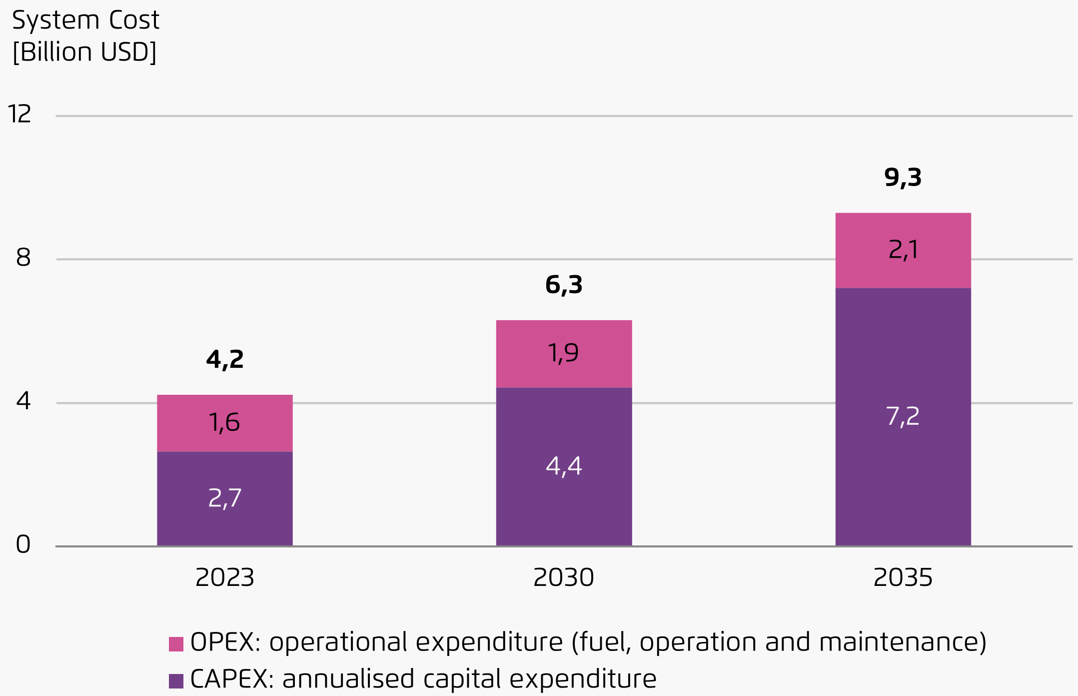


→ Utilisation rate of gas plants increase from 32% in 2023 to 62% in 2035 to flexibly adapt generation from wind.

 Figure left: KEGOC‘s plan in combination with Agora‘s own calculation using GEM dataset (2025); Figure right: Agora’s inhouse PyPSA-based model (2025)

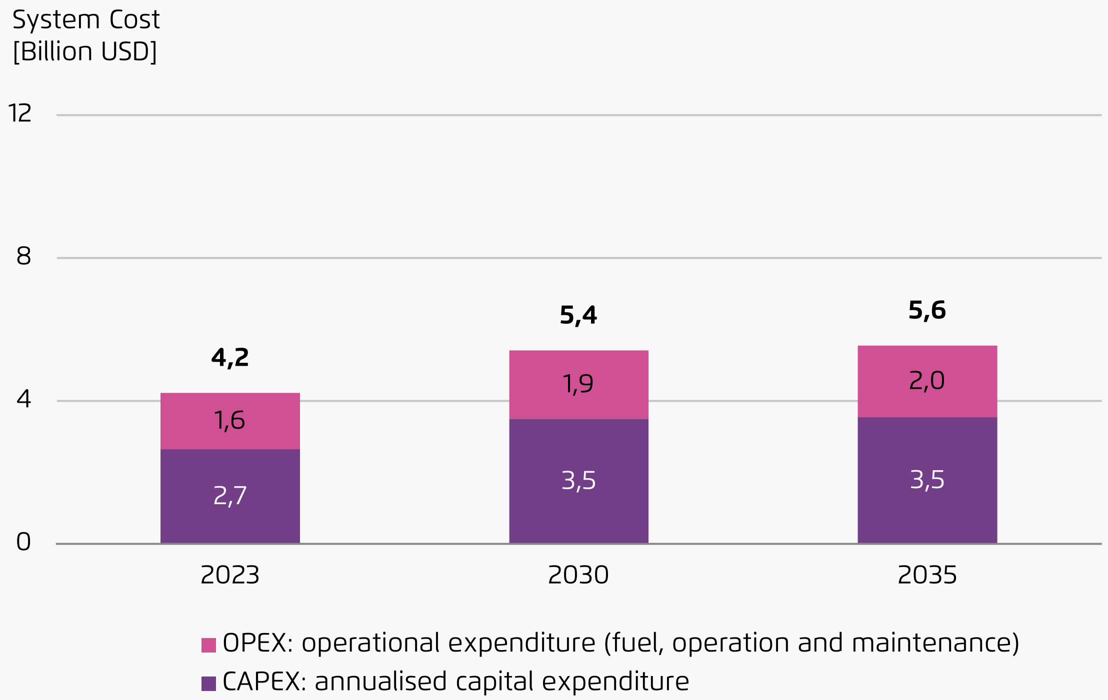
National plan's large investments in new coal & nuclear power plants would raise system costs by two-thirds, vs REF+ scenario using existing gas assets & expanding renewables

Total system cost under national plan (REF scenario)



→ System costs more than double by 2035, driven mostly by increased CAPEX for new fossil fuel capacity in 2030 and nuclear expansion in 2035

Total system costs in REF+ scenario

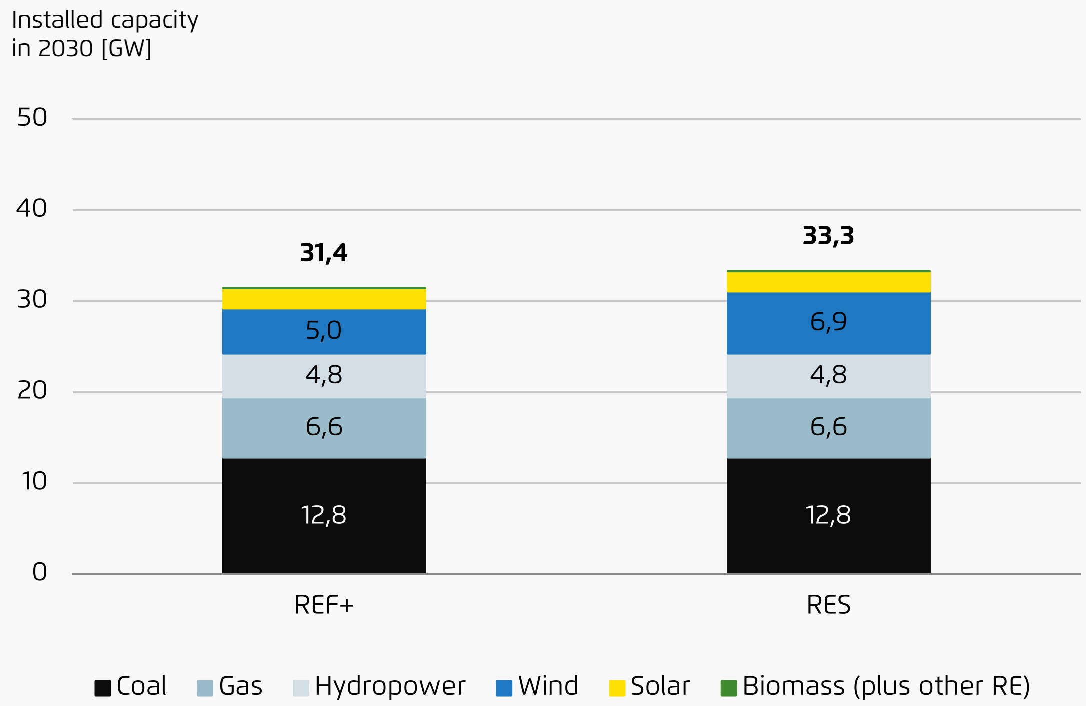


→ Approximately USD 3.7 billion in system costs can be avoided in 2035 as compared to REF scenario

 Figure left: KEGOC's plan in combination with Agora's own calculation using GEM dataset (2025); Figure right: Agora's inhouse PyPSA-based model (2025)

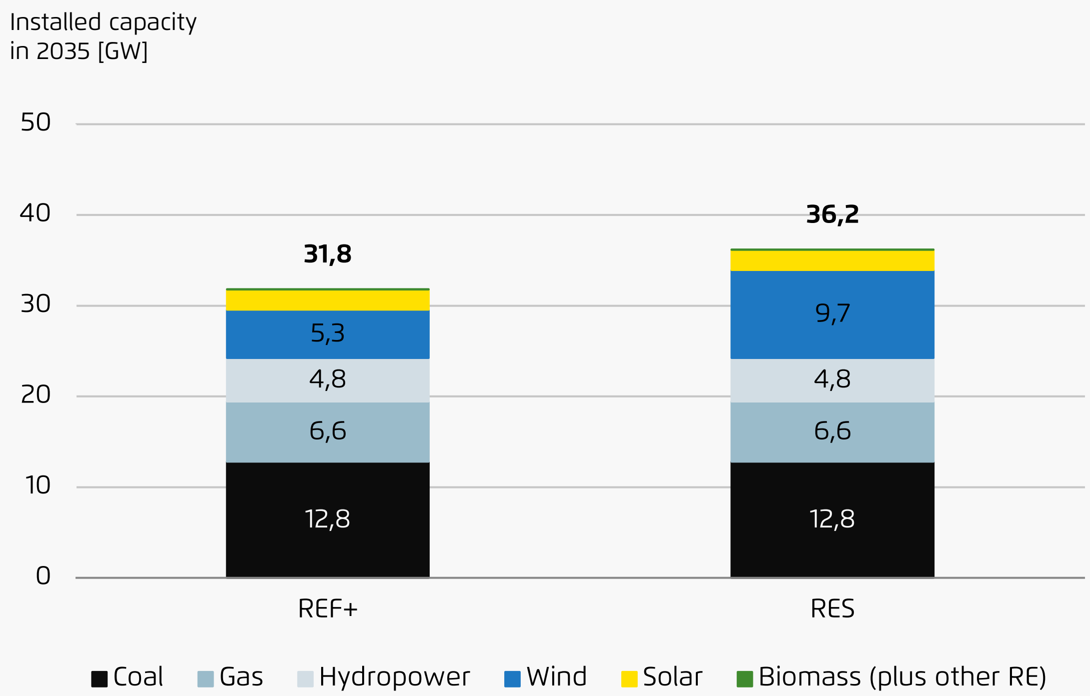
Kazakhstan's abundant, competitive wind resources could modernise power system and meet higher renewables targets at similar costs to current plan

Capacity expansion in 2030 REF+ vs RES scenario



→ 1.9 GW additional wind power could be deployed to meet 30% renewable generation share by 2030 in RES vs REF+ scenario

Capacity expansion in 2035 REF+ vs RES scenario



→ 4.4 GW additional wind power could be deployed to meet 35% renewable generation share by 2035 in RES vs REF+ scenario

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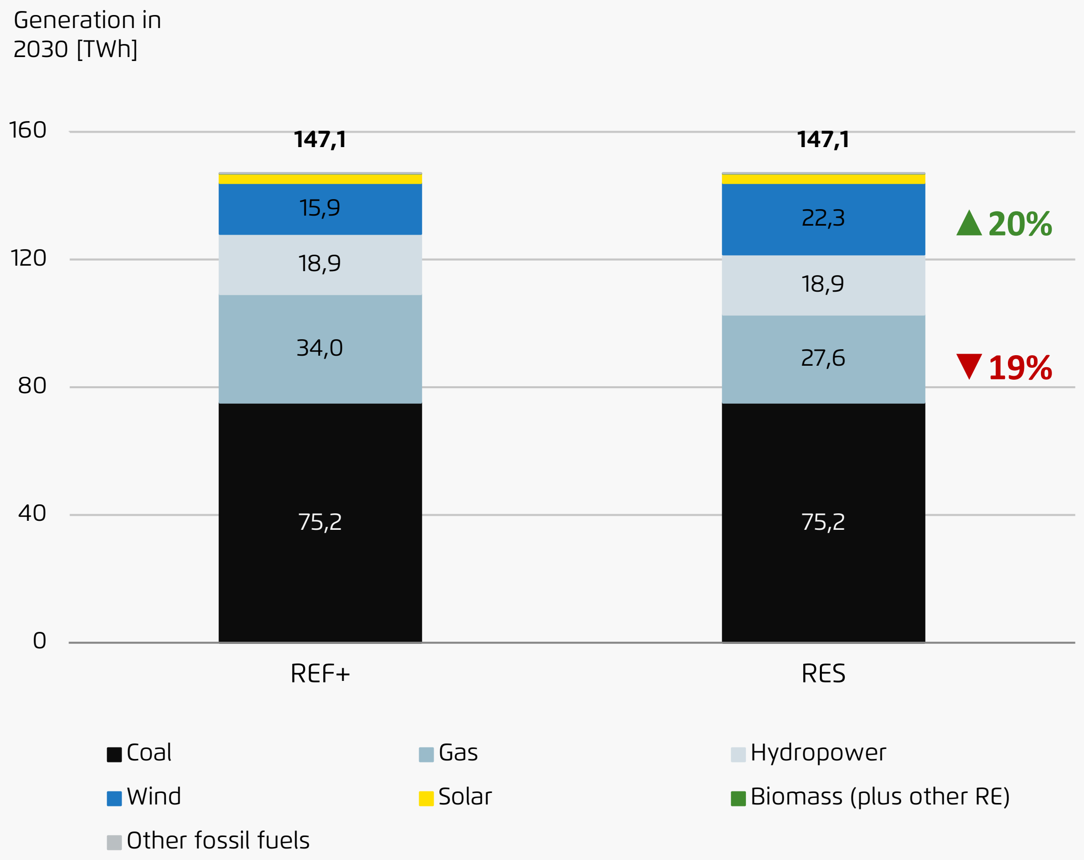
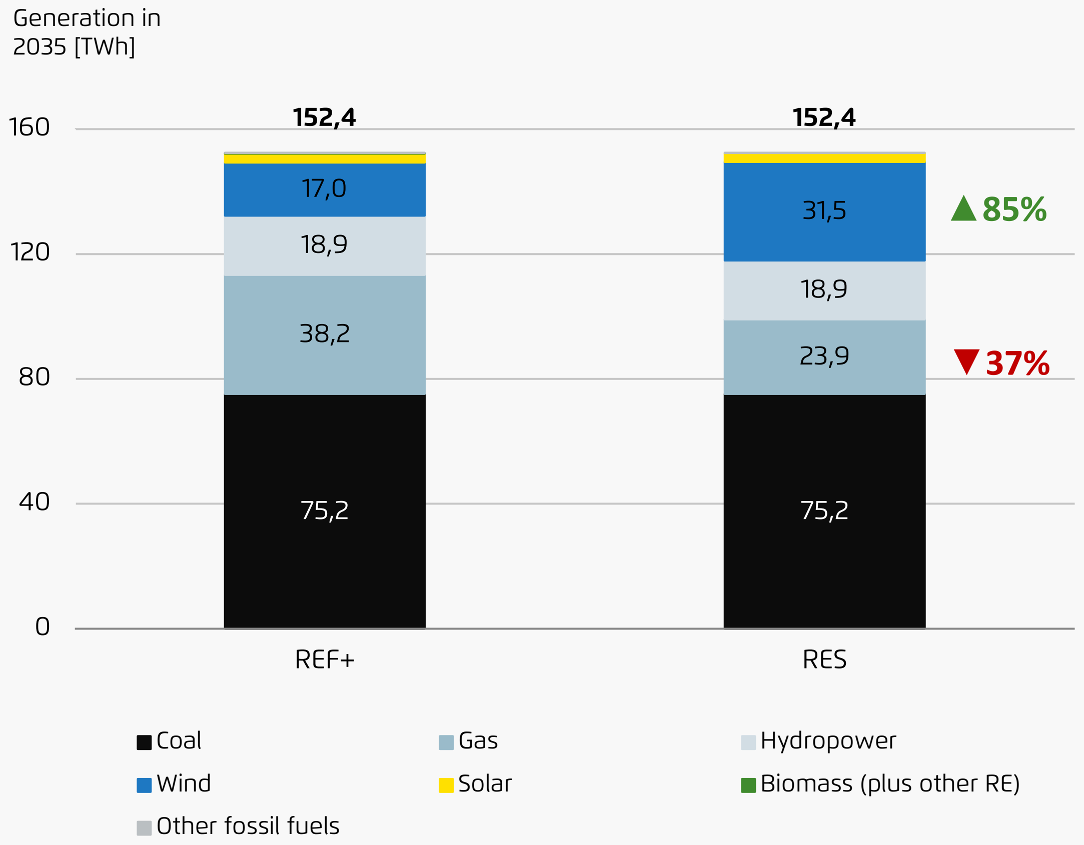
With added investment, Kazakhstan's power system can integrate 85% more wind-powered generation, compensate for 40% reduced fossil gas generation

Generation in 2030 between REF+ and RES scenario



Generation in 2035 between REF+ and RES scenario



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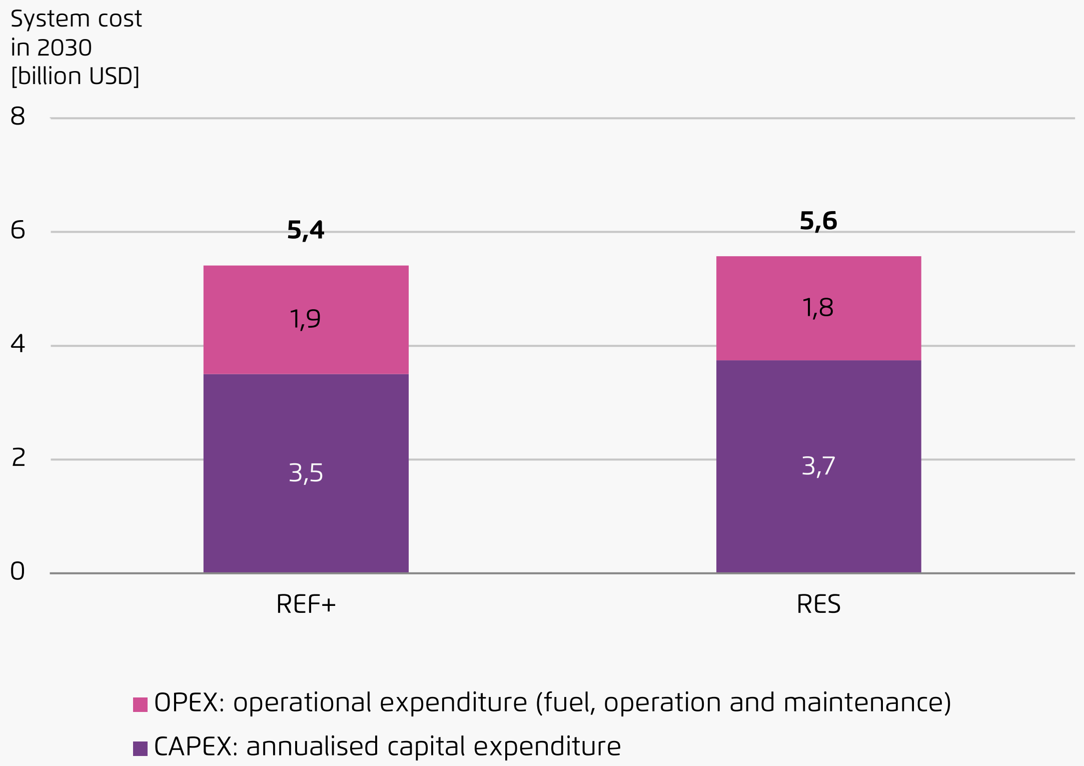
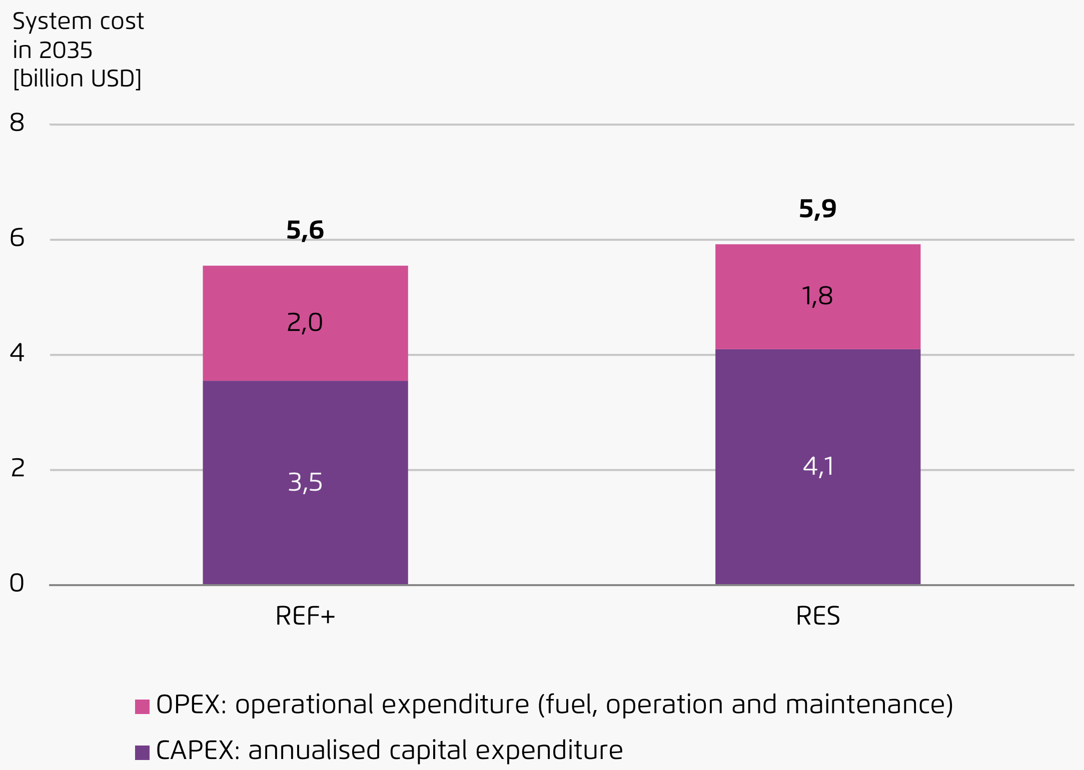
With added investment, Kazakhstan's power system can integrate 85% more wind-powered generation, compensate for 40% reduced fossil gas generation

Total system cost in 2030 REF+ vs RES scenario



→ Additional USD 200 million investment beyond REF+ scenario can enable a 30% share of renewable energy generation by 2030

Total system cost in 2035 REF+ vs RES scenario



→ Additional USD 300 million investment beyond REF+ scenario can enable a 35% share of renewable energy generation by 2035

Figure left: Agora's in-house PyPSA-based model (2025); Figure right: Agora's inhouse PyPSA-based model (2025)

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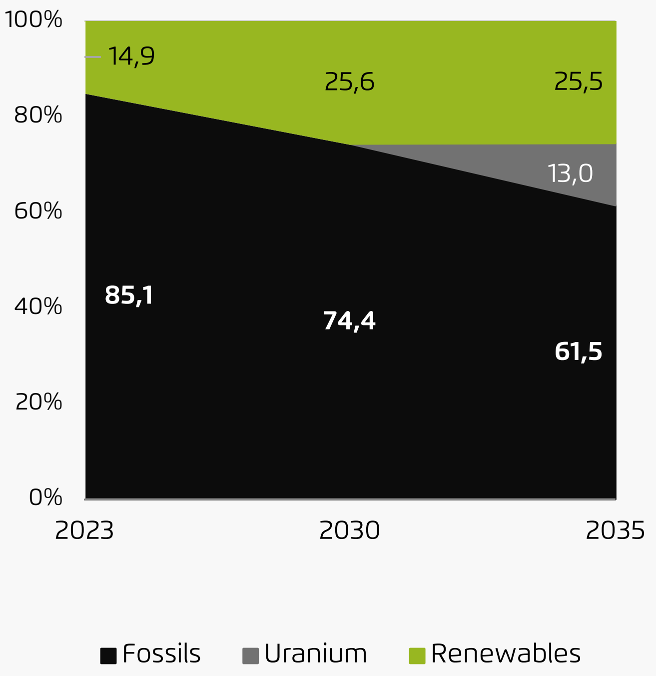
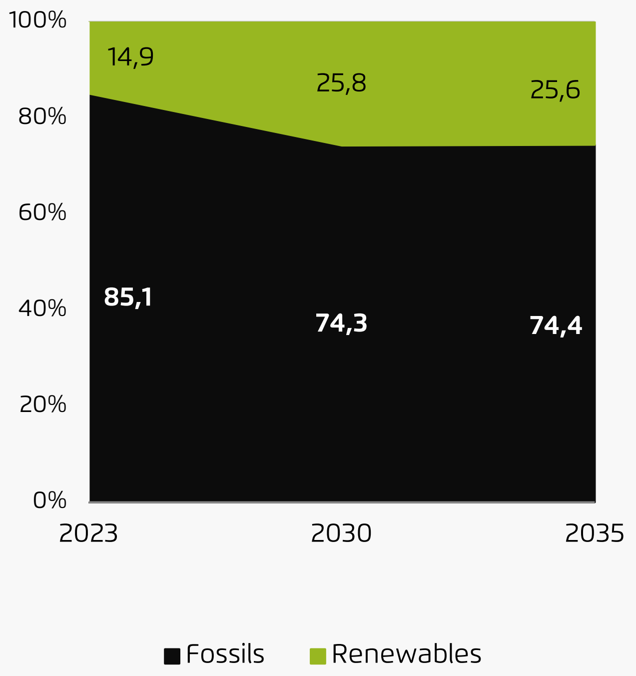
Summary of three modelled pathways

Development of renewable energy share across the three scenarios

Renewable generation share in REF scenario



Renewable generation share in REF+ scenario



Renewable generation share in RES scenario

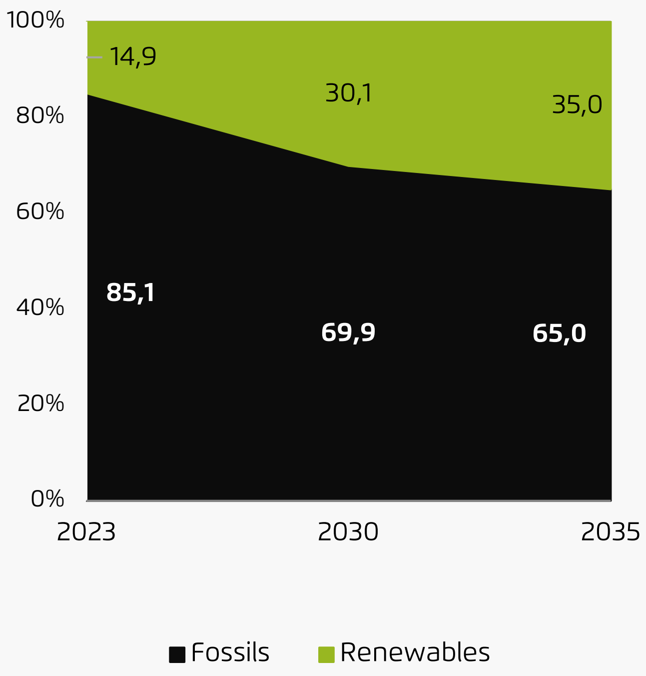


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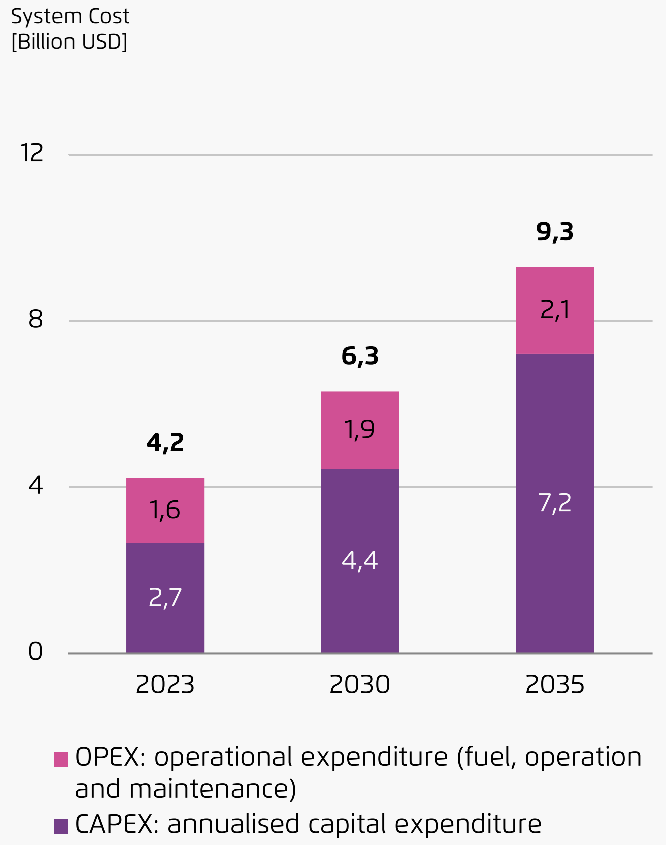
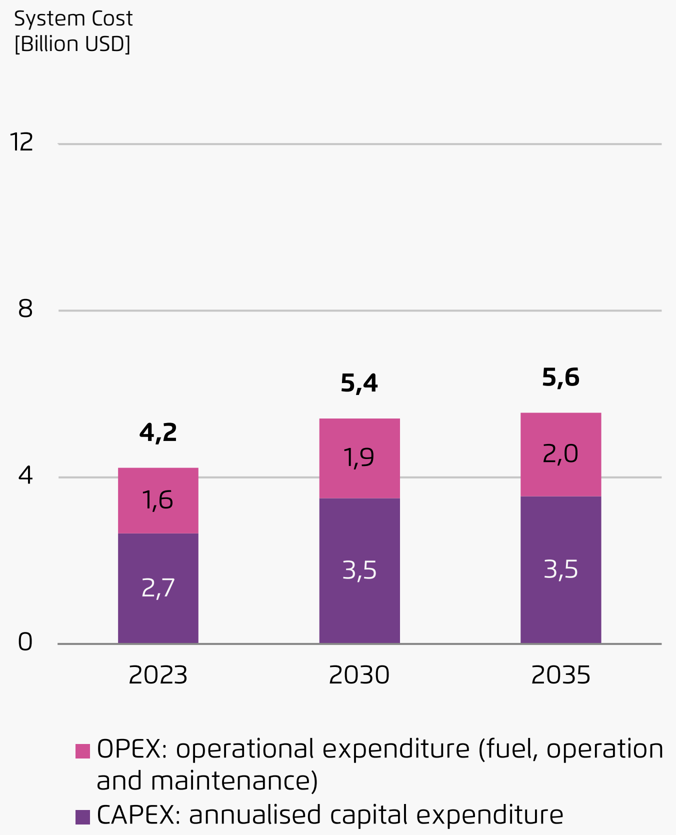
Figure rigt: Agora's inhouse PyPSA-based model (2025)

Development of total system cost across the three scenarios

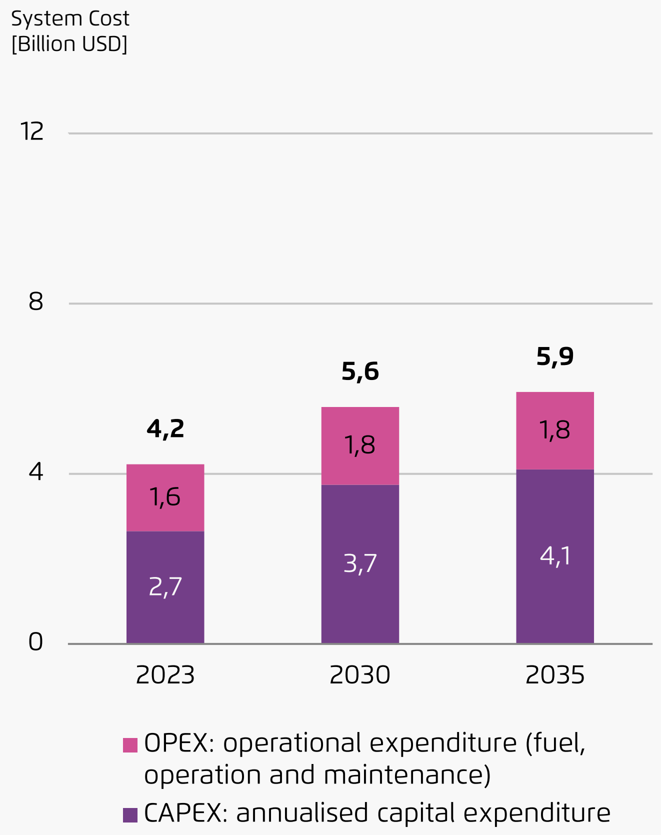
Total system cost in REF scenario



Total system cost in REF+ scenario



Total system cost in RES scenario



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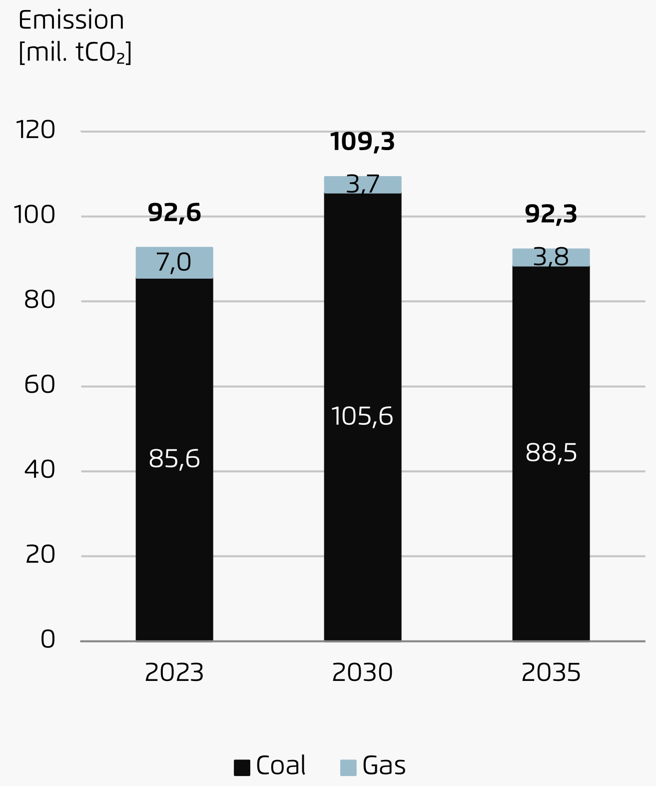
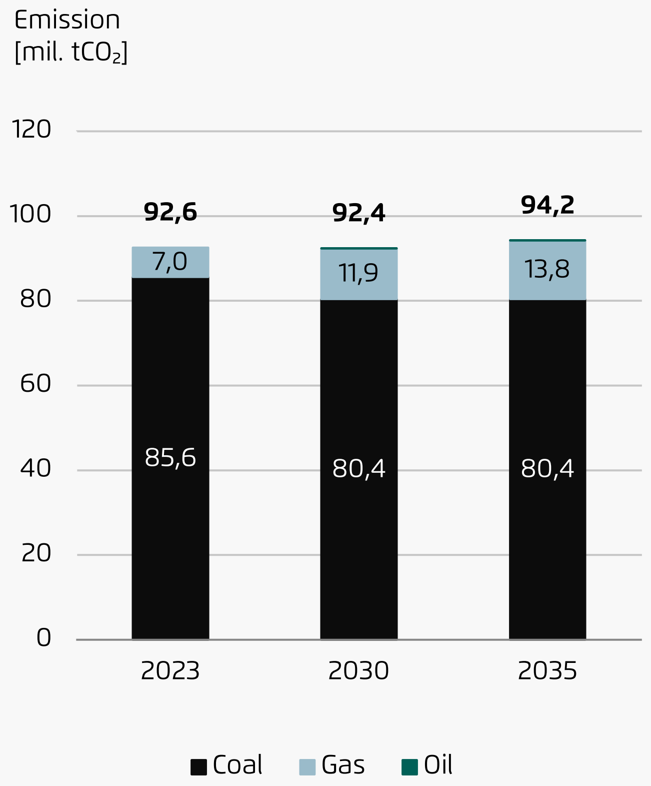
Development of power sector carbon dioxide emissions across three scenarios

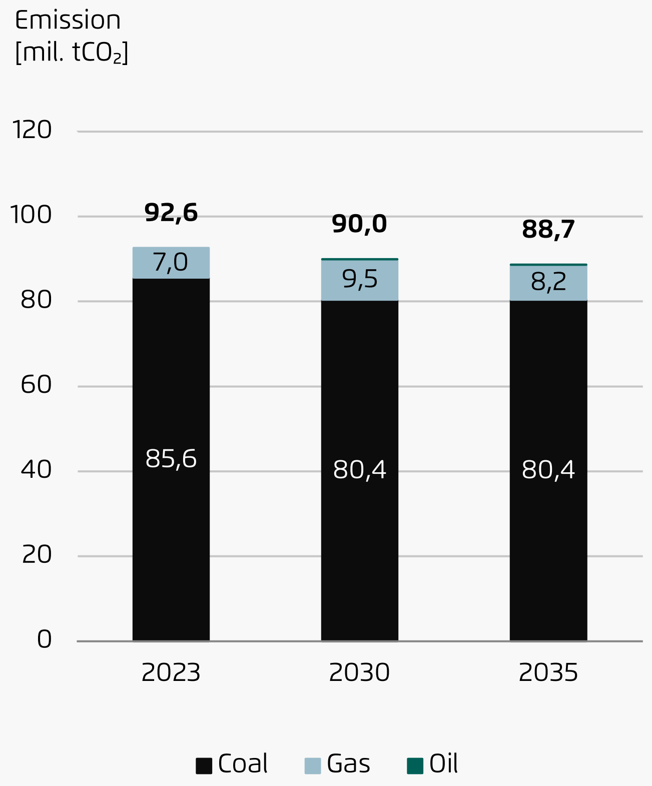
Emissions in REF scenario



Emissions in REF+ scenario



Emissions in RES scenario



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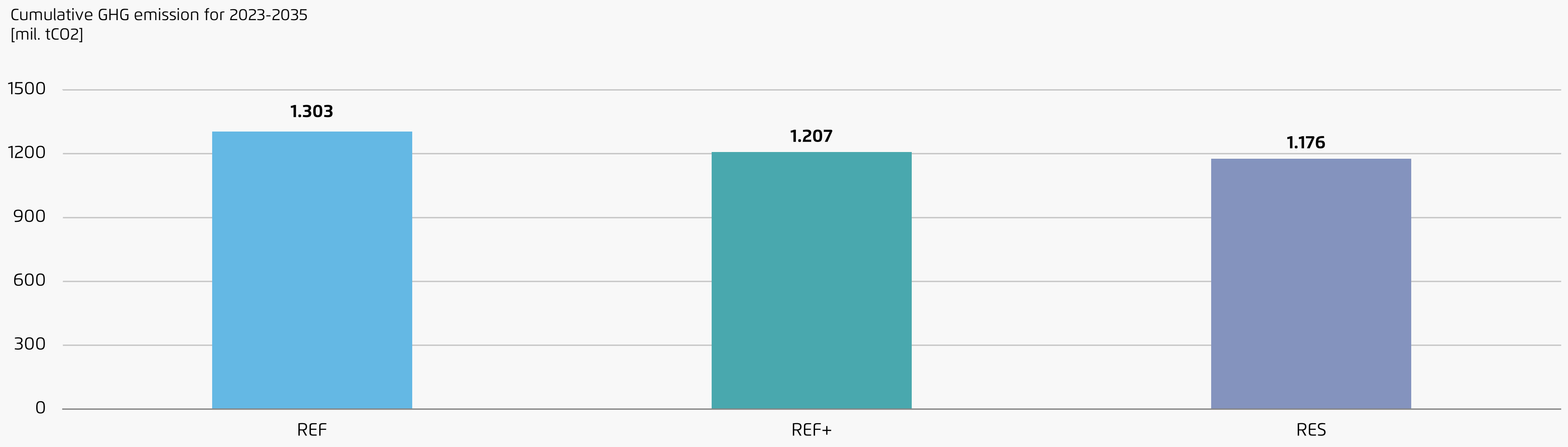
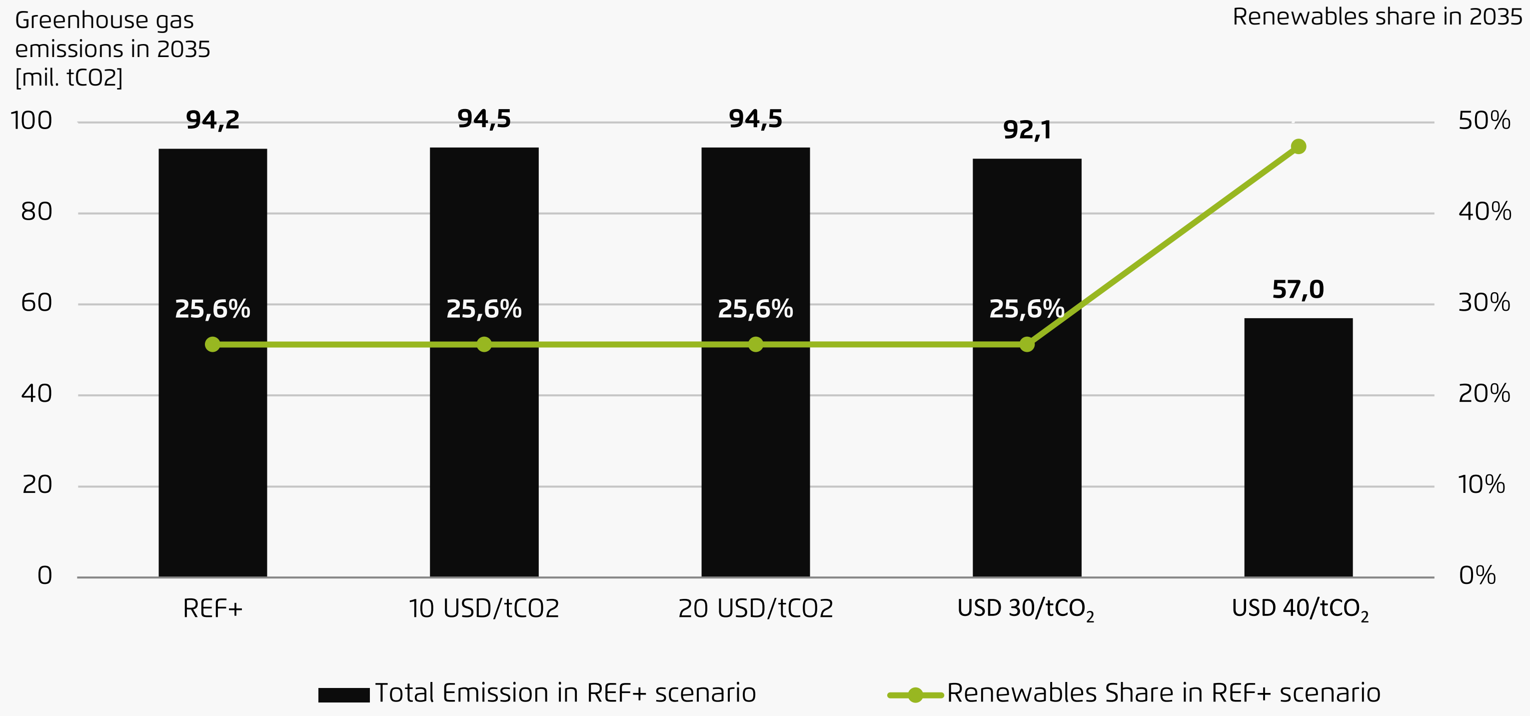
Cumulative power sector carbon dioxide emissions for 2023–2035 for the three scenarios



Sensitivity analysis: effects of carbon pricing

An approx. USD 40/tCO_2 under REF+ scenario would cut power sector emissions by 38% in 2035 (vs 2023) and achieve 47% share of generation from renewables...

Emissions and renewable share at different carbon prices for REF+ scenario



Sensitivity analysis of different carbon prices on the **REF+ scenario**, without allowing expansion of new fossil fuels shows:

1. Introducing a carbon price of **at least USD 30 per tonne of CO_2 is required** to trigger investment in renewables and reduce power sector emissions.
2. With a carbon price of **USD 40 per tonne of CO_2**, the system can achieve a **47%** share of renewable generation

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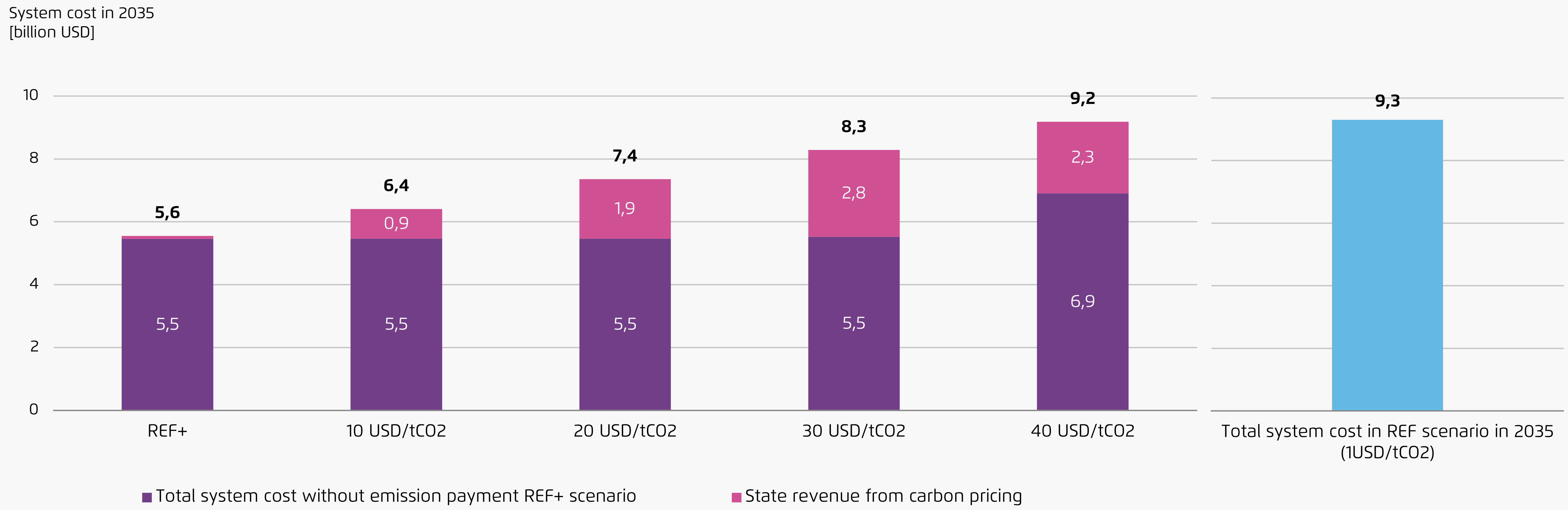
…while keeping power system costs near REF levels in 2035, additional CO2 pricing revenues can be reinvested in renewables, grid upgrades & clean energy subsidies

Total system cost at different carbon prices for REF+ scenario compared to REF scenario



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Modelling limitations and further research

This exercise marks our first effort to model power system in Kazakhstan. While the current model has several limitations, it serves as a foundation that will be further refined and expanded. Moving forward, we have identified several key priorities to advance this research:

→ Enhance the **geographic resolution** of the model to better represent Kazakhstan. A key challenge here is obtaining high-quality, high-resolution data.

→ Explore additional characteristics of **coal and gas operational constraints**. This would require deeper engagement with local stakeholders.

→ Incorporate modeling of **heat supply** through CHP plants.

→ Integrate **sector coupling** into the model, including industrial heat, electric vehicles, Power-to-X and more. This would help assess climate neutrality pathways.

→ Examine **additional system constraints** such as energy independence and dynamic reserve operation.

Imprint

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Acknowledgements
Special thanks to Thorsten Lenck, Saeed Sayadi, Dimitri Pescia, Emeline Spire, Maia Haru Hall, Lena Tropschug (all Agora Energiewende); Rustam Nassirkhan (Zhasyl Damu); Aida Aliyeva (NDC Partnership); Nikolay Posypanko and Alexandr Gasilov (ERG); Inna Kim (ESR); Yernar Bilyalov and Alexander Ten (United Nations Development Programme).

Title picture: Zingera