UNITED NATIONS ECONOMIC COMMISSION FOR EUROPE

Sustainable Hydrogen Production Pathways in Eastern Europe, the Caucasus and Central Asia

UNECE

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ECE ENERGY SERIES No. 77

UNITED NATIONS
GENEVA, 2023

United Nations publication issued by the United Nations Economic Commission for Europe.

Cover design: Shuyue Li

UNITED NATIONS PUBLICATION
Sales No. E.22.II.E.39
ISBN: 978921117324-6
eISBN: 9789210023795
ISSN: 1014-7225
eISSN: 2412-0022

Acknowldegements

This report was prepared by Yury Melnikov and is a result of extensive research and a series of multi-stakeholder dialogues. The secretariat thanks the lead author and the UNECE Task Force on Hydrogen for all the work put into developing this document.

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List of Abbreviations

Armenia NPP	Armenia Nuclear Power Plant
BelNPP	Belarusian Nuclear Power Plant
CCS	Carbon Capture and Storage
CCUS	Carbon Capture, Use and Storage
CNNC	China National Nuclear Corporation
CNPC	China National Petroleum Corporation
EAEU	Eurasian Economic Union
EDF	Électricité de France
ERI RAS	Energy Research Institute of the Russian Academy of Sciences
ESMAP	Energy Sector Management Assistance Program
EU	European Union
IAEA	International Atomic Energy Agency
ICE	Internal Combustion Engine
ICSHP	International Center on Small Hydro Power
IEA	International Energy Agency
IRENA	International Renewable Energy Agency
KEGOC	Kazakhstan Electricity Grid Operating Company
KHNP	Korea Hydro & Nuclear Power
MENA	Middle East and North Africa
MoU	Memorandum of Understanding
NDCs	Nationally Determined Contributions
RES	Renewable Energy Sources
SGC	Southern Gas Corridor
TANAP	Trans Anatolian Natural Gas Pipeline
TAP	Trans Adriatic Pipeline
UAE	United Arab Emirates
UNECE	United Nations Economic Commission for Europe
UNIDO	United Nations Industrial Development Organization

Executive Summary

Low-carbon hydrogen deployment is crucial for achieving the Paris Agreement goals and for deep decarbonization of the hard-to-abate sectors (such as heavy-duty transport, steel and fertilizers production, etc.). By the end of 2022, more than 70 countries globally have drafted or already adopted national hydrogen strategies, demonstrating that hydrogen is seen as one of the strategic priorities for the energy sector transition. In contrast, the countries of Central Asia, the Caspian region, and Eastern Europe, are still at the initial stage of evaluating hydrogen's role in more long-term strategies (apart from Russia, which adopted a hydrogen roadmap in 2020 and has been drafting a national hydrogen strategy since September 2021).

The nine countries considered in this study are: Armenia, Azerbaijan, Belarus, Republic of Moldova, Kazakhstan, Kyrgyzstan, Tajikistan, Turkmenistan, and Uzbekistan. Together, they cover an area and have a population which are about double that of Argentina, and their combined CO_2 emissions are equivalent to Germany's. Moreover, many of these countries are significant players in the energy sector in their regions, or across Eurasia as a whole.

These countries' transition towards low-carbon development, and towards establishing a hydrogen economy, will be determined by their individual energy and climate policies, the current state of their energy sector, their economic growth rates, as well as infrastructural opportunities and constraints. The nine countries can be divided in four groups which share similar energy policies and geographic features.

Armenia, Belarus and Moldova are united by dependence on energy imports and an orientation towards natural gas. In all three countries, renewables have so far received limited development, but in Armenia and Belarus, nuclear power plays a significant role. With relatively unambitious greenhouse gas emission reduction targets, there is practically no potential local demand for low-carbon hydrogen over the next 10 years. However, Belarus and Moldova's proximity to the EU market could open additional opportunities in the future, especially in connection with renewable hydrogen. .

Azerbaijan and Turkmenistan are major energy exporters towards the EU and China. Natural gas dominates their energy mix. As the role of the oil and gas sector is great in both countries, they developed significant competencies that could be put to good use in energy transition to net zero. Their climate policies do not yet create significant incentives for decarbonization and low-carbon technologies deployment. Still, the key consumers of gas from Azerbaijan and Turkmenistan - the EU and China - are actively developing the hydrogen economy, which could create additional incentives to embark on the path to decarbonization.

Kyrgyzstan and Tajikistan face similar energy shortage problems and in having significant hydropower share in their energy mix, which provides low-carbon, but intermittent, energy. Reliance on hydropower produces challenges associated with energy deficit during winter and energy surplus during summer. This creates potential for intermittent hydrogen production using surplus electricity from hydropower plants. Hydrogen which could potentially replace imported oil products. However, more pressing problems, such as energy security and infrastructure wear-out, currently take priority in the region.

Kazakhstan and Uzbekistan are showing impressive momentum in launching the low-carbon energy transition– despite being rich in and exporting their own fossil energy resources. Both countries are drafting national hydrogen strategies with the support of international organizations and are actively deploying renewable energy.

According to this study, the potential production of low carbon hydrogen, in all considered countries, is about 3.4-13.2 Mt of hydrogen annually by 2040. The potential production varies widely within each country, reflecting uncertainties under both the minimum and maximum scenarios. The potential production values are determined by the presence of own reserves of natural gas and by the pace of renewable energy development. These elements are most present in the group of Caspian countries exporting natural gas (Azerbaijan, Turkmenistan) and in the group of Central Asian countries actively reforming their economies towards low-carbon development (Kazakhstan, Uzbekistan). The maximum potential hydrogen production of each of these countries is estimated to be in the order of several Mt per year. Hydrogen production potential is about 10-20 times lower in energy-importing

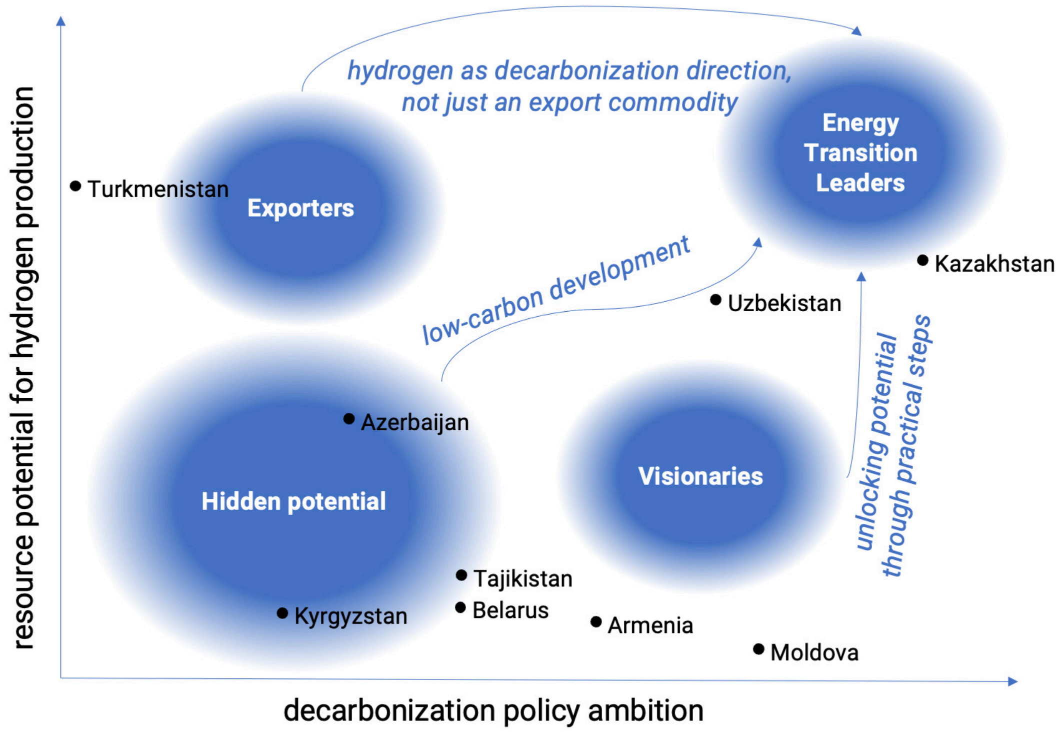
countries (Armenia, Belarus, Moldova, Kyrgyzstan, Tajikistan). Estimated low-carbon hydrogen cost also varies widely (\$1-\$8/kg H_2). Key uncertainties include levelized cost of renewable electricity, CCUS, electrolysis. It is likely that gas producing countries will have an advantage in the medium term.

Export-oriented hydrogen projects in all countries will face significant logistical constraints: none of them has access to the open sea, so potential exports to key hydrogen markets (EU, Southeast Asia) will most often require transhipment of cargo and transportation on both land and sea for several thousand kilometers. Similar projects in the MENA region are located closer to key markets and have direct access to the sea. While several countries in Central Asia are located relatively close to China, China's hydrogen strategy focuses on domestic hydrogen production rather than import. Belarus, Moldova and Azerbaijan have hydrogen export potential due to their relative proximity to the EU, but realizing it will require significant efforts.

The resource potential of low-carbon hydrogen production and decarbonization strategy ambitiousness are interconnected, and together form four scenario models for potential deployment of hydrogen economy in the countries covered by the study (Figure 1).

FIGURE 1

Possible typical scenario models for hydrogen economy establishment and deployment in the countries covered by the study, depending on their decarbonization policy ambition and resource potential for low-carbon hydrogen production



Source: UNECE

The scenario models do not have clear boundaries, and each country's transition between models will depend on the national economic circumstances. The study showed that a significant portion of the resource potential of hydrogen production in all countries is in a hidden state, as renewable energy and other low-carbon technologies deployment is still at an early stage.

The "Energy Transition Leaders" scenario model combines ambitious decarbonization policies (and thus guaranteed future domestic demand for low-carbon hydrogen and related technologies) with significant resource potential for hydrogen production (even if the strategy involves future imports). All countries leading the low-carbon hydrogen

economy deployment - such as members of the G7 - or future potential hydrogen exporters (Saudi Arabia, Chile, Australia) have adopted carbon neutrality goals, are intensively developing low-carbon technologies, and have adopted or are drafting national hydrogen strategies. Thus, they fit exactly the scenario model "Energy Transition Leaders".

This study shows that the hydrogen economy deployment pace in countries will be determined not so much by their resource potential as by the strategic focus on low-carbon development, building appropriate regulatory frameworks, expanding markets, and technological development. International cooperation will be of great importance as well, especially regarding international standardization (both of hydrogen and hydrogen related technologies). For the countries considered in this study, implementing pilot projects and developing a joint strategy for export-oriented projects will be important to unlock the potential of the hydrogen sector..

1. Introduction and Research Methodology

1.1 Introduction

Hydrogen produced with minimal life cycle greenhouse gas emissions – so-called low-carbon hydrogen – is seen as a key universal low-carbon energy carrier needed for deep decarbonization of hard-to-abate sectors and achieving the Paris Agreement goals on a global scale. Many hydrogen economy plans around the world have been translated into concrete investment decisions in 2021, and hydrogen companies have attracted more investment than ever before in history, according to the International Energy Agency. Production of low-carbon hydrogen in the Announced Pledges Scenario will increase from the current negligible levels to 30 Mt per year by 2030 (the equivalent of 100 billion m^3 of natural gas). The realization of this potential depends on the coordination of regulators in several countries and export-import infrastructure development, which so far lags behind the announced hydrogen production projects.

The countries of Central Asia, the Caspian region and Eastern Europe that were part of the USSR – Armenia, Azerbaijan, Belarus, Moldova, Kazakhstan, Kyrgyzstan, Tajikistan, Turkmenistan, Uzbekistan – with all the differences – in geographical location, population, economy size, energy sector structure, energy transition ambitions – may in the future play an important role in the hydrogen economy of the Eurasian continent. This may relate primarily to their ability to produce low-carbon hydrogen at home, but it is equally important for all other segments of the hydrogen value chain, including transportation, storage and use of hydrogen domestically. These prospects are determined both by the current capabilities of each of the countries, and by long-term strategies in the field of energy, climate, and low-carbon development.

Hydrogen economy development is one of the possible long-term priorities that countries can include in their strategies. At the same time, regulators will have to find a balance between the urgent and immediate tasks of the energy sector development and the 20-30-year horizon perspectives. This study is aimed to help policymakers in these countries take the first steps towards setting these priorities and assessing their place in the future global hydrogen economy.

1.2 Goals and objectives of the study

This study covers nine countries of the former USSR – Armenia, Azerbaijan, Belarus, Moldova, Kazakhstan, Kyrgyzstan, Tajikistan, Turkmenistan, Uzbekistan. These countries combined cover an area of 4.3 million km^2 and are home to 102 million people (which is about double that of Argentina). Combined CO_2 emissions from the energy and industrial sectors, according to the IEA, in 2020 amounted to about 500 $MtCO_2e$, which is comparable to emissions of Germany.

The study aims to increase the ability of these countries to use their potential to produce and trade hydrogen both domestically and throughout the region. To achieve this global goal, a cross-country comparative analysis of different segments of the energy sector has been performed to:

- assess the national low-carbon hydrogen production potential and the possibility of its increase in the future;
- evaluate opportunities for hydrogen export;
- determine possible directions of local hydrogen demand;
- outline sectors for the potential pilot projects implementation.

1.3 Research methodology

The study consisted of several interrelated blocks, within which the following were carried out:

- national energy mix and energy sector structure assessment;

- assessment of the current state of the energy sector and key opportunities and limitations associated with the resources, wear and tear and the pace of modernization, infrastructure;
- review of relevant strategic documents in the field of energy and climate;
- assessment of local resource potential: renewable energy sources (RES), natural gas, carbon capture and storage (CCUS), nuclear power;
- review of hydrogen economy related activities;
- conclusions about the potential (hydrogen production, local demand, export opportunities) and possible priorities for future national hydrogen strategies.

To conduct the study, open sources of information were used – the most relevant reports of international energy think tanks, national regulatory framework in the field of energy, climate and hydrogen, official press releases from government authorities and news in the media. An important additional source of information was the consultations of the UNECE team with representatives of the emerging hydrogen community of each country. They helped to find the right sources of information, form key directions of the research and verify its conclusions.

The assessment of the hydrogen deployment potential in the energy sector is carried out in this study at several levels – for each country:

- energy policy: is there a hydrogen roadmap/strategy being developed and what are its priorities?
- production: are there resources for low-carbon hydrogen production?
- local demand: is there a need for low-carbon hydrogen for low-carbon development purposes?
- transport infrastructure: is it possible to use the existing gas pipeline infrastructure for transporting hydrogen?
- hydrogen export opportunities: what are the distance from key future importers (EU, Southeast Asia) and export opportunities and risks?
- hydrogen community / stakeholders: at what stage of formation is the hydrogen community, and what are the degree and formats of stakeholder participation in the hydrogen economy development?

To assess the potential for low-carbon hydrogen production, a technologically neutral approach was used: all opportunities and technologies are considered that (given the appropriate resources, regulatory and market environment are in place) will enable the low-carbon hydrogen production in the country. The key factor here is greenhouse gas emissions along the entire technological chain and a number of additional criteria for the hydrogen production sustainability discussed by leading think tanks in 2019-2022 during the debates on international hydrogen certification. Among them:

- additionality criterion (production of low-carbon hydrogen should be provided by additional low-carbon energy sources, and not by redistribution of energy from the existing low-carbon sources);
- if existing sources of low-carbon energy underproduce electricity due to lack of demand (curtailment), it can be used to produce low-carbon hydrogen;
- CCUS development is critical to realize blue hydrogen production potential.

A thorough assessment of the potential for producing, storing, transporting and using low-carbon hydrogen in each country is possible only with several serious assumptions and only after the adoption of a full-scale national hydrogen strategy. This is due to significant uncertainty in key parameters of demand, supply, inter-fuel competition, logistical constraints, competitiveness with other countries, technological development in the context of long-term energy and climate policy. This study is intended to designate a guideline for the value of the resource potential of hydrogen production and the width of its variation range. This study cannot replace a national hydrogen strategy.

As conditional minimum and maximum scenarios (based on expert assessment of the study's authors), high-level estimates of the resource potential for the low-carbon hydrogen production by 2040 were taken, considering the current aspects of the country's energy sector development and its adopted and published long-term strategy.

2. Cross-country analysis

2.1 Azerbaijan

An analysis of the current status of the energy sector, key documents and regulatory bodies, the balance of energy production and demand, gas transportation infrastructure, greenhouse gas emissions, as well as existing forecasts and long-term goals of the country's energy and climate policy is provided in the Annex.

2.1.1 Potential for renewables, natural gas and CCUS

Low-carbon hydrogen production requires raw materials and energy sources (electricity from renewable energy sources, hydro power plants, nuclear power plants, natural gas or biomethane, coal with gasification, water, etc.), as well as (for the case of fossil fuels-based hydrogen production) the establishment of CCUS industry.

This section provides information about the relevant resource and energy potential of Azerbaijan, available from open sources.

2.1.1.1 Renewable Energy Sources

Renewables, including hydropower, accounted for 2% of total primary energy supply and 8% (2 TWh) of electricity generation in 2018 (according to the IEA). Electricity generation at hydro power plants is not constant from year to year: in 2010 it was more than 3.4 TWh, and in 2017 it was only 1.75 TWh.

At the same time, Azerbaijan has substantial untapped RES potential as it enjoys relatively sunny and windy conditions, as well as significant hydro, biomass and geothermal resources. The total potential could be from 7 GW, which is comparable to the total installed capacity of all power plants in the country (8 GW in 2017) (see Table 1). The maximum potential assessment exceeds 34 GW and more, depending on the approach to assessing the technical and economic potential of RES.

TABLE 1

Renewables installed capacity in Azerbaijan (2017) in comparison with the renewable energy potential according to the Ministry of Energy (2022)[1] and the World Bank (2022), MW

	INSTALLED CAPACITY OF POWER PLANTS IN 2021-2022 [MW]	RENEWABLE ENERGY POTENTIAL [MW]
Wind (onshore)	66.1	3000
Wind (offshore)	0	1500-7 200
Solar	45.9	1600-23040
Biomass	37.7	380
Small hydropower	44.3	520
Geothermal	0	40
TOTAL (excluding large HPPs)	**194**	**7040-34180**

1 https://area.gov.az/az/page/yasil-texnologiyalar/boem-potentiali

Solar energy technical potential can reach 23 GW, according to IRENA – this is facilitated by the high number of sunny hours per year (2400-3200) and solar activity indicators (1500-2000 kWh/m²). The optimal zones are concentrated in the valleys of the central rivers, as well as in the north and northwest of the country.

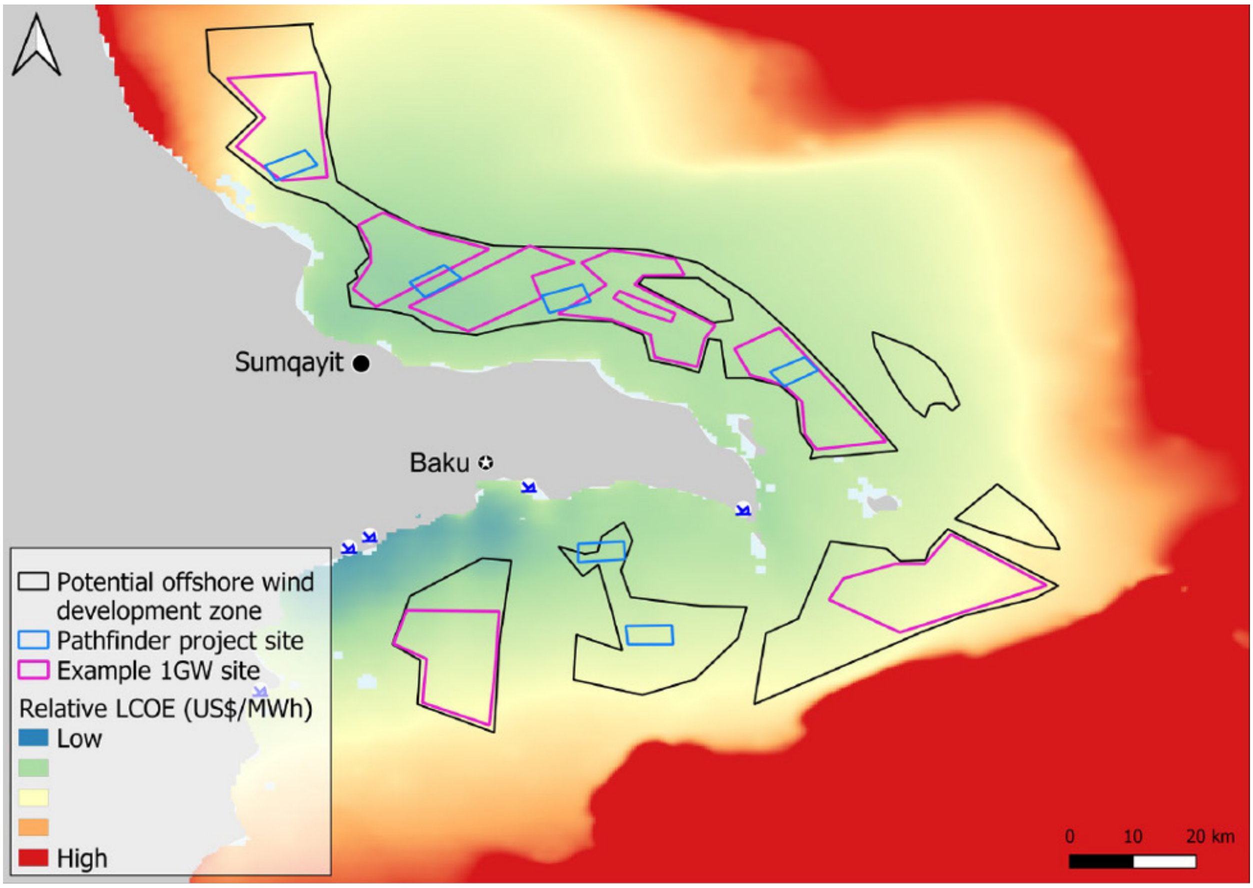
Wind energy potential is especially high along the Caspian Sea coast. In addition, in June 2022, within the framework of World Bank and the IFC project, an offshore wind potential assessment was published – from 1.5 to 7.2 GW by 2040 – as well as a map with the distribution of potential (Figure 2). This potential can be realized within seven large zones (1 GW each) using fixed foundation projects in shallow waters of 10 to 40 meters relatively close to the shore. It is estimated that the minimum cost of electricity will be produced in areas north of the Absheron Peninsula. An additional advantage of the offshore wind development in Azerbaijan is the opportunity to use Azeri oil and gas sector offshore projects-related competencies.

In 2022 ACWA Power (Saudi Arabia) and Masdar (UAE) signed an agreement on the renewable energy projects development in the republic with a total capacity of over 10 GW, including 2 GW in wind along with the production of "green" hydrogen. According to Mustafayev (2022), for the declared parameters of RES projects, the present cost of electricity can be about $32 per MWh.

Small hydro, bioenergy and geothermal potential is not so significant – but its realization will allow adding almost 1 GW of renewables.

FIGURE 2

Map of Azerbaijan's offshore wind potential and identification of favorable development zones



Source: *World Bank, IFC (2022)*

2.1.1.2 Natural gas

According to BP (2021), natural gas proven reserves in Azerbaijan in 2021 are 2.5 trillion m^3 – according to this indicator, the country is in second place among those covered by this study. By comparison, the combined reserves of European countries (including Norway and UK) are just over 3.2 trillion m^3.

Gas production in Azerbaijan has been consistently growing since 2004. During 2010-2020, production increased by 1.6 times to 25.8 bcm / year (2020) and continues to grow. According to the State Statistics Committee of Azerbaijan, in 2021 this figure increased by 18% – to 43.8 bcm.

The largest field in Azerbaijan is Shah Deniz (reserves of 1 trillion m^3), where gas production began in 2005. In 2010, the Umid field was discovered, and in 2011, Total discovered the deepwater Absheron field, which is capable of producing up to 5 bcm of natural gas per year. The growth of natural gas production can be facilitated by the development of the ACG (Azeri-Chirag-Guneshli), Babek, Shafag-Aziman fields. Another source of growth is the Dostluk ("Friendship") field on the border of Azerbaijan and Turkmenistan – joint development agreement was signed in January 2021.

According to the short-term forecast of gas production in Azerbaijan, which was published by the government, gas production by 2026 will approach 50 bcm per year. According to Nexant World Gas Model, in 2027-2032, production in Azerbaijan will grow to 45 billion m^3 per year, after which it may be reduced to 40 bcm per year. The cost of gas production, according to Nexant World Gas Model, ranges from $59 to $67 per 1,000 m^3.

Azerbaijan exports natural gas to Turkey and Europe via the recently launched Southern Gas Corridor (first deliveries began in 2021). Exports to Europe will increase as the share of other suppliers (primarily Russia) decreases in the short and medium term. In the long term (2040-2050) horizon, gas exports to the EU will decline as the EU transitions to low-carbon energy sources.

Experience in oil processing among companies in Azerbaijan is essential for the successful implementation of projects in the field of steam methane reforming. In addition, gas and oil refineries can become centers for hydrogen economy development due to production of "grey" hydrogen already in place and demand for hydrogen for hydrocarbons processing.

2.1.1.3 Carbon dioxide capture and long-term storage (CCUS)

For low-carbon hydrogen production from natural gas, it is important to provide carbon dioxide capture and long-term storage (CCUS) that is produced during the steam methane reforming process.

Azerbaijan is part of an extensive oil and gas system in the province of the South Caspian Basin, along with Iran and Turkmenistan, which suggests storage potential in both aquifers and oil fields (UNECE, 2021a).

There are no reliable public estimates of the CCUS potential in Azerbaijan yet. When studying it, they rely on the oil and gas sector experience – the country has depleted fields suitable for long-term CO_2 storage, a well-studied geological structure, and starting competencies for such projects implementation.

Mammad-zada (2020) made an approach to estimating CCUS parameters in the Mishovdag, Lokbatan and Azeri-Chirag-Guneshli fields, including with references to BP studies. The cost of capturing and storing CO_2 is estimated at about 44-47 euros per tCO_2 with a capacity of 2.26 $MtCO_2$ per annum.

2.1.2 Resource potential for low-carbon hydrogen production

This section analyzes the key assumptions that shape the potential for low-carbon hydrogen production by various technologies analyzed, among others, in UNECE (2021 b).

Assumptions and estimates adopted for the analysis

Based on the analysis, Azerbaijan will have resources for hydrogen production by water electrolysis using electricity from renewables (if renewable energy develops in the country), as well as for hydrogen production by steam methane reforming with CCUS (if the CCUS industry develops).

The resource potential of hydrogen production in 2040 is determined by:

- technical and economic potential for wind, solar and another renewables development (up to about 34 GW in the maximum scenario);
- the share of renewable electricity that would be appropriate to use for hydrogen production instead of being used directly in Azeri power sector or exported to neighboring countries;
- natural gas production potential (according to the government, the target level is 50 bcm per year);
- the share of natural gas that would be economically feasible to use for hydrogen production instead of direct use of gas in Azeri economy or its export;
- the CCUS potential for long-term storage of carbon dioxide produced during hydrogen production from natural gas.

With the current level of uncertainty, it is not possible to calculate these parameters, but it is possible to assess the resource potential by taking them at the minimum and maximum levels. In this study, two scenarios are adopted:

1) Minimum Scenario

- 30% of the increase in solar and wind electricity generation during 2020-2040 is used for hydrogen production;
- the growth rate of renewables remains at the same level as in 2013-2020 according to the IEA. The increase in electricity generation is determined by extrapolation: in 2013, electricity generation from renewables amounted to 2 GWh, in 2020 – 143 GWh, then by 2040, while maintaining the growth rate, it can reach 546 GWh, the increase for the period of 2020-2040 will be 403 GWh;
- 50% of natural gas, which is currently exported to the EU (about 10 bcm per annum), is used to produce hydrogen.

2) Maximum Scenario

- 50% of solar and wind electricity from new power plants is used for hydrogen production;
- Azerbaijan realizes 50% of the maximum renewable capacity growth potential (i.e., 17 GW out of 34 GW indicated in Table 1);
- capacity factor of renewables is 35%;
- 100% of natural gas, which is currently exported to the EU (about 10 bcm per annum), is used to produce hydrogen.

In both scenarios, it is assumed that hydrogen production by electrolysis of water will require 55 kWh/kg H_2 of electricity, and hydrogen production by steam methane reforming will require 5.3 m^3/kg H_2 of electricity. The amount of CO_2 released during the reforming process, which must be stored, is estimated as 10 kg CO_2 / 1 kg H_2.

2.1.2.1 Resource potential

In the minimum scenario, the increase in electricity generation from solar and wind sources by 2040 compared to 2020, while maintaining the current rate, will be 403 GWh/year, including 271 GWh/year from wind. 30% of this amount, that is, 121 GWh/year, would be used for hydrogen production. In addition, half of exports to the EU, that is, about 5 bcm per annum, will be used for hydrogen production.

In the maximum scenario, the increase in the solar and wind installed capacity by 2040 compared to 2020 will be 17 GW, which, with a capacity factor of 35%, means that 52.2 TWh of electricity will be produced. 50% of this amount will be used for hydrogen production, that is, 26.1 TWh/year. In addition, 100% of exports to the EU, that is, about 10 bcm per annum, will be used for hydrogen production.

The results of the potential assessment are summarized in Table 2.

TABLE 2

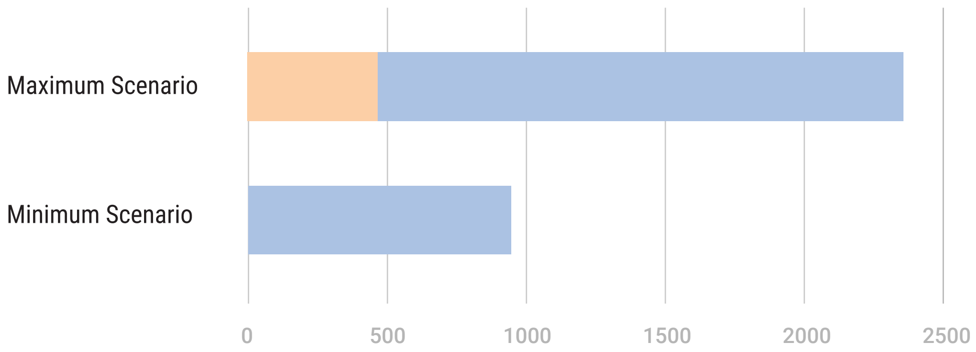
Resource potential of hydrogen production in Azerbaijan by 2040

	MINIMUM SCENARIO	MAXIMUM SCENARIO
Renewable electricity for hydrogen, GWh per year	121	26061
Natural gas for hydrogen, bcm per annum	5	10
Hydrogen by water electrolysis using solar and wind electricity, thousand tons per annum	2.2	474
Hydrogen from methane by SMR + CCUS, thousand tons per annum	943	1887
Hydrogen total, thousand tons per annum	**946**	**2361**
Required capacity of CCUS systems, $MtCO_2$ per annum	9	19

The evaluation results are shown in Figure 3. Thus, under the accepted assumptions, the main long-term opportunity for hydrogen production in Azerbaijan is steam methane reforming: this is determined by the significant proven natural gas reserves in place, the growth rate of its production and, at the same time, the transition of an important consumer (the EU) to low-carbon energy carriers in the long term. The key constraint and condition in this case is the outstripping development of CCUS industry – even in the minimum scenario, it is necessary to create CCUS facilities with a total capacity of 9 $MtCO_2$ per annum.

FIGURE 3

Resource potential of hydrogen production in Azerbaijan by 2040, thousand tons per annum



2.1.2.2 Cost analysis

The cost of hydrogen from natural gas consists of the cost of raw materials (for Azerbaijan, as a gas producing country, this is the cost of natural gas production), as well as the cost of CCUS. According to the IEA (2019), for gas producing countries, the natural gas cost was approximately 30% of the blue hydrogen cost. With the gas production cost at the level of $59-67 per thousand m^3, the blue hydrogen production cost can be estimated at $0.8-1.2 per kg of hydrogen.

The cost of hydrogen produced by electrolysis using renewable electricity will depend on the present value of renewable electricity in new large projects developed in Azerbaijan. According to IEA calculations, with an electricity price of about $30 USD / MWh[2], the number of electrolyzers capacity utilization hours is about 1500-2000 hours per year, CAPEX of electrolyzers is $450 / kW at a discount rate of 8%, the hydrogen present value will be about $3.5-4 /kg.

2.1.2.3 Logistical opportunities and barriers for export-oriented hydrogen projects

Azerbaijan has no access to the open sea. With a combination of land and sea transport, the distance to the port of Rotterdam (Netherlands) will be 7.5 thousand km, to the port of Kobe (Japan) - 17.3 thousand km. This is higher than for export-oriented hydrogen projects in the MENA region (such as the NEOM Green Hydrogen project in Saudi Arabia with a capacity of 4 GW - 6.5 thousand km to Rotterdam and 13.8 thousand km to Kobe), limiting the competitiveness of similar projects in Azerbaijan.

At the same time, the nearest capital of an EU member state is located at 2.8 thousand km by land from Baku (Sofia). The TANAP and TAP gas pipelines are of comparable length. Therefore, for export-oriented Azerbaijan-the EU projects, pipeline, rail and road transport possibilities can be checked, considering EU market prospects (imports of up to 10 Mt of hydrogen per year by 2030) and Azerbaijani suppliers competitiveness in terms of cost, carbon footprint of hydrogen and its origin (for EU market, green or renewable hydrogen has priority).

2 This price corresponds to promising renewable energy projects in the country according to Mustafayev (2022)

2.1.3 Existing and prospective pilot projects in the field of hydrogen

2.1.3.1 Existing pilot projects

There are no implemented pilot projects in the field of low-carbon hydrogen in Azerbaijan yet, but a number of stakeholders are exploring relevant opportunities and signing cooperation agreements.

So, in June 2022, an ACWA Power (Saudi Arabia) representative expressed[3] the company's readiness to collaborate with Azerbaijan in the field of decarbonization and hydrogen production, including in Karabakh, where Azerbaijan is going to achieve net-zero emissions.

In the same month, Masdar (UAE) signed agreements with the Ministry of Energy of Azerbaijan, one of which concerns 2 GW wind power project, including for hydrogen production, export and decarbonization.

2.1.3.2 Possible promising projects

Azerbaijan has not yet set carbon neutrality goals and is provided with its own inexpensive hydrocarbons, so the incentives to use low-carbon hydrogen within the Azeri economy are not yet as obvious to stakeholders as its export through the SGC to the EU.

The advantage of using SGC to export hydrogen is that this gas transmission corridor is relatively new (deliveries began in 2020-2021), efforts to retrofit it for hydrogen may be less compared to more worn-out gas pipelines.

BP 's participation as a SGC stakeholder creates additional opportunities – the company has set itself the goal of achieving carbon neutrality by 2050 and is implementing hydrogen projects in the regions of its operation[4].

The limitations for exporting hydrogen to the Southern Gas Corridor are since such projects have not yet been implemented in the world for a number of technological, legal and commercial reasons. While some EU countries are implementing a consistent policy to increase the hydrogen content in the gas distribution network (Germany, Italy, the Netherlands, etc.), Turkey, Greece, Albania, Serbia, and Bulgaria have so far refrained from these efforts. In any case, projects of this magnitude are recommended to be implemented in close cooperation with the SGC member countries, considering their long-term energy and climate policies.

Domestic hydrogen consumption, based on Azerbaijan's energy mix, would be fastest to start in the transport sector, which accounts for 30% of the country's final energy consumption. The launch of pilot hydrogen fuel cell electric buses, the phased development of hydrogen refueling infrastructure around hydrogen-producing enterprises (including oil refineries) are the first steps that begin the hydrogen economy development of countries around the world. Setting targets for achieving carbon neutrality and other energy policy measures related to the transport sector (ICE ban, environmental restrictions on emissions, preferential parking, priority travel, subsidies, tax incentives) can create a regulatory environment for such projects.

To get a clearer picture of the hydrogen economy perspectives in Azerbaijan, the country may need a national hydrogen strategy. International organizations can provide methodological assistance in this.

3 https://www.trend.az/business/energy/3604790.html

4 https://www.bp.com/en/global/corporate/what-we-do/gas-and-low-carbon-energy/hydrogen.html

2.1.4 Conclusions

1. Azerbaijan is an energy surplus country, an important regional oil and gas exporter with steadily growing natural gas proven reserves and production (strategic goal is 50 bcm per annum, with an actual level of about 35). One of the key export markets is the EU.

2. Natural gas dominates the power sector, providing about 90% of electricity generation. The solar and wind share is still insignificant.

3. Azerbaijan does not yet have adopted long-term energy and hydrogen strategies. Azerbaijan's climate goals are 35% reduction in gas emissions by 2030 (from 1990 levels) and 40% by 2050, as well as elimination of net emissions "in the territories liberated from occupation."

4. The renewable energy potential in Azerbaijan is underutilized and is about 7-34 GW, primarily due to wind (primarily offshore) and solar energy.

5. Based on the resources and energy available for hydrogen production, it is possible to estimate the resource potential for low-carbon hydrogen production in Azerbaijan at 946-2361 thousand tons per year.

6. The main long-term opportunity for hydrogen production in Azerbaijan is steam methane reforming with CCUS: this is determined by the significant proven natural gas reserves in place, the accelerating growth in its production, and at the same time the transition of an important consumer (the EU) to low-carbon energy carriers in the long term. The key constraint and condition in this case is the outstripping development of the CCUS industry.

7. The key gas transportation asset of Azerbaijan is the Southern Gas Transport Corridor, through which deliveries began in 2020-2021. Turkey and EU countries are key importers of gas from Azerbaijan, and due to the drop in supplies from Russia, their demand will only increase. This will require an increase in the throughput capacity of SGC in the short term. In the long term, it is possible to increase productivity from the current 16 to 31 bcm per annum, as well as consider the issue of its hydrogen-related retrofit.

8. There are no pilot projects in the field of low-carbon hydrogen in Azerbaijan yet, but several companies are already signing relevant agreements – in particular, ACWA Power (Saudi Arabia) and Masdar (UAE). BP 's participation in the SGC project increases the chances of its hydrogen-related retrofit. It is possible to start the low-carbon hydrogen consumption within the Azerbaijani economy from the transport sector.

9. To better understand the prospects for a hydrogen economy in Azerbaijan, the country may need a national hydrogen strategy, which international organizations can help develop.

2.2 Armenia

An analysis of the current status of the energy sector, key documents and regulatory bodies, the balance of energy production and demand, gas transportation infrastructure, greenhouse gas emissions, as well as existing forecasts and long-term goals of the country's energy and climate policy is provided in the Annex.

2.2.1 Potential for renewables, natural gas and CCUS

Low-carbon hydrogen production requires raw materials and energy sources (electricity from renewable energy sources, hydropower, nuclear power plants, natural gas or biomethane, coal with gasification, water, etc.), as well as (for the case of fossil fuels-based hydrogen production) the establishment of CCUS industry.

This section provides information about the relevant resource and energy potential of Armenia, available from open sources.

2.2.1.1 Renewable Energy Sources

Renewables, including hydropower, accounted for more than 20% of Armenia's electricity generation in 2020. Electricity generation at hydropower plants is relatively stable and stands for all mentioned amount.

At the same time, Armenia has substantial untapped renewables potential. Although a detailed assessment of this potential has yet to be made, it is likely to be measured in the order of hundreds of megawatts of installed capacity:

- PA Consulting Group (2010), commissioned by the US Agency for International Development, estimated a total wind energy potential at 1000 MW with an economic potential of 500 MW (Armenian energy strategy (2021) also mentions the target of 500 MW by 2040)
- The World Bank 's ESMAP (2020) project estimates that presumed country area proportion to be covered by PV plants producing the equivalent of yearly electricity consumption is 0.17%. At the same time, the solar intensity in the country is better than in Spain;
- Armenian energy strategy (2021) set a goal of 1000 MW solar power plants by 2030. The country's first major plant (Masrik-1) with a capacity of 55 MW is already under construction (commissioning is expected in 2024). The second major tender - AYG-1 for 200 MW - closed in 2021 with Masdar (UAE) as a winner and an expected electricity price of $0.029 / kWh. The third tender (AYG-2) is being prepared.
- In August 2022, an agreement with the Eurasian Development Bank was signed regarding allocation of up to $37 million to finance the 11 solar power plants construction project with a total capacity of up to 65 MW in the Gegharkunik and Aragatsotn regions of Armenia.

The combined potential could stand for more than 1.5 GW, which is comparable to the total installed capacity of all power plants in the country (2.9 GW in 2019). The maximum assessment depends on exploiting the hydropower potential (and addressing its environmental impact) and has yet to be done.

The geothermal energy and solar heating potential is important for the residential sector - especially if the natural gas availability decreases.

2.2.1.2 Nuclear power

In Armenia, nuclear power generation already plays a significant role in the energy system and is included in the long-term energy strategy (in the context of extending the existing Armenian NPP operation over the horizon of 2030). At the beginning of 2022, Rosatom (Russia) and Armenian NPP signed a MoU regarding possible cooperation in the project of new nuclear power units (of Russian design) construction in Armenia. In May 2022, Armenia and the United States signed a memorandum of cooperation in the field of Atoms for Peace. But the potential for significant growth of this sector in Armenia is unclear, and no specific plans to increase the nuclear power plants capacity have been published. It can be assumed that the Armenian NPP will be used only in the electric power sector of Armenia - without using its electricity for hydrogen production.

2.2.1.3 Natural gas

Armenia is completely dependent on gas supplies from exporting countries, and this energy source accounts for 55% of the total final energy consumption. Although the media reported on the natural gas deposits exploration in the Armavir region, but so far, according to BP, the country has no proven gas reserves.

Armenian energy strategy (2021) assumes an increase in energy efficiency, electric transport and renewables deployment, which may lead to reduce in consumption of corresponding natural gas amounts in Armenia. But the use of this "secondary source" for hydrogen production hardly makes sense in the context of energy security, which is discussed in the strategy.

2.2.1.4 Carbon dioxide capture and long-term storage (CCUS)

For low-carbon hydrogen production from natural gas, it is important to provide carbon dioxide capture and long-term storage (CCUS) that is produced during the steam methane reforming process.

There are no reliable public estimates of the CCUS potential in Armenia yet. But the relevance of this sector development is low in the context of lack of natural gas.

2.2.2 Resource potential for low-carbon hydrogen production

This section analyzes the key assumptions that shape the potential for low-carbon hydrogen production by various technologies analyzed, among others, in UNECE (2021 b).

2.2.2.1 Assumptions and estimates adopted for the analysis

Based on the analysis, Armenia will have resources for hydrogen production by water electrolysis using electricity from renewables (if renewable energy develops in the country). Significant resources for hydrogen production by other low-carbon methods have not been found.

The resource potential of hydrogen production in 2040 is determined by:

- technical and economic potential for wind, solar and other renewable energy sources development (1.5 GW in plans and forecasts by 2030-2040);
- the share of renewable electricity that would be appropriate to use for hydrogen production instead of being used directly in Armenian power sector or exported to neighboring countries.

With the current level of uncertainty, it is not possible to calculate these parameters, but it is possible to assess the resource potential by taking them at the minimum and maximum levels. In this study, two scenarios are adopted:

1) Minimum Scenario

- 30% of the increase in solar and wind electricity generation during 2020-2040 is used for hydrogen production;
- increase in renewable energy generation of +100 MW by 2024 with the trend remaining (that is, about +750 MW more over the next 15 years)

2) Maximum Scenario

- 50% of solar and wind electricity from new power plants is used for hydrogen production;
- increase in renewables electricity generation of +1500 MW - by 2040
- capacity factor of renewables – 35%.

In both scenarios, it is assumed that hydrogen production by water electrolysis will require 55 kWh/kg H_2 of electricity.

2.2.2.2 Resource potential

In the **minimum scenario**, the increase in solar and wind generation capacity by 2040 compared to 2020 is 850 MW, which, with a capacity factor of 35%, means that 2.6 TWh of electricity will be produced. 30% of this amount, that is, 782 GWh/year, would be used for hydrogen production.

In the **maximum scenario**, the increase in solar and wind generation capacity by 2040 compared to 2020 is 1.5 GW, which, with a capacity factor of 35%, means that 4.6 TWh of electricity will be produced. 50% of this amount, that is, 1.7 TWh/year, would be used for hydrogen production.

The results of the potential assessment are summarized in Table 3.

TABLE 3

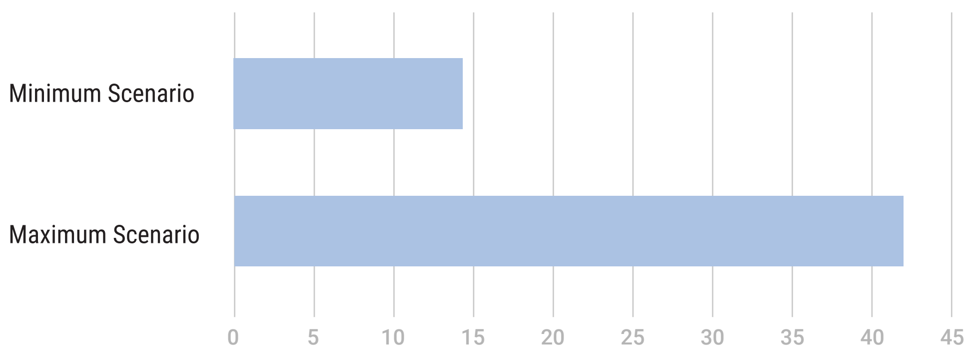
Resource potential of hydrogen production in Armenia by 2040

	MINIMUM SCENARIO	MAXIMUM SCENARIO
Renewable electricity for hydrogen, GWh per year	781	2300
Natural gas for hydrogen, bcm per annum	0	0
Hydrogen by water electrolysis using solar and wind electricity, thousand tons per annum	14.2	42
Hydrogen from methane by SMR + CCUS, thousand tons per annum	0	0
Hydrogen total, thousand tons per annum	**14.2**	**42**
Required capacity of CCUS systems, MtCO2 per annum	0	0

The evaluation results are shown in Figure 4. Thus, under the accepted assumptions, the only long-term opportunity for hydrogen production in Armenia is the water electrolysis using renewable electricity: firstly, renewable energy development is among the energy policy priorities by 2030, and secondly, other possibilities are limited or are completely absent.

FIGURE 4

Resource potential of hydrogen production in Armenia by 2040, thousand tons per annum



2.2.2.3 Cost analysis

The cost of hydrogen produced by water electrolysis using renewable electricity will depend on the present renewable electricity cost in large new projects being developed in Armenia. According to IEA calculations, with an electricity price of about $29 /MWh[5], the number of electrolyzers capacity utilization hours of 1500-2000 hours per year, electrolyzers CAPEX of $450 /kW and discount rate of 8%, the hydrogen present value will be about $2.5-3/kg.

2.2.2.4 Logistical opportunities and barriers for export-oriented hydrogen projects

Armenia has no access to the open sea. With a combination of land and sea transport, the distance to the port of Rotterdam (Netherlands) will be 7.2 thousand km, to the port of Kobe (Japan) - 17.1 thousand km. This is higher than for export-oriented hydrogen projects in the MENA region (such as the 4 GW NEOM Green Hydrogen project in Saudi Arabia), limiting the competitiveness of similar projects in Armenia.

At the same time, the nearest capital of an EU member state is located at 2.2 thousand km by land from Yerevan (Sofia). Therefore, for export-oriented Armenia-the EU projects, rail and road transport in the EU possibilities can be checked, considering EU market prospects (imports of up to 10 Mt of hydrogen per year by 2030) and Armenian suppliers competitiveness in terms of cost, carbon footprint of hydrogen and its origin (for EU market, green or renewable hydrogen has priority).

2.2.3 Existing and prospective pilot projects in the field of hydrogen

2.2.3.1 Existing pilot projects

There are no implemented pilot projects in the field of low-carbon hydrogen in Armenia yet. In the public domain, there is no information yet about the study of opportunities in the field of hydrogen economy by the corporate sector.

2.2.3.2 Possible promising projects

Armenia has not yet set carbon neutrality goals. Its energy sector depends on imports of fossil energy resources (primarily natural gas from Russia). The nuclear power plant operating in the country allows to reduce natural gas demand from the side of power sector, at the same time, the plant needs investments for modernization. Thus, low-carbon hydrogen production without increase in greenhouse gas emissions in other sectors of the economy in Armenia is possible only as the renewable energy sector develops, the share of which is still insignificant.

Domestic hydrogen demand, based on the structure of energy demand in Armenia, would be fastest to start in the transport sector, which accounts for 30% of total final energy consumption in the country. The launch of pilot hydrogen fuel cell electric buses, the phased development of hydrogen refueling infrastructure around hydrogen-producing enterprises (including oil refineries) are the first steps that begin the development of the hydrogen economy of countries around the world. Setting targets for achieving carbon neutrality and other energy policy measures related to the transport sector (ICE ban, environmental restrictions on emissions, preferential parking, priority travel, subsidies, tax incentives) can create a regulatory environment for such projects.

To get a clearer picture of the prospects for a hydrogen economy in Armenia, the country may need a national hydrogen strategy. According to IRENA, more than 30 states around the world have already approved such documents, and about 20 more are developing them, including Uzbekistan and Kazakhstan. International organizations can provide methodological assistance in this.

5 Corresponds to 200 MW AYG-1 tender result with Masdar winning (2021)

2.2.4 Conclusions

1. Armenia is an energy-deficient country, deprived of access to its own fossil energy resources. Natural gas accounts for 55% of total final energy consumption, while being completely exported.

2. The share of solar and wind energy is still insignificant, hydropower occupies an important place, but its development is slowed down by environmental restrictions. Nuclear power is used in a basic electricity source (Armenia is the only country in the South Caucasus that uses nuclear power).

3. Armenian long-term energy strategy assumes renewables deployment of +1000-1500 MW during 2030-2040. The maximum potential is certainly greater than these values, but it has not been sufficiently explored.

4. Renewable energy sources and energy efficiency development, electric transport, the extension of nuclear power plant operation is considered by regulator as directions to achieve energy security.

5. The main significant opportunity for low-carbon hydrogen production in Armenia is water electrolysis using renewable electricity from new power plants that are planned to be built in the country. The resource potential can be estimated at 14-42 thousand tons per year. For its implementation, the advanced renewables development will be required.

6. The gas transportation infrastructure in Armenia is controlled by the vertically integrated company Gazprom Armenia, which is part of the Gazprom Group (Russia). These companies do not have approved any plans to use the gas transportation infrastructure to transport hydrogen.

7. So far, there are no pilot projects in the field of low-carbon hydrogen in Armenia, and there is no public information yet about the study of opportunities in the field of hydrogen economy by the corporate sector. It is possible to start low-carbon hydrogen demand within the Armenian economy from the transport sector.

8. To better understand the prospects for a hydrogen economy in Armenia, the country may need a national hydrogen strategy, which international organizations can help develop.

2.3 Belarus

An analysis of the current status of the energy sector, key documents and regulatory bodies, the balance of energy production and demand, gas transportation infrastructure, greenhouse gas emissions, as well as existing forecasts and long-term goals of the country's energy and climate policy is provided in the Annex.

2.3.1 Potential in renewables, nuclear power, natural gas and CCUS

Low-carbon hydrogen production requires raw materials and energy resources (electricity from renewable energy sources, hydropower, nuclear power plants, natural gas or biomethane, coal with gasification, water, etc.), as well as (for the case of fossil-fuels based hydrogen production) the establishment of CCUS industry.

This section provides information about the relevant resource and energy potential of Belarus, available from open sources.

2.3.1.1 Renewable Energy Sources

Renewable energy sources share in the energy balance of Belarus in 2019 was about 6-7%, according to IRENA (2021). First, these are biofuels (primarily solid), as well as, to a lesser extent, solar and wind power.

At the same time, Belarus has significant untapped renewables potential, the exact potential of which has yet to be determined:

ESMAP (2022), IRENA (2021), and IEA (2020) provide the following data:

- 3.3 bcm/year – technical potential for biogas production from animal waste (source: Greenworld.org);
- economic potential of hydropower - 250 MW (sources - UNIDO and ICSHP);
- average theoretical potential of solar PV - 2.94 kWh/m²; presumed country area proportion to be covered by PV plants producing the equivalent of yearly electricity consumption is 0.36%; LCOE from PV solar generation could be $0.14 per kWh.
- by the end of December 2018, 22 biogas power plants (34.3 MW), more than 2.5 thousand small hydro power plants (about 7 MW in total), 50 wind power plants (103 MW in total), 63 solar power plants (about 154 MW in total) were already operating in Belarus.

All this potential can be used directly in the power sector, for gasification (biogas) and for heat supply (solar energy) - this was aimed, among other things, by the current regulator's program documents for the period of 2025-2030 - that is, to increase the renewable energy share in the energy balance from 6-7% to 8% (that is, up to 33% for the period 2020-2030).

According to Belstat, renewable electricity generation in 2015 were about 159 GWh, in 2019 - 696 GWh. In accordance with the Energy Security Concept forecast, by 2035 this amount may reach 2600 GWh.

2.3.1.2 Nuclear power

In Belarus, the role of nuclear power (Belarusian nuclear power plant, BelNPP) will be key to achieve diversifying energy supplies goals. The new 2400 MW nuclear power plant, according to the forecast indicators from the energy security concept of Belarus, will have to produce about 18 TWh per year, replacing gas-fired thermal power plants electricity generation. In this case, the BelNPP's capacity factor will be about 86%, which is a good indicator for nuclear power (the average capacity factor of Rosatom's plants in Russia in the first half of 2021 was 83%). At the same time, at such rates, the nuclear power plant will be fully loaded without any ability to produce additional low-carbon electricity for low-carbon hydrogen production.

If BelNPP electricity generation targets cannot be achieved – for example, due to power grid constraints, more gas-fired power plants will have to be kept in operation than planned – then hydrogen production near the BelNPP site may be a solution. This issue requires further study.

A similar project is going to be implemented in Russia – Rosatom plans to supply electricity for pilot hydrogen production project from underloaded Kola nuclear power plant starting from 2023-2024.

2.3.1.3 Natural gas and biogas

Belarus has insignificant natural gas reserves, and the entire amount produced (about 0.21 bcm per annum) is used at one gas processing plant. All the gas needed for the economy is currently imported from Russia at a price below the global market.

The technical potential for biogas production from animal waste is more significant (3.5 bcm per annum), but this potential can also be used to replace imported gas.

2.3.1.4 Carbon dioxide capture and long-term storage (CCUS)

For low-carbon hydrogen production from natural gas, it is important to provide carbon dioxide capture and long-term storage (CCUS) that is produced during the steam methane reforming process. In the case of biomethane reforming, CCUS provides hydrogen production with a negative carbon footprint.

There are no reliable public estimates of the potential of CCUS in Belarus yet. But the relevance of this sector development is low in the context of lack of own natural gas.

2.3.2 Resource potential for low-carbon hydrogen production

This section analyzes the key assumptions that shape the potential for low-carbon hydrogen production by various technologies analyzed, among others, in UNECE (2021b).

2.3.2.1 Assumptions and estimates adopted for the analysis

Based on the analysis, Belarus will have resources for hydrogen production by water electrolysis using electricity from nuclear power - if the BelNPP has relatively low capacity factor - and from renewables (if renewable energy sector develops in the country). Significant resources for hydrogen production by other low-carbon methods have not been found.

The resource potential of hydrogen production in 2040 is determined by:

- technical and economic potential for wind, solar and another renewables development;
- share of renewable electricity that would be appropriate to use for hydrogen production instead of being used directly in Belarusian power sector or exported to neighboring countries.

With the current level of uncertainty, it is not possible to calculate these parameters, but it is possible to assess the resource potential by taking them at the minimum and maximum levels. In this study, two scenarios are adopted:

1) Minimum Scenario

- 30% of the increase in solar and wind electricity generation during 2020-2035 is used for hydrogen production;
- 5% of the annual electricity generation by BelNPP is used for hydrogen production (the rest 95% of electricity is used in the power system for another consumers)

2) Maximum Scenario

- 50% of the increase in solar and wind electricity generation during 2020-2035 is used for hydrogen production;
- 8.3% of the annual electricity generation by BelNPP is used for hydrogen production (the rest is used in the power system for another consumers)
- capacity factor of renewables – 35%.

In both scenarios, it is assumed that hydrogen production by water electrolysis will require 55 kWh/kg H_2 of electricity.

2.3.2.2 Resource potential

In the **minimum scenario**, the increase in renewable electricity generation during 2020-2035 is 2059 GWh. 30% of this value, that is, 618 GWh/year, would be used for hydrogen production. In addition, 5% of the annual electricity generation by BelNPP, that is, 900 GWh/year, will be used for hydrogen production.

In the **maximum scenario**, the increase in renewable electricity generation during 2020-2035 is 2059 GWh. 50% of this value, that is, 1030 GWh/year, would be used for hydrogen production. In addition, 5% of the annual electricity generation by BelNPP, that is, 1494 GWh/year, will be used for hydrogen production.

The results of the potential assessment are summarized in Table 4.

TABLE 4

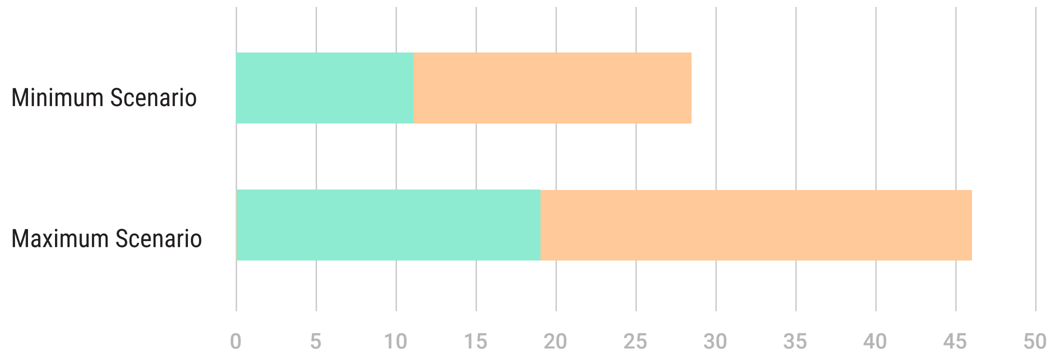
Resource potential of hydrogen production in Belarus by 2040

	MINIMUM SCENARIO	MAXIMUM SCENARIO
Renewable electricity for hydrogen, GWh per year	617.7	1029.5
Natural gas for hydrogen, bcm per annum	900	1494
Hydrogen by water electrolysis using renewable electricity, thousand tons per annum	11.23	19
Hydrogen by water electrolysis using nuclear electricity, thousand tons per annum	16.36	27.16
Hydrogen total, thousand tons per annum	**28**	**46**
Required capacity of CCUS systems, $MtCO_2$ per annum	0	0

The evaluation results are shown in Figure 5. Thus, under the accepted assumptions, there are two different possibilities for low-carbon hydrogen production in Belarus.

FIGURE 5

Resource potential of hydrogen production in Belarus by 2040, thousand tons per year



2.3.2.3 Cost analysis

According to ERI RAS estimates (ERIRAS, 2022), the cost of low-carbon hydrogen produced using nuclear electricity from new power plants in Russia, considering their 60-year operation, can be more than $4 per kg. The BelNPP was built according to Russian design in the same time as the new nuclear power units in Russia, so this estimate can be taken as the minimum for BelNPP conditions, since if the payback period is reduced from 60 years to 20-30 years, the cost of electricity and hydrogen will increase.

The cost of solar and wind electricity from new power plants can be taken at the level of $0.15-0.2 per kWh (this level is approximately the same as both in Russia and ESMAP estimates for PV solar plants in Belarus). According to IEA estimates, at this price of electricity, the number of electrolyzers capacity utilization hours of 1500-2000 hours per year, electrolyzers CAPEX of $450 per kW, and discount rate of 8%, the hydrogen present value will be about $6–8 per kg.

2.3.2.4 Logistical opportunities and barriers for export-oriented hydrogen projects

Belarus has no access to the open sea. With a combination of land and sea transport, the distance to the port of Kobe (Japan) will be 22.3 thousand km, which significantly exceeds similar indicators for hydrogen suppliers from the MENA region, Australia and Chile. At the same time, the EU market is close: the nearest capital of an EU member state is only 180 km away (Vilnius), the distance to the port of Rotterdam by land transport is about 1.7 thousand km. The gas transport infrastructure directly links Belarus with the EU countries.

Therefore, for export-oriented Belarus-the EU projects, pipeline, road and rail transport possibilities can be checked, considering EU market prospects (imports of up to 10 Mt of hydrogen per year by 2030) and Belarusian suppliers competitiveness in terms of cost, carbon footprint of hydrogen and its origin (for EU market, green or renewable hydrogen has priority).

2.3.3 Existing and prospective pilot projects in the field of hydrogen

2.3.3.1 Existing pilot projects

There are no implemented pilot projects in the field of low-carbon hydrogen in Belarus yet. In the public domain, there is no information yet about the study of opportunities in the field of hydrogen economy by the corporate sector.

2.3.3.2 Possible promising projects

Belarus has not yet set carbon neutrality goals. Its energy sector depends on imports of fossil energy resources (primarily natural gas from Russia). New nuclear power plant operating in the country, among other things, aims to reduce natural gas consumption in power sector. There are scenarios of relatively low (less than planned) capacity factor of this plant - this will create opportunities for low-carbon hydrogen production using nuclear power.

Domestic low-carbon hydrogen demand, based on the energy consumption structure in Belarus, could be started in the transport sector, which accounts for about 20% of total final energy consumption in the country, as well as in the hydrocarbon processing sector. The launch of pilot hydrogen fuel cell electric buses, the phased development of a hydrogen refueling infrastructure around hydrogen-producing enterprises (including oil refineries, nuclear power plants) are the first steps that begin the development of a hydrogen economy in countries around the world. Setting targets for achieving carbon neutrality and other energy policy measures related to the transport sector (ICE ban, environmental restrictions on emissions, preferential parking, priority travel, subsidies, tax incentives) can create a regulatory environment for such projects.

To get a clearer picture of the hydrogen economy perspectives in Belarus, the country may need a national hydrogen strategy. According to IRENA, more than 30 states around the world have already adopted such documents, and about 20 more are developing them, including Russia, Uzbekistan and Kazakhstan. International organizations can provide methodological assistance in this.

2.3.4 Conclusions

1. Belarus is an energy-deficient country, more than 80% dependent on energy imports. Natural gas accounts for about 60% of the total final energy consumption, while it is completely imported.

2. The share of solar and wind energy is still insignificant. Nuclear power plant will be put into operation in 2022 and will be used in the power sector as a basic source - for the analysis it is assumed that no more than 5-8% of nuclear power generation can be used in future to produce hydrogen.

3. The energy security concept of Belarus assumes an increase in renewable electricity generation by 2059 GWh per year by 2035, although the theoretical potential is larger and has not yet been sufficiently studied. Part of this electricity can be used for hydrogen production (the range between 30 and 50% is assumed in the analysis).

4. The main significant resource for hydrogen production In Belarus will be water electrolysis using renewable electricity from new power plants that are planned to be built in the country, and a part of electricity generated by the newly built Belarusian nuclear power plant. The resource potential can be estimated at 28-46 thousand tons of hydrogen per year.

5. Depending on pricing approaches, hydrogen produced using electricity from nuclear power plants may be cheaper than hydrogen produced using renewable electricity.

6. The gas transportation infrastructure in Belarus is controlled by Gazprom Transgaz Belarus, a member of the Gazprom Group (Russia). These companies do not have approved plans to use the gas transportation infrastructure to transport hydrogen.

7. There are no pilot projects in the field of low-carbon hydrogen in Belarus yet; there is no public information yet about the study of opportunities in the field of hydrogen economy by the corporate sector. It is possible to start the local demand of low-carbon hydrogen within the Belarusian economy from the transport sector, as well as in the hydrocarbon processing sector.

8. To better understand the prospects for a hydrogen economy in Belarus, the country may need a national hydrogen strategy, which international organizations can help develop.

2.4 Kazakhstan

An analysis of the current status of the energy sector, key documents and regulatory bodies, the balance of energy production and demand, gas transportation infrastructure, greenhouse gas emissions, as well as existing forecasts and long-term goals of the country's energy and climate policy is provided in the Annex.

2.4.1 Potential for renewables, nuclear power, natural gas and CCUS

Low-carbon hydrogen production requires raw materials and energy sources (electricity from renewable energy sources, hydropower, nuclear power plants, natural gas or biomethane, coal with gasification, water, etc.), as well as (for the case of fossil fuels-based hydrogen production) the establishment of CCUS industry.

This section provides information about the relevant resource and energy potential of Kazakhstan, available from open sources.

2.4.1.1 Renewable Energy Sources

According to KEGOC data cited by Kazenergy (2021), as of 2020, hydropower plants share in electricity generation in Kazakhstan was 8.8%, the solar power share was 1%, and the wind farms share was 1.2%.

At the same time, Kazakhstan has substantial untapped renewables energy potential, especially in wind and solar. This potential has already begun to be realized - after auctions introduction in 2018, investors from 12 countries entered Kazakhstan, 58 companies signed agreements for a total capacity of more than 1,700 MW in 75 projects during 2018-2021. This was accompanied by a 4% decline in the levelized cost of electricity for wind and 34% for solar, to 4.8 and 5.7 USc/kWh, respectively.

Renewables performance efficiency differs by region: the highest capacity factor for wind farms was in Atyrau region, for solar power plants - in Almaty region. The national average is 24% and 16%.

Wind energy potential alone in Kazakhstan exceeds its current electricity demand by about 10 times, according to the data cited by the Deputy Minister of Energy in 2017. This is determined, among other things, by the vast territory of the country. In the Doctrine's Baseline scenario, renewable electricity generation (including by hydropower) is estimated to grow by 2.2 times (by 15.6 TWh) during 2017-2040, and in the Carbon neutrality scenario, by almost 15 times (by 161 TWh).

According to ESMAP (2022), the average theoretical solar PV potential in Kazakhstan is 3.82 kWh/m^2; Presumed country area proportion to be covered by PV plants producing the equivalent of yearly electricity consumption is 0.05%; LCOE solar PV generation could be $0.12/kWh.

2.4.1.2 Nuclear power

There are no operating nuclear power plants in Kazakhstan, although research reactors have been built and launched as part of space programs in the country since the mid-1970s, and the National Nuclear Center was established in the 1990s. Discussions about nuclear energy future, taking place in the country nowadays[6], demonstrate controversial assessments: on the one hand, 60% of Kazakhstanis are against nuclear power, on the other hand, nuclear power plant(s) could help achieve national decarbonization goals and provide baseload low-carbon electricity generation.

In the summer of 2022, it became known that Kazakhstan had decided on a site for the future first nuclear power plant (near Balkhash Lake, Ulken village in the Almaty region) and a preliminary shortlist of suppliers (KHNP, CNNC, Rosatom, EDF). The site near the city of Kurchatov on the river Irtysh[7] is being considered as location for a possible second nuclear power plant.

6 https://forbes.kz/process/energetics/ekspertyi_ob_aes_v_kazahstane_est_plohoy_variant_i_esche_huje
7 https://tengrinews.kz/kazakhstan_news/stroitelstvo-vtoroy-aes-na-irtyishe-obsujdayut-v-kazakhstane-474555/

It is important to note that Kazakhstan is the largest producer of uranium, that could create long-term opportunity for decarbonization if nuclear energy will develop beyond the Balkhash power plant project.

By default, it can be assumed that all available electricity from the new nuclear power plant will be used in the power sector. But if nuclear power generation targets do not be achieved – for example, due to grid constraints, more thermal power plants will remain in operation than planned – then hydrogen production near the site of the new nuclear power plant may be a solution. This issue requires further study.

A similar project is going to be implemented in Russia – Rosatom plans to supply electricity for pilot hydrogen production project from underloaded Kola nuclear power plant starting from 2023-2024.

2.4.1.3 Natural gas

According to BP (2021), proven natural gas reserves in Kazakhstan in 2021 are 2.3 trillion m^3 - according to this indicator, the country is in third place among those covered by this study. By comparison, the combined reserves of European countries (including Norway and the United Kingdom) are just over 3.2 trillion m^3.

According to IHS Markit, commercial gas production in Kazakhstan increased between 2010 and 2020 to 34.8 bcm (growth rate of 4% per year). Further growth in production, notes IHS Markit, is limited by the lack of commercial incentives for gas producers, and will be limited to 36 bcm in 2030, subsequently decreasing to 30 bcm/year by 2050. At the same time, according to Nexant model, production can be obtained by introducing new fields 50 bcm/year.

On gas demand side, there is uncertainty regarding the growth rate – but as Kazakhstan move away from coal, gas demand will increase in the economy. Starting from 2023-2024, Kazakhstan can completely stop exporting natural gas to focus on ensuring the domestic demand growth (having priority over exports), according to public assessments of key stakeholders in 2022 - President Tokayev[8], Minister of Energy B. Akchulakov[9], QazaqGaz's Chairman of the Board S. Zharkeshov[10]. Among other things, natural gas will be important to reduce power sector emissions and increase the thermal power plants flexibility as renewables share in electricity mix grows.

Experience in gas and oil processing among companies in Kazakhstan is essential for the successful implementation of projects in the field of steam methane reforming. In addition, gas and oil refineries can become centers for hydrogen economy development due to production of "grey" hydrogen already in place and demand for hydrogen for hydrocarbons processing.

2.4.1.4 Carbon dioxide capture and long-term storage (CCUS)

For low-carbon hydrogen production from natural gas, it is important to provide carbon dioxide capture and long-term storage (CCUS) that is produced during the steam methane reforming process.

In 2020, the KazCCUS research project (Abuov, Lee, 2020) was launched in Kazakhstan, aimed at identifying appropriate geological structures in sedimentary basins and estimating their storage capacity. CO_2 storage options were identified in 6 sedimentary basins of the country: Preacaspian, Mangyshlak, Ustyurt, South Torgay, Chu-Sarysu and Zaysan basins. The total effective CO_2 storage capacity in 6 basins was estimated to be 204 Mt, 610 Mt, and 403 Gt in oil reservoirs, gas reservoirs, and saline aquifers, respectively. The results of this study show that there is a huge potential for CCS in Kazakhstan and CCS could be deployed in depleted fields in the oil producing basins.

The Doctrine of Achieving Carbon Neutrality considers that it will be required to capture and store (using CCS technologies) at least 50 Mt CO_2e per annum in 2040-2060 to offset emissions from the remaining operating

8 https://www.interfax.ru/business/845567
9 https://www.inform.kz/ru/podnimat-ceny-na-gaz-v-kazakhstane-budut-after-2024-goda_a3926949
10 https://www.inform.kz/ru/gazovaya-otrasl-kazahstana-mozhet-stolknut-sya-s-krizisom-uzhe-cherez-dva-goda_a3941277

thermal power plants in the Carbon neutrality scenario. Thus, part of this potential can be used to maintain low-carbon hydrogen production from natural gas.

2.4.2 Resource potential for low-carbon hydrogen production

This section analyzes the key assumptions that shape the potential for low-carbon hydrogen production by various technologies analyzed, among others, in UNECE (2021 b).

2.4.2.1 Assumptions and estimates adopted for the analysis

Based on the analysis, Kazakhstan will have resources for hydrogen production by water electrolysis using renewable electricity (if renewable energy develops in the country), electricity from a nuclear power plant (after its commissioning), as well as for hydrogen production by steam methane reforming with CCUS (if the CCUS industry develops).

The resource potential of hydrogen production in 2040 is determined by:

- technical and economic potential for wind, solar and another renewables development;
- the share of renewable electricity that would be appropriate to use for hydrogen production instead of being used directly in the power sector of Kazakhstan or exported to neighboring countries;
- natural gas production potential;
- the share of natural gas that would be economically feasible to use for hydrogen production instead of direct use of gas in the national economy or its export;
- the CCUS potential for long-term storage of carbon dioxide produced during hydrogen production from natural gas.

With the current level of uncertainty, it is not possible to calculate these parameters, but it is possible to assess the resource potential by taking them at the minimum and maximum levels. In this study, two scenarios are adopted:

1) Minimum Scenario

- 30% of the increase in solar and wind electricity generation during 2020-2040, determined for the Baseline scenario of the Doctrine, is used for hydrogen production;
- 30% of the increase in natural gas production, determined according to the IHS Markit forecast, is used for hydrogen production;
- 5% of the annual electricity generation by new nuclear power plant is used for hydrogen production (the rest 95% of electricity is used in the power system for another consumers)

2) Maximum Scenario

- 50% of the increase in wind and solar electricity generation during 2020-2040, determined for the Carbon neutrality scenario of the Doctrine, is used for hydrogen production;
- 30% of the increase in natural gas production, determined by the Nexant model is used for hydrogen production;
- 8.3% of the annual electricity generation by new nuclear power plant is used for hydrogen production (the rest is used in the power system for another consumers)

In both scenarios, it is assumed that hydrogen production by electrolysis of water will require 55 kWh/kg H_2 of electricity, and hydrogen production by steam methane reforming will require 5.3 m^3/kg H_2 of electricity. The amount of CO_2 released during the reforming process, which must be stored, is estimated as 10 kg CO_2 / 1 kg H_2.

2.4.2.2 Resource potential

The results of the potential assessment are summarized in Table 5.

TABLE 5

Resource potential of hydrogen production in Kazakhstan by 2040·

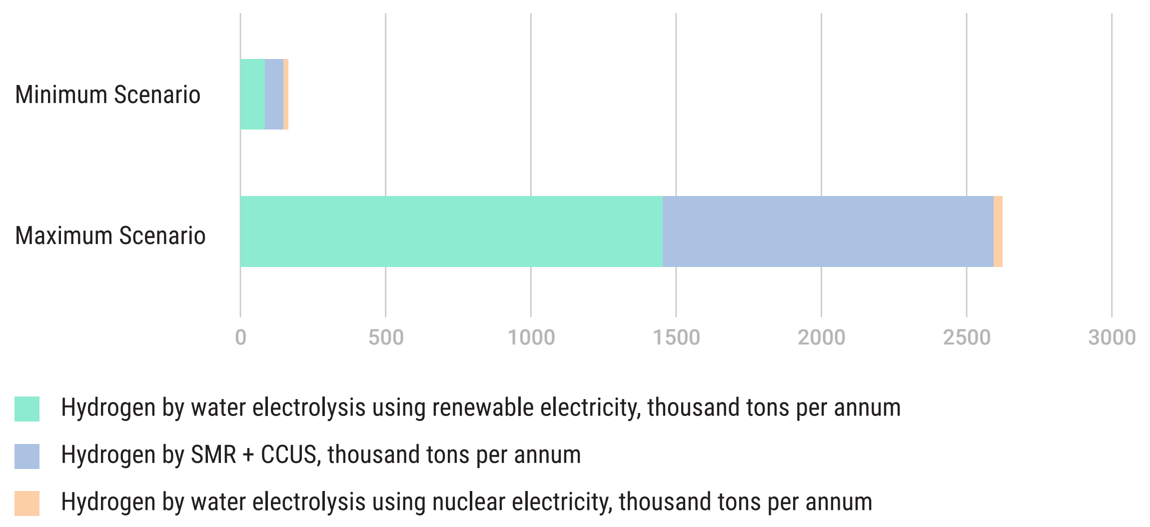
	MINIMUM SCENARIO	MAXIMUM SCENARIO
Renewable electricity for hydrogen, GWh per annum	4680	80500
Nuclear electricity for hydrogen, GWh per annum	900	1530
Natural gas for hydrogen, bcm per annum	0.36	6
Hydrogen by water electrolysis using renewable electricity, thousand tons per annum	85	1464
Hydrogen by water electrolysis using nuclear electricity, thousand tons per annum	16	28
Hydrogen from methane by SMR + CCUS, thousand tons per annum	68	1132
Hydrogen total, thousand tons per annum	**169**	**2624**
Required capacity of CCUS systems, $MtCO_2$ per annum	1	11

The evaluation results are shown in Figure 6. Thus, under the accepted assumptions, the main long-term opportunities for hydrogen production in Kazakhstan are water electrolysis using renewable electricity and steam methane reforming with CCS.

This is determined by the setting of ambitious goals and the accumulated dynamics in the field of renewables development in the country, by significant proven natural gas reserves, and the growth rate of its production. The key constraint and condition is the outstripping development of the CCUS industry - even in the minimum scenario, it is necessary to create CCUS facilities with a total capacity of 1 $MtCO_2$ per annum, as well as implement combined renewables + electrolysis projects.

FIGURE 6

Resource potential of hydrogen production in Kazakhstan by 2040, thousand tons per year



2.4.2.3 Cost analysis

According to ERI RAS estimates (ERIRAS, 2022), the cost of low-carbon hydrogen produced using electricity from new nuclear power plants in Russia, considering their 60-year operation, can be more than $4 per kg. A nuclear power plant in Kazakhstan can be built according to Russian design in the same time as the new nuclear power units in Russia, so this estimate can be taken as the minimum for a nuclear power plant in Kazakhstan, since when the payback period is reduced from 60 years to 20-30 years, the cost of electricity and hydrogen will increase.

The cost of solar and wind electricity from new power plants can be taken at the level of $0.05 per kWh[11]. According to IEA estimates, at this price of electricity, the number of electrolyzers capacity utilization hours of 1500-2000 hours per year, electrolyzers CAPEX of $450 per kW, and discount rate of 8%, the hydrogen present value will be about $3.5–5 per kg.

The cost of hydrogen from natural gas consists of the cost of raw materials (for Kazakhstan, as a gas producing country, this is the cost of natural gas production), as well as the cost of CCUS. According to the IEA (2019), for gas producing countries, the natural gas cost was approximately 30% of the blue hydrogen cost. With the gas production cost at the level of $59-67 per thousand m^3, the blue hydrogen production cost can be estimated at $0.8-1.2 per kg of hydrogen.

2.4.2.4 Logistical opportunities and barriers for export-oriented hydrogen projects

Kazakhstan has no access to the open sea. With a combination of land and sea transport, the distance from Aktau (the Mangistau region's center, where the potential Svevind project is being developed) to the port of Rotterdam (Netherlands) will be 7.7 thousand km, to the port of Kobe (Japan) - 17.5 thousand km. This is higher than for export-oriented hydrogen projects in the MENA region (such as the NEOM Green Hydrogen project in Saudi Arabia with a capacity of 4 GW - 6.5 thousand km to Rotterdam and 13.8 thousand km to Kobe), limiting the competitiveness of similar projects in Kazakhstan.

The nearest capital of an EU member state is located at 4.1 thousand km from Aktau by land transport (Sofia) with transit through Russia, Georgia and Turkey - this is 1.5 times more than the same indicator of Azerbaijan, which also has existing TAP and TANAP pipelines transporting gas to the EU. Thus, the position of Kazakhstan relative to the future European hydrogen market (imports up to 10 Mt of hydrogen per year by 2030) can hardly be called competitive. During drafting an export strategy, these routes may need to be studied in more detail, considering Kazakhstani suppliers competitiveness in terms of cost, carbon footprint of hydrogen and its origin (green or renewable hydrogen has priority for the European market).

Kazakhstan has a common border with China, the distance from Aktau to Urumqi (the largest industrial center of the Xinjiang Uygur Autonomous Region of China) by land transport is about 2.8 thousand km. The Central Asia-China gas pipeline passes through Kazakhstan, which connects with the Chinese West-East gas pipeline in Khorgos on the border of Kazakhstan and the Xinjiang Uygur Autonomous Region of China. This creates opportunities for investigation of hydrogen export opportunities to China by pipeline, road, and rail transport.

2.4.3 Existing and prospective pilot projects in the field of hydrogen

2.4.3.1 Existing pilot projects

There are no implemented pilot projects in the field of low-carbon hydrogen in Kazakhstan yet, but companies are beginning to explore opportunities and sign agreements in this field.

The low-carbon development program for the period 2022-2031 of KazMunayGas, the largest vertically integrated oil and gas company in Kazakhstan, as part of the hydrogen energy development provides for such projects as:

11 Corresponds to the results of renewable energy auctions (see the section "RES" above)

- hydrogen mobility development in Atyrau on the basis of refinery (hydrogen refueling, special hydrogen-fueled electric vehicles and pilot projects in hydrogen public electric transport);
- autonomous fuel cell-based power generators - for power supply of offices and remote camps;
- establishment of a hydrogen energy competence center that will serve as a hydrogen research hub (based on a subsidiary of KMG Engineering).

As of September 2022, the Hydrogen Energy Competence Center has been established, several universities of Kazakhstan are involved in R&D on this topic (Nazarbayev University, NAO "Kazakh National Research Technical University named after K.I. Satpayev", Eurasian National University named after L.N. Gumilyov, LLP "Institute of Coal Chemistry and Technology", JSC "Institute of Fuel, Catalysis and Electrochemistry" named after D.V. Sokolsky, Kazakh-British Technical University).

KazMunayGas has entered into cooperation agreements in the field of hydrogen energy with Eni[12], AirLiquide[13], Linde[14].

In June 2022 in Kazakhstan, several companies from Germany, Italy, Spain and Kazakhstan, at the initiative of KAZAKH INVEST, signed an agreement to establish the Green Hydrogen Alliance. Linde (Germany), Svevind Energy Gmbh (Germany), Roedl&Partners (Germany), Qazaq Gaz (Kazakhstan), Atasu Group (Kazakhstan), Green Spark LTD (Italy), Green Finance Center – AIFC (Kazakhstan), GCA Partners (Kazakhstan), Ajusa Hydrogen Technologies (Spain) and other international companies from the EU are among them.

Kazakh Invest and the Swedish company Svevind signed a roadmap for 30 GW green-hydrogen project development in Western Kazakhstan (Mangistau region)[15] in October 2021. A representative of ACWA Power (Saudi Arabia)[16] declared intentions to consider similar projects in August 2022.

The mining and metallurgical company ERG is considering the possibility of replacing fuel oil and diesel fuel at its enterprises with hydrogen as part of the Environmental Strategy development[17], as reported in October 2021.

2.4.3.2 Possible promising projects

Kazakhstan's intention to achieve carbon neutrality by 2060 is the most important basis for the hydrogen economy development in the country.

Large-scale low-carbon hydrogen production in the country will be possible subject to the development of low-carbon electricity sources (renewables, nuclear power plants), as well as CCUS (for hydrogen production from natural gas produced in Kazakhstan). For pilot projects, hydrogen associated with greenhouse gas emissions (for example, hydrogen from existing refineries) can be used - this will help to scale-up value chain by the time when low-carbon hydrogen production becomes possible.

Domestic hydrogen demand can start with pilot projects in the transport sector (especially since KazMunayGas and ERG are already considering these areas). The launch of pilot hydrogen fuel-cell electric buses, the phased development of hydrogen refueling infrastructure around hydrogen-producing enterprises (including oil refineries) are the first steps that begin the development of the hydrogen economy of countries around the world. Setting targets for achieving carbon neutrality and other energy policy measures related to the transport sector (ICE ban, environmental restrictions on emissions, preferential parking, priority travel, subsidies, tax incentives) can create a

12 https://www.eni.com/en-IT/media/press-release/2021/07/eni-ceo-claudio-descalzi-meets-president-kazakhstan-kassym-jomart-tokayev.html

13 https://www.airliquide.com/group/press-releases-news/2021-03-02/air-liquide-increases-its-presence-kazakhstan-significant-acquisition-and-long-term-contract

14 https://nangs.org/news/renewables/hydrogen/kazmunajgaz-i-linde-podpisali-memorandum-o-vzaimoponimanii-po-proektu-proizvodstva-zelenykh-vodoroda-i-ammiaka

15 https://svevind.se/en/2021/10/10/roadmap-signed-or-30-gw-green-hydrogen-developments-in-kazakhstan/

16 https://astanatimes.com/2022/08/saudi-arabia-investor-acwa-power-considers-building-wind-farm-in-kazakhstan/

17 https://www.erg.kz/ru/news/2284

regulatory environment for such projects. If infrastructure develops and technologies become cheaper, the use of low-carbon hydrogen in industry (oil refining, metallurgy) can be considered.

Transportation of hydrogen through the existing gas transmission infrastructure requires additional research, considering experience of European and American gas companies (Shell, Gasunie, Snam, etc.).

Large-scale hydrogen export through existing infrastructure (gas pipelines) will require joint research with the gas companies of the importing countries (Russia and China). Russian Gazprom has no plans to use the gas transportation infrastructure to transport hydrogen. Among Kazakhstan's immediate neighbors, only China, Russia, and Uzbekistan are developing hydrogen strategies, and there is no explicit request for hydrogen imports among these countries.

It is important to consider the variety of possible options for the hydrogen economy development while drafting the national hydrogen strategy. International organizations can provide methodological assistance in this.

2.4.4 Conclusions

1. Kazakhstan is an energy surplus country, an important regional exporter of coal, oil and gas with growing production rates. Coal dominates the electricity and heat supply, driving relatively fast growth in greenhouse gas emissions.
2. Despite this, Kazakhstan has adopted an ambitious carbon neutrality goal by 2060, the first long-term strategic documents (and additional ones are being drafted) regarding radical energy sector restructuring with the aggressive renewables development. Since 2018, the country has relaunched the CO_2 emissions trading system, and dozens of renewable energy projects with investors from 12 countries have been selected at auctions.
3. Renewable energy potential in Kazakhstan is huge due to the large territory, strategic documents consider the goals of a multiple increase in renewable electricity during 2030-2050. In addition, the country has a great CCS potential, which has already begun to be explored, there are opportunities for increasing natural gas production, and first potential nuclear power plants projects are under consideration.
4. The diversity of resources for low-carbon hydrogen production available in Kazakhstan creates opportunities for synergies and accelerated development of the country's hydrogen economy through economies of scale.
5. Based on the resources and energy sources available for hydrogen production, it is possible to estimate the future low-carbon hydrogen production resource potential by 2040 in Kazakhstan at 169-2624 thousand tons per year - using water electrolysis with renewable electricity and steam methane reforming with CCUS.
6. The most affordable low-carbon hydrogen production option in Kazakhstan appears to be steam methane reforming in combination with CCUS.
7. Gas transportation infrastructure in Kazakhstan is controlled by QazaqGaz and is used both to connect the country's gas-producing regions with gas-consuming regions, and to transit gas from Uzbekistan and Turkmenistan for export to Russia and China. Kazakhstan in the short term may stop gas exports and focus on domestic gas demand growth in industry, power sector and households. Gas pipeline infrastructure use for hydrogen transportation will require additional research involving all interested parties.
8. There are no implemented pilot projects in the field of low-carbon hydrogen in Kazakhstan yet, but the companies like KazMunayGas, ERG, QazaqGaz, Kazakh Invest and others are already considering this direction in their strategies and are entering into agreements with international partners. It is possible to start domestic low-carbon hydrogen consumption from the transport sector, as well as in the sector of hydrocarbon processing and metallurgy.
9. To better understand the prospects for a hydrogen economy in Kazakhstan, the country may need a national hydrogen strategy, which international organizations can help develop.

2.5 Kyrgyzstan

An analysis of the current status of the energy sector, key documents and regulatory bodies, the balance of energy production and demand, gas transportation infrastructure, greenhouse gas emissions, as well as existing forecasts and long-term goals of the country's energy and climate policy is provided in the Annex.

2.5.1 Potential for renewables, natural gas and CCUS

Low-carbon hydrogen production requires raw materials and energy sources (electricity from renewable energy sources, hydropower, nuclear power plants, natural gas or biomethane, coal with gasification, water, etc.), as well as (for the case of fossil fuels-based hydrogen production) the establishment of CCUS industry.

This section provides information about the relevant resource and energy potential of Kyrgyzstan, available from open sources.

2.5.1.1 Renewable Energy Sources

Kyrgyzstan has a huge hydropower potential - about 18.5 GW of capacity and 140 TWh/year of electricity generation - which today is only about 10% developed, according to sources analyzed in the UNECE report (2019). To realize this potential, several powerful hydropower plants were planned more than 30 years ago, among which the 1.9 GW Kambarata HPP-1 project (electricity output of about 6 TWh/year) stands out. This project has already entered the active stage of implementation about 10 years ago (basic engineering has started), but as of June 2022, the active construction phase has not yet begun.

Hydropower potential implementation using large hydropower plants in the region is associated with river flow regulation, as well as use of water for agricultural needs in four countries - Kyrgyzstan, Uzbekistan, Tajikistan and Kazakhstan - which requires an increased level of mutual trust and cooperation over the decades of implementation and operation of hydropower projects. In addition, projects of this scale are unique in many respects, very capital-intensive, they have technical and cost risks, which reduces their attractiveness for investors.

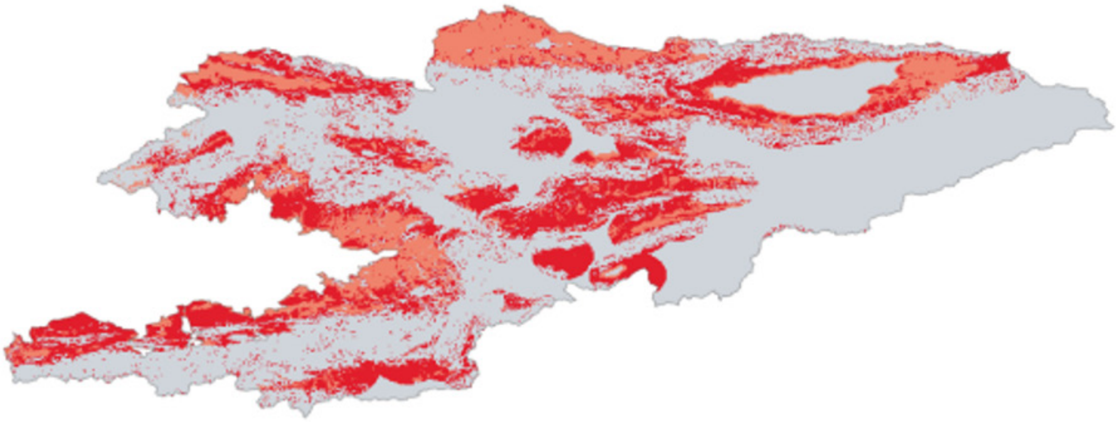
If during the summer months water influx into the reservoirs of operating hydropower plants exceeds the energy system's electricity demand (including possible exports), then water is either accumulated or discharged idly, losing its energy potential. In Kyrgyzstan, such no-operation discharges amount requires further study - perhaps this "curtailed" energy can be used for low-carbon hydrogen production.

Small hydropower (with a single plant capacity less than 40 MW) also has great potential in Kyrgyzstan. Small rivers hydropower potential in all parts of the country makes it possible to create 92 new small hydropower plants with a total capacity of about 178 MW and an average annual output of up to 1 TWh, including the most promising 31 plants (78.5 MW and 0.4 TWh respectively).

Solar energy potential in the country has not been studied in the same detail as the hydropower potential. According to the World Bank 's ESMAP project (2021), average theoretical solar PV potential in Kyrgyzstan is about 4.1 kWh/m^2, which is almost 1.5 times more than in Germany. Presumed country area proportion to be covered by PV plants producing the equivalent of yearly electricity consumption is 0.055% (see Figure 7); LCOE solar PV generation could be $0.1/kWh.

FIGURE 7

Model of the Kyrgyzstan's territory with solar PV practical potential zonation



Red color stands for a territory convenient for locating utility-scale PV plants without any land-use constraints (possibly under land use regulations due to nature and cropland protection); pink stands for a territory convenient for locating utility-scale PV plants with some land-use constraints, gray is an area inconvenient for utility-scale PV plants due to identifiable physical obstacles.

Source: *ESMAP (2021)*

Wind energy potential in Kyrgyzstan is estimated to reach 2 TWh, but is allocated mainly in remote areas (UNECE, 2019), so the best way to realize it may be to deploy small wind farms close to local electricity consumers.

Thus, hydropower and solar energy potential is of maximum importance for low-carbon hydrogen production in the country.

In accordance with the 2018-2040 National Development Strategy's target, the share of small hydropower, solar, wind and biogas power plants, solar heating, heat pumps, will reach at least 10% in the total energy balance, while energy and resource efficiency indicators will need to correspond to those of OECD countries by 2040.

2.5.1.2 Natural gas and biomethane

According to BP (2021), there are no confirmed significant natural gas reserves in Kyrgyzstan in 2021. Imported gas is used mainly in the residential sector, and there are plans to increase consumption in this sector.

Bioenergy potential in the country - in terms of available agricultural waste - is estimated at 9.732 thousand TJ per year. Small biogas plants located close to consumers could not only process waste and reduce greenhouse gas (methane) emissions, but also provide rural residents with energy (which can also be stored in the form of biogas between seasons).

Thus, there are no available natural gas and biomethane resources for hydrogen production in Kyrgyzstan.

2.5.1.3 Carbon dioxide capture and long-term storage (CCUS)

For low-carbon hydrogen production from natural gas, it is important to provide carbon dioxide capture and long-term storage (CCUS) that is produced during the steam methane reforming process.

There are no reliable public estimates of the CCUS potential in Kyrgyzstan yet. But the relevance of this sector development is low in the context of lack of natural gas.

2.5.2 Resource potential for low-carbon hydrogen production

This section analyzes the key assumptions that shape the potential for low-carbon hydrogen production by various technologies analyzed, among others, in UNECE (2021 b).

2.5.2.1 Assumptions and estimates adopted for the analysis

Based on the analysis, Kyrgyzstan faces a serious challenge associated with electricity shortage in seasonal and even annual context accompanied by increasing infrastructure wear-out and climate change that changes river flows. At the same time, the country will have resources for low carbon hydrogen production by water electrolysis using renewable electricity (from hydropower and solar power plants). It will be possible to start realizing this potential only after solving the problems of energy shortage and infrastructure wear-out.

If these problems are solved by 2030-2040, then the resource potential of hydrogen production by 2040 will reach significant values. It is defined by:

- technical and economic potential for hydropower, solar and other renewables;
- share of renewable electricity that would be appropriate to use for hydrogen production instead of being used directly in the country's power sector or exported to neighboring countries.

With the current level of uncertainty, it is not possible to calculate these parameters, but it is possible to assess the resource potential by taking them at the minimum and maximum levels. In this study, two scenarios are adopted:

1) Minimum Scenario

- 30% of the increase in electricity generation from small hydropower and solar power during 2020-2040 is used for hydrogen production;
- increase in solar electricity generation is unknown (as potential is underexplored), the total increase in small hydropower electricity generation is about 1 TWh per annum;

2) Maximum Scenario

- 50% of the increase in electricity generation from small hydropower and solar power, as well as 30% of the increase in the large hydropower plants generation during 2020-2040 is used for hydrogen production.
- total increase in small hydropower electricity generation is about 1 TWh per annum, so that for large hydropower plants is about 25 TWh.

In both scenarios, it is assumed that hydrogen production by water electrolysis will require 55 kWh/kg H_2 of electricity.

2.5.2.2 Resource potential

The results of the potential assessment are summarized in Table 6.

TABLE 6

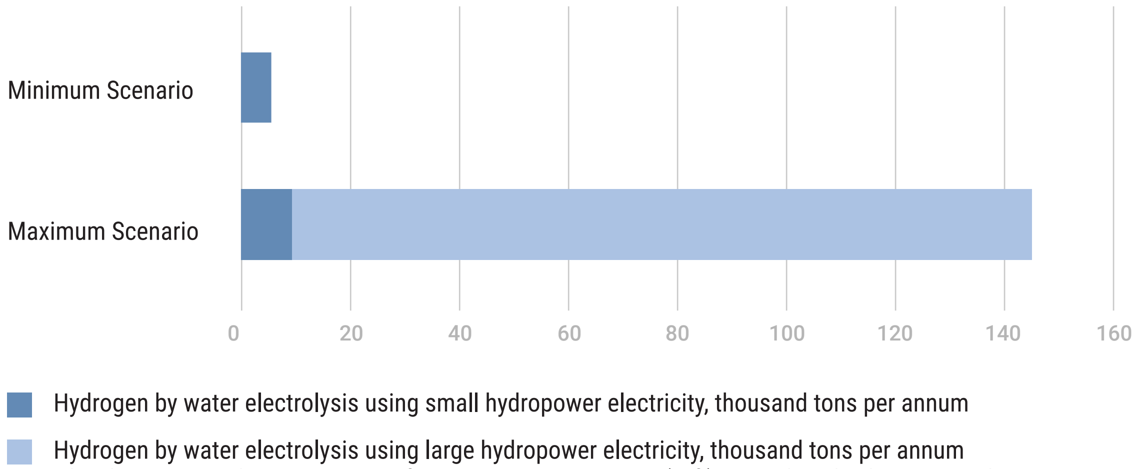
Resource potential of hydrogen production in Kazakhstan by 2040

The evaluation results are shown in Figure 8.

	MINIMUM SCENARIO	MAXIMUM SCENARIO
Small hydropower electricity for hydrogen, GWh per year	300	500
Large hydropower electricity for hydrogen, GWh per year	0	7500
Hydrogen by water electrolysis using small hydropower electricity, thousand tons per annum	5	9
Hydrogen by water electrolysis using large hydropower electricity, thousand tons per annum	0	136
Hydrogen total, thousand tons per annum	**5**	**145**
Required capacity of CCUS systems, $MtCO_2$ per annum	0	0

FIGURE 8

Resource potential of hydrogen production in Kyrgyzstan by 2040, thousand tons per year



Thus, under the accepted assumptions, future resource potential of low-carbon hydrogen production in Kyrgyzstan varies over a wide range, and the main influencing parameter is the rate of renewable energy (hydro and solar) development in the country.

2.5.2.3 Cost analysis

The cost of hydrogen produced by electrolysis using renewable electricity will depend on the renewable electricity's present cost in new large projects being developed in Kyrgyzstan. According to IEA estimates, at the electricity price of $0.1 per kWh[18], the number of electrolyzers capacity utilization hours of 1500-2000 hours per year, electrolyzers CAPEX of $450 per kW, and discount rate of 8%, the hydrogen present value will be about $6 per kg.

If electricity price reduces (for example, due to cheaper technologies or if there is an excess of electricity generated during the seasons of no-operation discharges at hydropower plants), the cost of hydrogen can be significantly reduced. The current electricity tariffs for industrial consumers in Kyrgyzstan are about $0.03/kWh[19] - at this price, the cost of hydrogen will be about $2.5-3 per kg.

2.5.2.4 Logistical opportunities and barriers for export-oriented hydrogen projects

Kyrgyzstan has no access to the open sea. With a combination of land and sea transport, the distance from Bishkek to the port of Rotterdam (Netherlands) will be 17.1 thousand km, to the port of Kobe (Japan) - 10.8 thousand km (through China). The distance from European ports is more than double that for export-oriented hydrogen projects in the MENA region (such as the NEOM Green Hydrogen project in Saudi Arabia with a capacity of 4 GW - 6.5 thousand km to Rotterdam). The distance from the ports of Japan and Korea is comparable to that of export-oriented projects in Australia (9,000 km). But the overland part of the route, which is thousands of kilometers long, question the competitiveness of similar projects in Kyrgyzstan.

The nearest capital of an EU member state is located at 5.8 thousand km from Bishkek by land transport (Sofia) with transit through Kazakhstan, Uzbekistan, Turkmenistan, Iran and Turkey - this is 2 times more than the same indicator of Azerbaijan, which also has existing TAP and TANAP pipelines transporting gas to the EU. Thus, Kyrgyzstan location relative to the future European hydrogen market (imports up to 10 Mt of hydrogen per year by 2030) can hardly be called competitive. During drafting an export strategy, these routes may need to be studied

18 Corresponds to the LCOE estimate from solar power plants in Kyrgyzstan according to ESMAP (2021)
19 https://knews.kg/2021/10/01/kabmin-kyrgyzstana-utverdil-novye-tarify-na-elektrichestvo-i-teplo-na-2021-2025-gody/

in more detail, considering suppliers competitiveness in terms of cost, carbon footprint of hydrogen and its origin (green or renewable hydrogen has priority for the European market).

Kyrgyzstan has a common border with China, the distance from Bishkek to Urumqi (the largest industrial center of the Xinjiang Uygur Autonomous Region of the PRC) by land transport is about 1.1 thousand km. This creates opportunities for investigation of hydrogen export opportunities to China by pipeline, road, and rail transport.

2.5.3 Existing and prospective pilot projects in the field of hydrogen

2.5.3.1 Existing pilot projects

There are no implemented pilot projects in the field of low-carbon hydrogen in Kyrgyzstan yet. In the public domain, there is no information yet about the study of opportunities in the field of hydrogen economy by the corporate sector.

2.5.3.2 Possible promising projects

Kyrgyzstan has not yet set carbon neutrality goals, so local low-carbon hydrogen demand is not a priority for the country.

The energy sector of Kyrgyzstan depends on imports of fossil energy resources. Thus, low-carbon hydrogen production of without an increase in greenhouse gas emissions across other national economy sectors will be possible only as the renewable energy sector develops - in particular, hydropower and solar energy - and only after solving the pressing energy sector problems (energy shortage and wear-out of infrastructure).

Domestic hydrogen demand, based on the energy mix in Kyrgyzstan, would be fastest to start in the transport sector, which accounts for 35% of total final energy consumption. The launch of pilot hydrogen fuel cells electric buses, the phased development of a hydrogen refueling infrastructure around hydrogen-producing enterprises are the first steps that begin the development of a country's hydrogen economy around the world. Setting targets for achieving carbon neutrality and other energy policy measures related to the transport sector (ICE ban, environmental restrictions on emissions, preferential parking, priority travel, subsidies, tax incentives) can create a regulatory environment for such projects.

For Kyrgyzstan, in the long term, it may be promising to create seasonal low-carbon energy storage systems based on hydrogen, which would help dampen the intermittent hydropower and other renewable electricity generation.

To get a clearer picture of the prospects for a hydrogen economy in Kyrgyzstan, the country may need a national hydrogen strategy. International organizations can provide methodological assistance in this.

2.5.4 Conclusions

1. Kyrgyzstan is an energy-deficient country that has practically no own fossil energy resources but provides itself with 90% of its own renewable electricity from hydropower plants. Energy security, energy system modernization and seasonal energy shortages accompanied by increasing infrastructure wear-out and climate change that changes river flows are important priority energy policy issues that will have to be addressed jointly with neighboring countries - they are common by issues of water supply and energy supply.

2. The country has a huge hydropower and solar energy (yet unexplored) potential. Presumed country area proportion to be covered by PV plants producing the equivalent of yearly electricity consumption is 0.055%.

3. With a significant development of this potential, Kyrgyzstan will have a resource potential for low-carbon hydrogen production of up to about 140 thousand tons of hydrogen per year.

4. The existing gas transportation infrastructure in the country is worn out (35 years or more), and its use for hydrogen transportation is not relevant yet.

5. There are no implemented pilot projects in the field of low-carbon hydrogen in Kyrgyzstan yet. In the public domain, there is no information yet about the study of opportunities in the field of hydrogen economy by the corporate sector.

6. The country has not yet set goals for achieving carbon neutrality, so local low-carbon hydroge demand within the economy is not a priority for energy policy.

7. As the pressing problems of energy shortages and aging electricity and gas infrastructure are resolved, Kyrgyzstan will have possibility to produce low-carbon hydrogen and start using it in the transport sector (instead of oil products), as well as for energy storage systems that compensate fluctuations in hydropower plants and other renewables electricity generation.

8. Hydrogen produced by electrolysis using renewable electricity during hydropower plants no-operation discharges seasons can be much cheaper.

2.6 Moldova

An analysis of the current status of the energy sector, key documents and regulatory bodies, the balance of energy production and demand, gas transportation infrastructure, greenhouse gas emissions, as well as existing forecasts and long-term goals of the country's energy and climate policy is provided in the Annex.

2.6.1 Potential for renewable energy, natural gas and CCUS

Low-carbon hydrogen production requires raw materials and energy resources (electricity from renewable energy sources, hydropower, nuclear power plants, natural gas or biomethane, coal with gasification, water, etc.), as well as (for the case of fossil-fuels based hydrogen production) the establishment of CCUS industry.

This section provides information about the relevant resource and energy potential of Moldova, available from open sources.

2.6.1.1 Renewable Energy Sources

Renewables share in total final energy consumption of Moldova was about 22% in 2019, according to the IEA. First, it is a solid biofuel for heat supply. Renewables share in electricity generation was 7% (including hydropower) and 2% (excluding hydropower - mainly due to wind and biogas energy, about 55 GWh) in 2020. At the same time, Moldova has a significant untapped renewables potential, the exact potential of which has yet to be determined:

IRENA (2017) provides the following data for Moldova:

- the technical wind energy potential is about 21 GW and 50.2 TWh;
- the technical solar energy potential is about 4.6 GW and 6.04 TWh;
- the technical small hydropower potential is about 0.3 GW and 1.1 TWh.

According to ESMAP (2021), the average theoretical solar PV potential in Moldova is 3.55 kWh/m^2. Presumed country area proportion to be covered by PV plants producing the equivalent of yearly electricity consumption is 0.2%, LCOE solar PV generation could be around $0.13/kWh.

Thus, the technical potential of renewables in the country is up to 150 times greater than the current electricity generation.

For comparison, in Romania, neighboring Moldova, wind energy share in electricity generation reaches 15% (according to the IEA for 2020), and annual wind electricity generation (almost 7 TWh) exceeds the total electricity generation in Moldova. Romania is 9 times larger in area, Romania's GDP is 19 times that of Moldova, but these figures highlight the possible potential.

Law No. 10 on promoting the renewable energy use was adopted in 2016, aimed at creating the basis for the application of the relevant Directive of the European Parliament and of the Council 2009/28/EC of 23.04.09. Government Decree regarding the approval of capacity limits, maximum quotas and capacity categories in the field of renewable electricity valid until December 31, 2025 was adopted in 2021. Capacity limits for renewables are set at 250 MW, incl. 120 MW for wind power and 130 MW solar power plants.

2.6.1.2 Natural gas and biogas

Moldova does not have its own natural gas reserves. The technical potential for biogas production from animal waste is unknown, but this potential could also be used to replace imported gas.

2.6.1.3 Carbon dioxide capture and long-term storage (CCUS)

For low-carbon hydrogen production from natural gas, it is important to provide carbon dioxide capture and long-term storage (CCUS) that is produced during the steam methane reforming process.

There are no reliable public estimates of the CCUS potential in Moldova yet. But the relevance of this sector development is low in the context of lack of natural gas.

2.6.2 Resource potential for low-carbon hydrogen production

This section analyzes the key assumptions that shape the potential for low-carbon hydrogen production by various technologies analyzed, among others, in UNECE (2021 b).

2.6.2.1 Assumptions and estimates adopted for the analysis

Based on the analysis, Moldova has a significant untapped renewable energy potential that could be used to produce low-carbon hydrogen in the future.

The resource potential of hydrogen production in Moldova by 2040 will be determined by:

- technical and economic potential for wind, solar, hydropower and another renewables development;
- share of renewable electricity that would be appropriate to use for hydrogen production instead of being used directly in the country's power sector or exported to neighboring countries.

With the current level of uncertainty, it is not possible to calculate these parameters, but it is possible to assess the resource potential by taking them at the minimum and maximum levels. In this study, two scenarios are adopted:

1) Minimum Scenario

- 30% of the increase in wind and other renewables electricity generation for the period 2020-2040 is used for hydrogen production;
- increase in renewable electricity generation until 2040 is determined based on linear extrapolation of existing trends in solar and wind energy development: 2016 - 5 GWh, 2020 - 55 GWh; thus, about 300 GWh is expected in 2040;

2) Maximum Scenario

- Moldova will manage to realize 10% of the technical renewables potential, according to IRENA (that is, about 5.7 TWh per year) by 2040;
- 30% of the increase in renewable electricity generation is used for hydrogen production.

In both scenarios, it is assumed that hydrogen production by water electrolysis will require 55 kWh/kg H_2 of electricity.

2.6.2.2 Resource potential

The results of potential assessment are summarized in Table 7.

TABLE 7

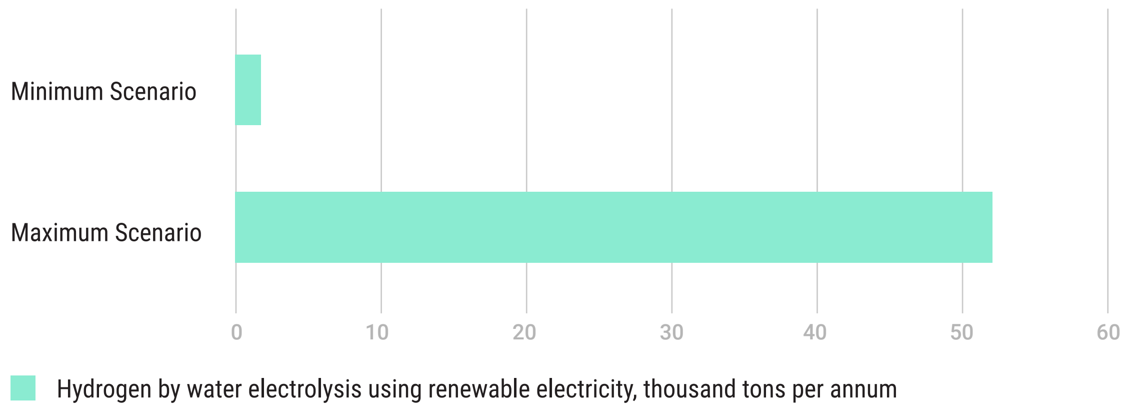
Resource potential of hydrogen production in Moldova by 2040

	MINIMUM SCENARIO	MAXIMUM SCENARIO
Renewable electricity for hydrogen, GWh per year	73.5	2850
Hydrogen by water electrolysis using renewable electricity, thousand tons per annum	1	52
Hydrogen total, thousand tons per annum	**1**	**52**

The evaluation results are shown in Figure 9.

FIGURE 9

Resource potential of hydrogen production in Moldova by 2040, thousand tons per year



Thus, under the accepted assumptions, future resource potential of low-carbon hydrogen production in Moldova varies in a wide range, and the main influencing parameter is the pace of renewable energy (wind and solar) development in the country.

2.6.2.3 Cost analysis

The cost of hydrogen produced by electrolysis using renewable electricity will depend on the renewable electricity's present cost in new large projects being developed in Moldova. According to IEA estimates, with an electricity price of about $0.05-0.1/kWh[20], the number of electrolyzers capacity utilization hours of 1500-2000 hours per year, electrolyzers CAPEX of $450 per kW, and discount rate of 8%, the hydrogen present value will be about $3.5-8 per kg.

2.6.2.4 Logistical opportunities and barriers for export-oriented hydrogen projects

Moldova has no access to the open sea. With a combination of land and sea transport, the distance to the port of Kobe (Japan) will be 16.2 thousand km, which significantly exceeds similar indicators for hydrogen suppliers from the MENA region and Australia. At the same time, the EU market is close: the nearest capital of an EU member state is only 500 km away (Bucharest), the distance to the port of Rotterdam by land transport is about 2.3 thousand km.

Therefore, for export-oriented Moldova-the EU projects, pipeline, road and rail transport possibilities can be checked, considering EU market prospects (imports of up to 10 Mt of hydrogen per year by 2030) and Moldovan suppliers competitiveness in terms of cost, carbon footprint of hydrogen and its origin (for EU market, green or renewable hydrogen has priority).

20 Corresponds to the LCOE from renewables estimate in Romania by 2030 according to Deloitte (2019) and the LCOE estimate from solar power in Moldova according to ESMAP (2021)

2.6.3 Existing and prospective pilot projects in the field of hydrogen

2.6.3.1 Existing pilot projects

There are no implemented pilot projects in the field of low-carbon hydrogen in Moldova yet. In the public domain, there is no information yet about the study of opportunities in the field of hydrogen economy by the corporate sector.

2.6.3.2 Possible promising projects

Moldova has not yet set carbon neutrality goals, so local low-carbon hydrogen demand is not a priority for the country.

The energy sector of Moldova depends on imports of fossil energy resources. Thus, low-carbon hydrogen production without an increase in greenhouse gas emissions in other sectors will be possible only as the renewable energy sector develops, in particular, wind and solar energy.

Domestic hydrogen consumption, based on the total final energy consumption mix in Moldova, would be fastest to start in the transport sector, which accounts for about 30% of the energy consumption in the country. The launch of pilot hydrogen fuel-cell electric buses, the phased development of a hydrogen refueling infrastructure around hydrogen-producing enterprises are the first steps that begin the development of a country's hydrogen economy around the world. Setting targets for achieving carbon neutrality and other energy policy measures related to the transport sector (ICE ban, environmental restrictions on emissions, preferential parking, priority travel, subsidies, tax incentives) can create a regulatory environment for such projects.

To get a clearer picture of the prospects for a hydrogen economy in Moldova, the country may need a national hydrogen strategy. International organizations can provide methodological assistance in this.

2.6.4 Conclusions

1. Moldova is an energy-deficient country, 75% of the energy consumed is imported, including all fossil resources and 60% of electricity. Important energy policy priorities include improving energy security, increasing integration with neighboring countries by electricity and gas interconnections, and increasing energy system sustainability by increase of renewable energy share.

2. Renewable energy share in total final energy consumption is more than 20% due to solid biofuels used for heat supply, solar and wind share in electricity generation is about 2%.

3. The technical potential of renewables in the country exceeds the actual electricity generation by about 150 times. In neighboring Romania, wind energy share electricity generation is about 15%.

4. In Moldova, the main significant resource for low-carbon hydrogen production is water electrolysis using renewable electricity from new power plants that are planned to be built in the country. It is possible to estimate the resource potential by 2040 at 1-52 thousand tons of hydrogen per annum depending on renewables generation growth rate.

5. The gas transportation infrastructure in Moldova is controlled mainly by the Moldovagaz company owned mainly by Russian Gazprom and the Moldovan government. This company has no approved plans to use the gas transportation infrastructure to transport hydrogen.

6. There are no pilot projects in the field of low-carbon hydrogen in Moldova yet; there is no public information yet about the study of opportunities in the field of hydrogen economy by the corporate sector. It is possible to start local low-carbon hydrogen consumption within the Moldovan economy from the transport sector.

To get a clearer picture of the prospects for a hydrogen economy in Moldova, the country may need a national hydrogen strategy, which international organizations can help develop.

2.7 Tajikistan

An analysis of the current status of the energy sector, key documents and regulatory bodies, the balance of energy production and demand, gas transportation infrastructure, greenhouse gas emissions, as well as existing forecasts and long-term goals of the country's energy and climate policy is provided in the Annex.

2.7.1 Potential for renewable energy, natural gas and CCUS

Low-carbon hydrogen production requires raw materials and energy sources (electricity from renewable energy sources, hydropower, nuclear power plants, natural gas or biomethane, coal with gasification, water, etc.), as well as (for the case of fossil fuels-based hydrogen production) the establishment of CCUS industry.

This section provides information about the relevant resource and energy potential of Tajikistan, available from open sources.

2.7.1.1 RES

Tajikistan has a huge **hydropower potential** - about 527 TWh / year of electricity, of which only 4% was used in 2017, according to the data provided in the General Plan for Electricity Sector Development.

The 2030 National Strategy of Tajikistan mentions the need to increase hydropower generation by 2030 to about 31.6-41.6 GWh per year (actual hydropower electricity generation in 2019 was 19.2 TWh).

To realize this potential, several powerful hydropower plants were planned more than 30 years ago. Hydropower potential implementation using large hydropower plants in the region is associated with river flow regulation, as well as use of water for agricultural needs in four countries - Kyrgyzstan, Uzbekistan, Tajikistan and Kazakhstan - which requires an increased level of mutual trust and cooperation over the decades of implementation and operation of hydropower projects. In addition, projects of this scale are unique in many respects, very capital-intensive, they have technical and cost risks, which reduces their attractiveness for investors.

If during the summer months water influx into the reservoirs of operating hydropower plants exceeds the energy system's electricity demand (including possible exports), then water is either accumulated or discharged idly, losing its energy potential. According to the Ministry of Energy and Water Resources and OAHK Barqi Tojik, annual no-operation water discharges at hydropower plants in Tajikistan (excluding dry years) reach 5-6 TWh. Part of the curtailed electricity can already be used for low-carbon hydrogen production during summer months (through a corresponding reduction in no-operation discharges). In the future, part of the electricity from new hydropower plants can be used for hydrogen production.

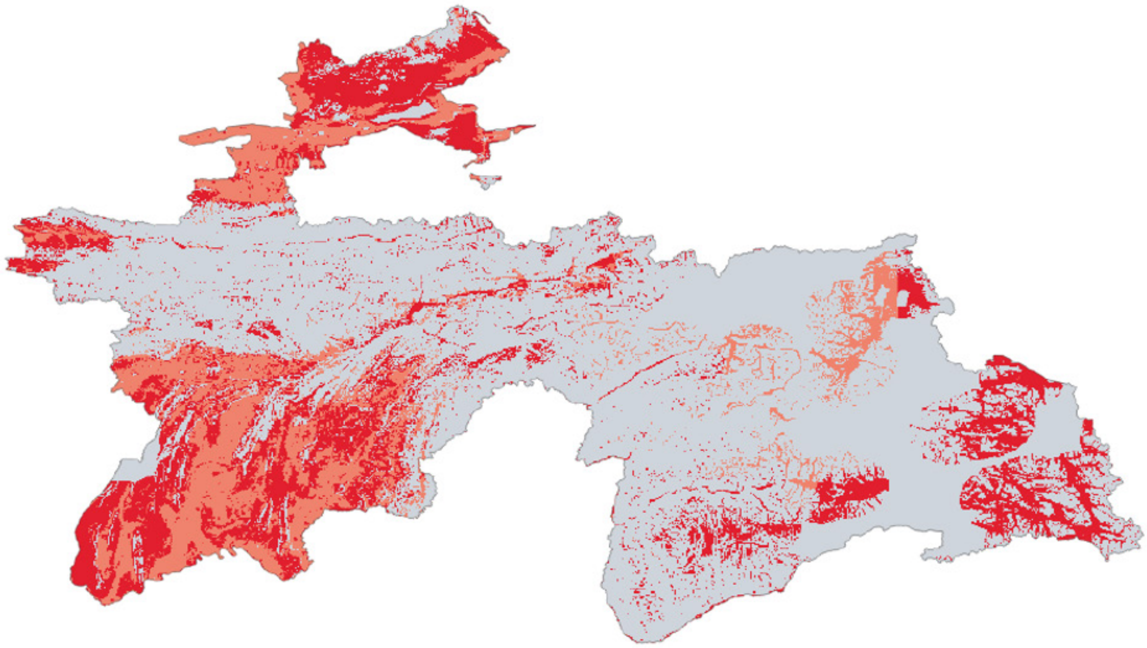
Tajikistan also has **solar and wind energy potential**.

In accordance with the General Plan for Electricity Sector Development, the most promising areas in terms of wind energy potential are the Pamir Mountains north of Lake Sarez, the Turkestan Range, located in the headwaters of the Zerafshan River, and the Vakhsh Range on the border with Afghanistan. Among these territories, only the Turkestan Range in the upper reaches of the Zerafshan River with an average wind speed of up to 9 m/s can provide a certain wind power to the energy system, since the rest of the possible territories are located far from the electricity grid.

Solar energy potential in the country has not been studied in the same detail as the hydropower potential. According to the World Bank 's ESMAP project (2021), average theoretical solar PV potential in Tajikistan is about 4.3 kWh/m^2. Presumed country area proportion to be covered by PV plants producing the equivalent of yearly electricity consumption is 0.074% (see Figure 10); LCOE solar PV generation could be $0.1/kWh.

FIGURE10

Model of the Tajikistan's territory with solar PV practical potential zonation



Red color stands for a territory convenient for locating utility-scale PV plants without any land-use constraints (possibly under land use regulations due to nature and cropland protection); pink stands for a territory convenient for locating utility-scale PV plants with some land-use constraints, gray is an area inconvenient for utility-scale PV plants due to identifiable physical obstacles.

Source: *ESMAP (2021)*

Thus, hydropower potential is of maximum importance for low-carbon hydrogen production in the country, with solar and wind potential will supplement it if its knowledge increases.

2.7.1.2 Natural gas and biomethane

According to BP (2021), there are no confirmed significant natural gas reserves in Tajikistan in 2021.

Bioenergy potential in the country is determined by the amount of available agriculture and animal husbandry waste. Given the large role of this sector for the country's economy, this potential will certainly be significant, but its estimates have not yet been published. Small biogas plants located close to consumers could not only process waste and reduce agricultural greenhouse gas (methane) emissions, but also provide rural residents with energy (which can also be stored in the form of biogas between seasons).

Thus, there are no available natural gas and biomethane resources suitable for hydrogen production in Tajikistan.

2.7.1.3 Carbon dioxide capture and long-term storage (CCUS)

For low-carbon hydrogen production from natural gas, it is important to provide carbon dioxide capture and long-term storage (CCUS) that is produced during the steam methane reforming process. There are no reliable public estimates of the CCUS potential in Tajikistan yet. But the relevance of this sector development is low in the context of lack of natural gas.

2.7.2 Resource potential for low-carbon hydrogen production

This section analyzes the key assumptions that shape the potential for low-carbon hydrogen production by various technologies analyzed, among others, in UNECE (2021 b).

2.7.2.1 Assumptions and estimates adopted for the analysis

Based on the analysis, Tajikistan faces a serious challenge associated with seasonal electricity shortage accompanied by increasing infrastructure wear-out and increase in electricity consumption. At the same time, the country will have resources for low carbon hydrogen production by water electrolysis using renewable electricity (from hydropower and solar power plants). It will be possible to start realizing this potential in full after solving the problems of energy shortage and infrastructure wear-out, but already now it is possible to check the case of hydrogen production using electricity from hydropower plants during summer months (through a corresponding reduction in no-operation discharges).

If these problems are solved by 2030-2040, then the resource potential of hydrogen production by 2040 will reach significant values. It is defined by:

- technical and economic potential for hydropower, solar and other renewables;
- share of renewable electricity that would be appropriate to use for hydrogen production instead of being used directly in the country's power sector or exported to neighboring countries.

With the current level of uncertainty, it is not possible to calculate these parameters, but it is possible to assess the resource potential by taking them at the minimum and maximum levels. In this study, two scenarios are adopted:

1) Minimum Scenario

- 10% of unmet electricity demand due to no-operation water discharges, which stands for 10% of 5 TWh per annum, is used for low-carbon hydrogen production;
- increase in solar electricity generation is unknown (as potential is underexplored) and is taken equal to zero.

2) Maximum Scenario

- 30% of the increase in hydropower and solar power electricity generation;
- increase from hydropower electricity generation is determined from the minimum scenario according to the 2030 Development Strategy of Tajikistan.

In both scenarios, it is assumed that hydrogen production by water electrolysis will require 55 kWh/kg H_2 of electricity.

2.7.2.2 Resource potential

The results of the potential assessment are summarized in Table 8.

TABLE 8

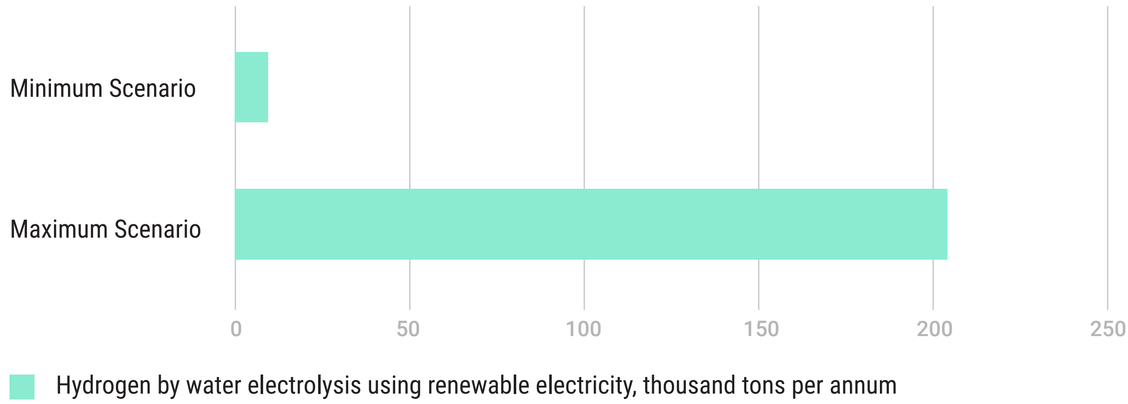
Resource potential of hydrogen production in Moldova by 2040

	MINIMUM SCENARIO	MAXIMUM SCENARIO
Renewable electricity for hydrogen, GWh per year	500	11200
Hydrogen by water electrolysis using renewable electricity, thousand tons per annum	9	204
Hydrogen total, thousand tons per annum	**9**	**204**

The evaluation results are shown in Figure 11.

FIGURE 11

Resource potential of hydrogen production in Moldova by 2040, thousand tons per year



Thus, under the accepted assumptions, the resource potential of low-carbon hydrogen production in Tajikistan varies over a wide range, and the main influencing parameter is the rate of renewable energy (hydro and solar) development in the country.

2.7.2.3 Cost analysis

The cost of hydrogen produced by electrolysis using renewable electricity will depend on the renewable electricity's present cost in new large projects being developed in Tajikistan. According to IEA estimates, at the electricity price of $0.1 per kWh[21], the number of electrolyzers capacity utilization hours of 1500-2000 hours per year, electrolyzers CAPEX of $450 per kW, and discount rate of 8%, the hydrogen present value will be about $6-8 per kg.

If electricity price reduces (for example, due to cheaper technologies or if there is an excess of electricity generated during the seasons of no-operation discharges at hydropower plants), the cost of hydrogen can be significantly reduced. The current electricity tariffs for industrial consumers in Tajikistan are about $0.05/kWh[22] - at this price, the cost of hydrogen will be about $3.5-5 per kg.

2.7.2.4 Logistical opportunities and barriers for export-oriented hydrogen projects

Tajikistan has no access to the open sea. With a combination of land and sea transport, the distance from Dushanbe to the port of Rotterdam (Netherlands) will be 7.4 thousand km, to the port of Kobe (Japan) - 11.4 thousand km (through India). The distance from European ports exceeds the ones for export-oriented hydrogen projects in the MENA region (such as the NEOM Green Hydrogen project in Saudi Arabia with a capacity of 4 GW - 6.5 thousand km to Rotterdam). The distance from the ports of Japan and Korea is comparable to that of export-oriented projects in Australia (9,000 km). But the land part of the route, which is thousands of kilometers long, calls into question the competitiveness of similar projects in Tajikistan.

The nearest capital of the EU member state is located at a distance of 5.1 thousand km from Dushanbe by land transport (Sofia) with transit through Uzbekistan, Turkmenistan, Iran and Turkey - this is almost 2 times more than the same indicator of Azerbaijan, which also has existing TAP and TANAP gas pipelines to the EU countries. Thus, the position of Tajikistan in relation to the future European hydrogen market (imports up to 10 million tons of hydrogen per year by 2030) can hardly be considered competitive. During the development of an export strategy,

21 Corresponds to the LCOE estimate from solar power plants in Tajikistan according to ESMAP (2021)
22 https://avesta.tj/2022/09/13/v-tadzhikistane-s-1-oktyabrya-povysyatsya-tarify-na-elektroenergiyu/

these routes may need to be worked out in more detail, taking into account the competitiveness in terms of cost, carbon footprint of hydrogen and its origin (for the European market, green or renewable hydrogen has priority).

Tajikistan has a common border with China, the distance from Dushanbe to Urumqi (the largest industrial center of the Xinjiang Uygur Autonomous Region of China) by land transport is about 1.7 thousand km. This creates opportunities for considering the export of hydrogen to China by pipeline, road, and rail transport.

2.7.3 Existing and prospective pilot projects in the field of hydrogen

2.7.3.1 Existing pilot projects

There are no implemented pilot projects in the field of low-carbon hydrogen In Tajikistan yet. In the public domain, there is no information yet about the study of opportunities in the field of hydrogen economy by the corporate sector.

2.7.3.2 Possible promising projects

Tajikistan has not yet set carbon neutrality goals, so local low-carbon hydrogen consumption is not a priority for the country. National greenhouse gas emissions reduction goals can be achieved without fundamental changes in the energy mix.

The energy sector of Tajikistan depends on fossil energy resources import, primarily oil products. Thus, the production of low-carbon hydrogen without greenhouse gas emissions increase in other sectors in the country will be possible only if the renewable energy sector develops - in particular, hydropower and solar energy - and after solving the pressing energy sector problems (energy shortage and wear-out of infrastructure).

Domestic hydrogen consumption, based on the structure of energy consumption in Tajikistan, would be fastest to start in the transport sector, which accounts for 35% of total final energy consumption in the country. The launch of pilot hydrogen fuel cell electric buses, the phased development of a hydrogen refueling infrastructure around hydrogen-producing enterprises are the first steps that begin the development of a country's hydrogen economy around the world. Setting targets for achieving carbon neutrality and other energy policy measures related to the transport sector (ICE ban, environmental restrictions on emissions, preferential parking, priority travel, subsidies, tax incentives) can create a regulatory environment for such projects.

For Tajikistan, in the long term, it may be promising to create seasonal low-carbon energy storage systems based on hydrogen, which would help dampen the intermittent hydropower and other renewable electricity generation. The new Line D transit gas pipeline to China can be considered as a potential opportunity for hydrogen exports - subject to cooperation with China and other interested parties.

To get a clearer picture of the prospects for a hydrogen economy in Tajikistan, the country may need a national hydrogen strategy. International organizations can provide methodological assistance in this.

2.7.4 Conclusions

1. Tajikistan is an energy-deficient country that does not have significant fossil energy resources reserves but provides itself with 90% of domestic hydropower renewable electricity. Energy security, energy system modernization and seasonal energy shortages are important priority energy policy issues to be solved jointly with neighboring countries - they are common by issues of water and energy supply.

2. There is greenhouse gas emissions increase in Tajikistan, including due to coal and oil products share increase in the energy mix. However, national greenhouse gas emissions goals can be achieved without major changes in the energy mix. The country has not yet set carbon neutrality goals, so local low-carbon hydrogen consumption is not a priority for energy policy.

3. The country has a huge hydropower potential and the yet unexplored potential of solar energy (presumed country area proportion to be covered by PV plants producing the equivalent of yearly electricity consumption is 0.074%).

4. With a significant development of this potential, in 2040 Tajikistan will have a resource potential for low-carbon hydrogen production of up to about 200 thousand tons of hydrogen per annum.

5. Already in 2022, there is a resource potential associated with a no-operation water discharges reduction at hydropower plants. With the development of 10% of this potential, it is possible to produce about 9 thousand tons of low-carbon hydrogen per annum.

6. The existing gas transportation infrastructure was built to import gas from Uzbekistan with its delivery to industrial consumers in Tajikistan. There is a promising Line D transit gas pipeline project, which also passes through the territory of Tajikistan and is designed to supply gas from Turkmenistan to China. There are no published plans to use the infrastructure for transporting hydrogen, but such use of Line D could be considered if China is interested.

7. There are no implemented pilot projects in the field of low-carbon hydrogen in Tajikistan yet. In the public domain, there is no information yet about the study of opportunities in the field of hydrogen economy by the corporate sector.

8. As the pressing problems of energy shortages and aging electricity and gas infrastructure are resolved, Tajikistan can produce low-carbon hydrogen and start using it in the transport sector (instead of oil products), as well as for low-carbon energy storage systems based on hydrogen, which would help dampen the intermittent hydropower and other renewable electricity generation.

9. Hydrogen produced by electrolysis using renewable electricity during hydropower plants no-operation discharges seasons can be much cheaper.

2.8 Turkmenistan

An analysis of the current status of the energy sector, key documents and regulatory bodies, the balance of energy production and demand, gas transportation infrastructure, greenhouse gas emissions, as well as existing forecasts and long-term goals of the country's energy and climate policy is provided in the Annex.

2.8.1 Potential for renewable energy, natural gas and CCUS

Low-carbon hydrogen production requires raw materials and energy sources (electricity from renewable energy sources, hydropower, nuclear power plants, natural gas or biomethane, coal with gasification, water, etc.), as well as (for the case of fossil fuels-based hydrogen production) the establishment of CCUS industry.

This section provides information about the relevant resource and energy potential of Tajikistan, available from open sources.

2.8.1.1 Renewable energy sources

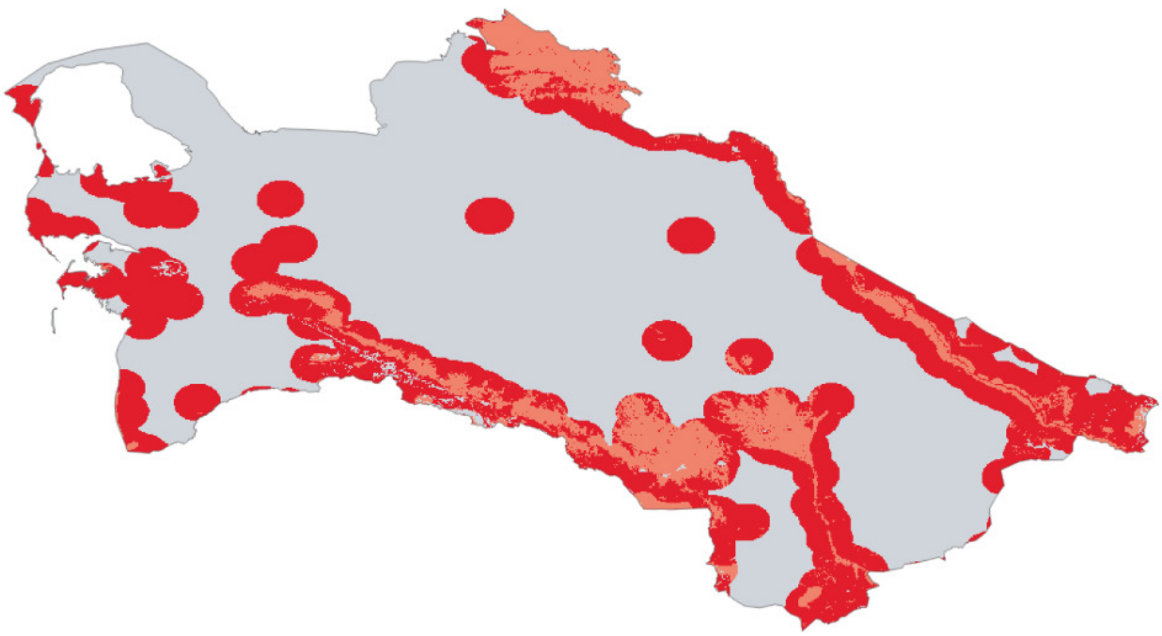
According to the IEA and IRENA, renewable energy sources do not yet play a significant role in the country's energy supply - renewable energy share is less than 0.5% limited by biofuels use in households.

At the same time, Turkmenistan has significant untapped renewable energy potential, primarily in solar and wind energy.

According to the World Bank 's ESMAP project (2021), average theoretical solar PV potential in Turkmenistan is about 4.4 kWh/m^2. Presumed country area proportion to be covered by PV plants producing the equivalent of yearly electricity consumption is 0.025% (see Figure 12); LCOE solar PV generation could be $0.1/kWh.

FIGURE 12

Model of the Turkmenistan's territory with solar PV practical potential zonation



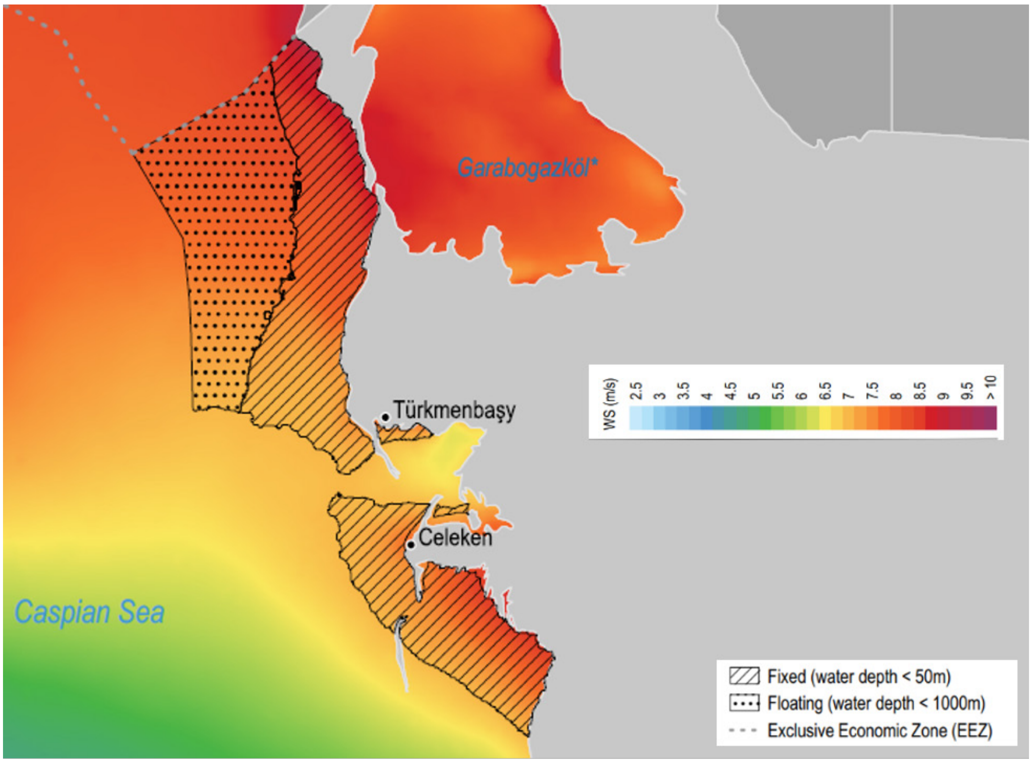
Red color stands for a territory convenient for locating utility-scale PV plants without any land-use constraints (possibly under land use regulations due to nature and cropland protection); pink stands for a territory convenient for locating utility-scale PV plants with some land-use constraints, gray is an area inconvenient for utility-scale PV plants due to identifiable physical obstacles.

Source: *ESMAP (2021)*

According to the World Bank, the technical wind offshore power potential in Turkmenistan exceeds 70 GW, which is 10 times the capacity of all power plants in the country in 2020 (Figure 13).

FIGURE 13

Technical potential for fixed and floating offshore wind in Turkmenistan within 200 kilometers of the shoreline depending on average wind speed



Source: *World Bank, IFC (2022)*

As of June 2022, the existing technical potential is being explored, including through international projects. In October 2021, Masdar (UAE) signed a strategic cooperation agreement on exploring the renewable energy potential in Turkmenistan with the Ministry of Energy. In January 2022, the Turkish company Calik Enerji Sanayi ve Ticaret AS won a tender for the construction of the first renewable power plant in Turkmenistan – it's 10 MW wind and solar plant in the Turkmen Lake area. It is expected that the power plant commissioning will take place before 2025.

2.8.1.2 Natural gas

According to BP (2021), the proven natural gas reserves in Turkmenistan amounted to 13,600 bcm in 2021 - according to this indicator, the country is in first place among covered by this study. For comparison, the total US reserves are 12,600 bcm. For the period 2009-2019, reserves grew by 5.6% annually. Gas production increased by 32% between 2011 and 2020.

According to Nexant World Gas Model, during 2020-2040 gas production capacity in Turkmenistan will grow to 200 bcm per annum with a slight increase in domestic demand (from 32 to 53 bcm per annum over the same period). The gas production cost, according to Nexant World Gas Model, ranges from \$20 to \$99 per 1,000 m^3.

For hydrogen production by steam methane reforming, the natural gas carbon footprint is important, which is determined primarily by methane leaks during production and transportation. Managing the carbon footprint of gas and hydrogen produced this gas, international certification of hydrogen based on the principles of open access to data is an important condition for the competitiveness of potential hydrogen exporters. In this sense, it will be important for Turkmenistan to work to reduce methane leaks like those that occurred in February 2021, when a 10

t/h methane leak from eight gas pipelines during a few hours was detected, according to the Canadian company GHGSat Inc., which operates satellites[23].

In June 2019, the first gas-to-liquid (GTL) plant based on Haldor Topsoe TIGAS™ (improved gasoline synthesis) technology, began operation in the country. The plant processes 1.785 bcm of gas and produces 600,000 tons of ECO-93 synthetic gasoline, 12,000 tons of diesel fuel and 115,000 tons of liquefied gas per annum[24].

Experience in gas and oil processing is essential for the successful implementation of projects in the field of steam methane reforming. In addition, gas and oil refineries can become centers for hydrogen economy development due to production of "grey" hydrogen already in place and demand for hydrogen for hydrocarbons processing.

2.8.1.3 Carbon dioxide capture and long-term storage (CCUS)

For low-carbon hydrogen production from natural gas, it is important to provide carbon dioxide capture and long-term storage (CCUS) that is produced during the steam methane reforming process.

Turkmenistan is part of an extensive oil and gas system in the province of the South Caspian Basin, along with Iran and Azerbaijan, which suggests CO_2 storage potential in both aquifers and oil fields (UNECE, 2021a).

There are no reliable public estimates of the CCUS potential in the country yet. By analogy with Azerbaijan, international oil and gas companies, including oilfield services companies, can help explore this potential. One of the possible options is the use of depleted deposits.

2.8.2 Resource potential for low-carbon hydrogen production

This section analyzes the key assumptions that shape the potential for low-carbon hydrogen production by various technologies analyzed, among others, in UNECE (2021 b).

2.8.2.1 Assumptions and estimates adopted for the analysis

Based on the analysis, by 2040 Turkmenistan will have resources for hydrogen production by water electrolysis using electricity from renewables (if renewable energy develops in the country), as well as for hydrogen production by steam methane reforming with CCUS (if the CCUS industry develops). As of 2022, both renewables and CCS development are at a very early stage in the country.

The resource potential of hydrogen production in 2040 is determined by:

- technical and economic potential for wind, solar and another renewables development;
- the share of renewable electricity that would be appropriate to use for hydrogen production instead of being used directly in Turkmenistan power sector or exported to neighboring countries;
- natural gas production potential;
- the share of natural gas that would be economically feasible to use for hydrogen production instead of direct use of gas in Turkmenistan economy or its export;
- the CCUS potential for long-term storage of carbon dioxide produced during hydrogen production from natural gas.

With the current level of uncertainty, it is not possible to calculate these parameters, but it is possible to assess the resource potential by taking them at the minimum and maximum levels. In this study, two scenarios are adopted:

23 https://www.bloomberg.com/news/articles/2021-02-12/new-climate-satellite-spotted-giant-methane-leak-as-it-happened
24 https://www.trade.gov/country-commercial-guides/turkmenistan-oil-and-natural-gas-refining

1) Minimum Scenario

- 10% of the increase in solar and wind electricity generation during 2020-2040 is used for hydrogen production;
- renewables installed capacity addition by 2040 is 1 GW;
- 10% of the increase in natural gas production by 2040 is used for hydrogen production.

2) Maximum Scenario

- 50% of the increase in solar and wind electricity generation during 2020-2040 is used for hydrogen production;
- 25% of the technical potential for offshore wind on a fixed foundation is realized (17.5 GW);
- renewables capacity factor is – 35%;
- 30% of the increase in natural gas production by 2040 is used for hydrogen production.

In both scenarios, it is assumed that hydrogen production by electrolysis of water will require 55 kWh/kg H_2 of electricity, and hydrogen production by steam methane reforming will require 5.3 m^3/kg H_2 of electricity. The amount of CO_2 released during the reforming process, which must be stored, is estimated as 10 kg CO_2 / 1 kg H_2.

2.8.2.2 Resource potential

The results of the potential assessment are summarized in Table 9.

TABLE 9

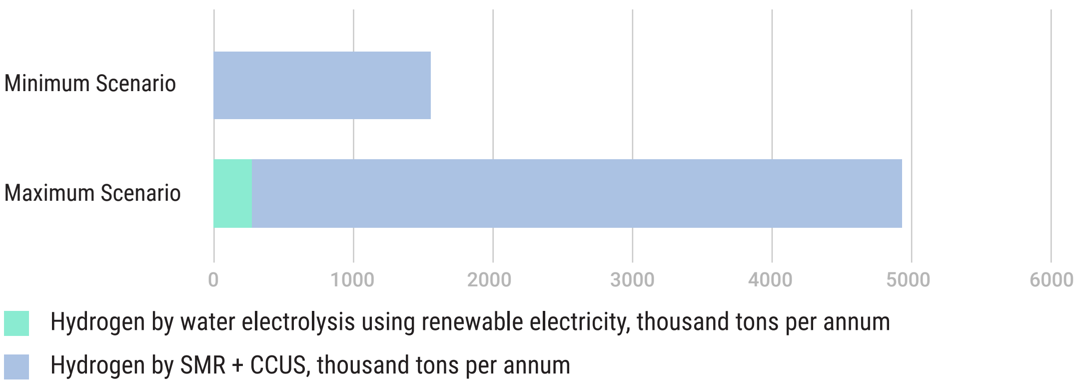
Resource potential of hydrogen production in Turkmenistan by 2040

	MINIMUM SCENARIO	MAXIMUM SCENARIO
Renewable electricity for hydrogen, GWh per year	306.6	17630
Natural gas for hydrogen, bcm per annum	9.609	28.827
Hydrogen by water electrolysis using solar and wind electricity, thousand tons per annum	6	321
Hydrogen from methane by SMR + CCUS, thousand tons per annum	1813	5439
Hydrogen total, thousand tons per annum	**1819**	**5760**
Required capacity of CCUS systems, $MtCO_2$ per annum	18	54

The evaluation results are shown in Figure 14. Thus, under the accepted assumptions, the main long-term opportunity for hydrogen production in Turkmenistan is steam methane reforming in combination with CCUS.

FIGURE 14

Resource potential of hydrogen production in Turkmenistan by 2040, thousand tons per year



This is determined by the significant proven natural gas reserves in place and the growth rate of its production. The key constraint and condition in this case is the outstripping development of CCUS industry – even in the minimum scenario, it is necessary to create CCUS facilities with a total capacity of 18 $MtCO_2$ per annum.

2.8.2.3 Cost analysis

The cost of hydrogen from natural gas consists of the cost of raw materials (for Turkmenistan, as a gas producing country, this is the cost of natural gas production), as well as the cost of CCUS. According to the IEA (2019), for gas producing countries, the natural gas cost was approximately 30% of the blue hydrogen cost. With the gas production cost at the level of $20-99 per thousand m^3, the blue hydrogen production cost can be estimated at $1.6-2.0 per kg of hydrogen.

The cost of hydrogen produced by electrolysis using renewable electricity will depend on the present value of renewable electricity in new large projects developed in Turkmenistan. As of June 2022, no major renewable energy projects have yet been planned or announced; it will be possible to estimate the cost of hydrogen after the implementation of the first of them. According to IEA calculations, with an electricity price of about $0.1/kWh[25], the number of electrolyzers capacity utilization hours of about 1500-2000 hours per year, CAPEX of electrolyzers of $450 USD / kW at a discount rate of 8%, the hydrogen present value will be about $6-8/kg.

2.8.2.4 Logistical opportunities and barriers for export-oriented hydrogen projects

Turkmenistan has no access to the open sea. With a combination of land and sea transport, the distance from Ashgabat to the port of Rotterdam (Netherlands) will be 13.5 thousand km, to the port of Kobe (Japan) - 13.6 thousand km. The distance from European ports is more than double that for export-oriented hydrogen projects in the MENA region (such as the NEOM Green Hydrogen project in Saudi Arabia with a capacity of 4 GW - 6.5 thousand km to Rotterdam). The distance from the ports of Japan and Korea is 1.5 times higher than that of export-oriented projects in Australia (9 thousand km). The remoteness from future key markets and the overland part of the routes with a length of thousands of kilometers questions the competitiveness of similar projects in Turkmenistan.

The nearest capital of an EU member state is located at 4.3 thousand km from Ashgabat by land transport (Sofia) with transit through Iran and Turkey - this is 1.5 times more than the same indicator of Azerbaijan, which also has existing TAP and TANAP pipelines transporting gas to the EU. Thus, Turkmenistan location relative to the future European hydrogen market (imports up to 10 Mt of hydrogen per year by 2030) can hardly be called competitive. During drafting an export strategy, these routes may need to be studied in more detail, considering Turkmen suppliers competitiveness in terms of cost, carbon footprint of hydrogen and its origin (green or renewable hydrogen has priority for the European market).

Turkmenistan does not have a common border with China, and the distance from Ashgabat to Urumqi (the largest industrial center of the Xinjiang Uygur Autonomous Region of China) by land transport is about 2.5 thousand km - the route runs through Uzbekistan and Kazakhstan. The Central Asia-China gas pipeline runs along the same route, which connects with the Chinese West-East gas pipeline in Khorgos on the border of Kazakhstan and the Xinjiang Uygur Autonomous Region of China. This creates opportunities for investigation of hydrogen export opportunities to China by pipeline, road, and rail transport.

2.8.3 Existing and prospective pilot projects in the field of hydrogen

2.8.3.1 Existing pilot projects

There are no implemented pilot projects in the field of low-carbon hydrogen in Turkmenistan yet. In the public domain, there is no information yet about the study of opportunities in the field of hydrogen economy by the corporate sector. At the state level, attention is paid to hydrogen in the context of international relations: there is a hydrogen energy international cooperation development roadmap for 2022-2023 (not published), webinars are

25 Corresponds to the LCOE estimate from solar power plants in Turkmenistan according to ESMAP (2021)

held with participation of international organizations. The Hydrogen Energy Center was created in the International University of Oil and Gas named after Kakaev in 2022.

2.8.3.2 Possible promising projects

Turkmenistan has not yet set carbon neutrality goals, so local low-carbon hydrogen consumption is not a priority for the country.

Natural gas industry is the basis of the country's energy sector. Renewable energy sources have not yet been deployed, but Turkmenistan has potential in this area. Thus, low-carbon production without increasing greenhouse gas emissions in other sectors will be possible using natural gas resources (subject to combination with CCUS and combating methane leaks) and if the renewable energy sector develops.

Domestic hydrogen consumption, based on Turkmenistan's energy mix, would be fastest to start in the transport sector, which accounts for 25% of the country's energy consumption. The launch of pilot hydrogen fuel cell electric buses, the phased development of a hydrogen refueling infrastructure around hydrogen-producing enterprises are the first steps that begin the development of a country's hydrogen economy around the world. Setting targets for achieving carbon neutrality and other energy policy measures related to the transport sector (ICE ban, environmental restrictions on emissions, preferential parking, priority travel, subsidies, tax incentives) can create a regulatory environment for such projects.

For Turkmenistan, in the long term, it may be promising to consider transporting hydrogen using the existing gas transport infrastructure, especially in the direction of China. This can be done in cooperation with China and other stakeholders. The advantage is the relatively low wear of the system (compared to neighboring countries) and the Chinese partner in place - China National Petroleum Corporation (CNPC), which already manages part of the gas transmission system. The challenge is that China's national hydrogen strategy does not focus on hydrogen imports, but rather focuses on domestic production. One example is the Sinopec Xinjiang Kuqa Green Hydrogen Pilot Project (20 thousand tons per year) in the Xinjiang Uygur Autonomous Region which started construction in November 2021[26]. It is through this region that China imports Turkmen gas.

To get a clearer picture of the prospects for a hydrogen economy in Turkmenistan, the country may need a national hydrogen strategy. International organizations can provide methodological assistance in this.

2.8.4 Conclusions

1. Turkmenistan is an energy-abundant country, a major gas exporter with steadily growing proven natural gas reserves and production. One of the key export markets is China.
2. Natural gas dominates the power sector, providing nearly 100% of electricity generation. Renewables share in the energy sector is insignificant.
3. Turkmenistan does not have an approved long-term energy strategy containing long-term quantitative targets for all energy sectors (electricity, oil, gas), as well as a hydrogen strategy. Turkmenistan's climate goals are to reduce greenhouse gas emissions by 2030 (from 2000 levels) - so far without specifying a quantitative goal.
4. Top-level strategic documents (social and economic development strategy, national climate change strategy, etc.) have not been published and are not available for analysis by the expert community and investors. Statistical data related to the energy sector are not published, IEA data on Turkmenistan energy sector is contradictory.
5. The renewable energy potential in Turkmenistan is understudied, but significant: presumed country area proportion to be covered by PV plants producing the equivalent of yearly electricity consumption is 0.025%, and the technical potential for wind offshore on Caspian Sea shelf is estimated at 75 GW.

26 https://hydrogen-central.com/sinopec-worlds-largest-photovoltaic-green-hydrogen-production-project-kuqa-xinjiang/

6. Based on the resources and energy sources that are expected to be available for hydrogen production by 2040, it is possible to estimate the resource potential for low-carbon hydrogen production in Turkmenistan at 1.82-5.76 Mt per annum. The main long-term opportunity is steam methane reforming in combination with CCUS. Focus on managing of the natural gas carbon footprint will be important (due to methane leaks issue).

7. Turkmenistan has a developed gas transportation infrastructure for export to China, Iran and distribution of gas in the domestic market. The wear of the system is relatively small. There are no published plans to use infrastructure to transport hydrogen, but such use of some export gas pipelines can be considered, subject to the interest of China.

8. There are no implemented pilot projects in the field of low-carbon hydrogen yet in Turkmenistan. In the public domain, there is no information yet about the study of opportunities in the field of hydrogen economy by the corporate sector. At the state level, there are activities in the field of hydrogen as a topic of international relations.

9. Turkmenistan can produce low-carbon hydrogen and start using it in the transport sector (instead of oil products), as well as enter export projects in the future. A prerequisite for competitiveness is the readiness for international certification of hydrogen, which will require increased openness to the international community and management of the natural gas carbon footprint.

2.9 Uzbekistan

An analysis of the current status of the energy sector, key documents and regulatory bodies, the balance of energy production and demand, gas transportation infrastructure, greenhouse gas emissions, as well as existing forecasts and long-term goals of the country's energy and climate policy is provided in the Annex.

2.9.1 Potential in renewables, nuclear energy, natural gas and CCUS

Low-carbon hydrogen production requires raw materials and energy sources (electricity from renewable energy sources, hydropower, nuclear power plants, natural gas or biomethane, coal with gasification, water, etc.), as well as (for the case of fossil fuels-based hydrogen production) the establishment of CCUS industry.

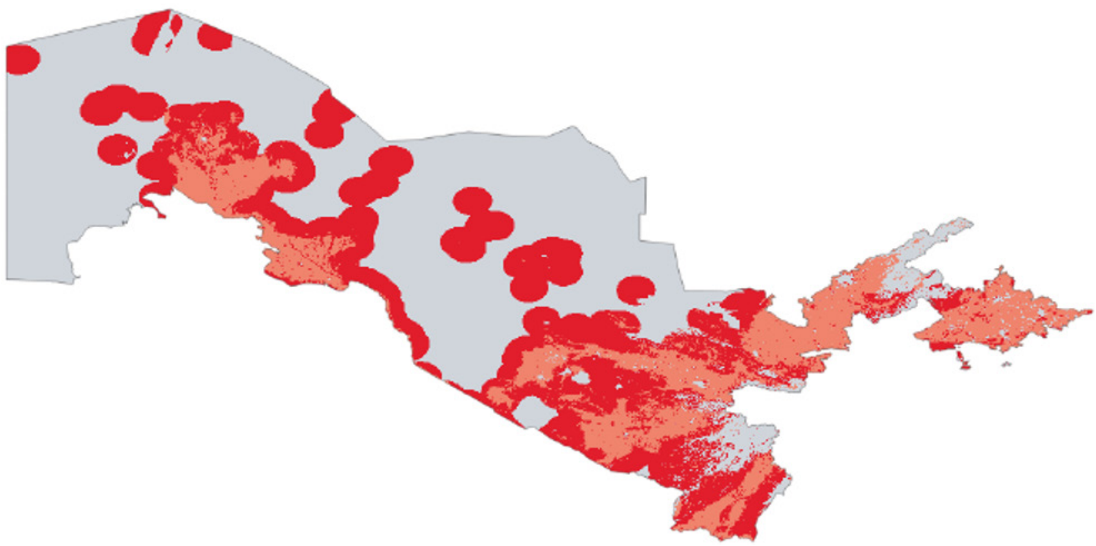
This section provides information about the relevant resource and energy potential of Uzbekistan, available from open sources.

2.9.1.1 RES

Uzbekistan has significant untapped renewable energy potential, especially in wind and solar energy. This potential has already begun to be realized - several utility-scale solar and wind projects are in various stages of development, the target level is introducing 3 GW of wind, 5 GW of solar and 1.9 GW of hydroelectric power plants by 2030.

FIGURE 15

Model of the Uzbekistan's territory with solar PV practical potential zonation



Red color stands for a territory convenient for locating utility-scale PV plants without any land-use constraints (possibly under land use regulations due to nature and cropland protection); pink stands for a territory convenient for locating utility-scale PV plants with some land-use constraints, gray is an area inconvenient for utility-scale PV plants due to identifiable physical obstacles.

Source: *ESMAP (2021)*

According to the World Bank 's ESMAP project (2021), average theoretical solar PV potential in Uzbekistan is about 4.3 kWh/m^2. Presumed country area proportion to be covered by PV plants producing the equivalent of yearly electricity consumption is 0.11% (see Figure 15); LCOE solar PV generation could be $0.1/kWh.

According to the IEA (2022), the technical solar energy potential in Uzbekistan is estimated between 177 and 265 Mtoe, which is a multiple of the current total energy consumption of the country. The technical wind energy potential stands for 360 Mtoe. Power sector carbon neutrality transition roadmap by 2050 estimates the wind power technical potential of about 520-1000 GW and solar potential of about 3000 GW. The paper outlines a scenario for increasing intermittent renewables installed capacity to 47 GW by 2040 and to 97 GW by 2050. Surplus

electricity that will exceed the energy system demand can be converted into "renewable" hydrogen, as highlighted in this roadmap.

The first solar PV plant in Uzbekistan, with a capacity of 100 MW was commissioned in 2021 by Masdar (United Arab Emirates) in the Karmaninsky district of the Navoi region. The generated electricity is to be sold to JSC National Electric Networks of Uzbekistan for a period of 25 years (until 2046) at a fixed price of 2.7 US cents per kWh, according to REN21 (2022).

2.9.1.2 Nuclear power

Introducing a new 2.4 GW nuclear power plant is indicated in the conceptual strategic documents as a target. In October 2018, the starting engineering surveys ceremony was held, which was attended by the presidents of Uzbekistan and Russia, as of June 2022, a dialogue is underway to reduce estimated power plant construction cost so that the electricity cost is more attractive. The new plant could be important to replace gas-fired power generation and ensure baseload carbon-free electricity generating capacity.

It is important to note that Uzbekistan is a major producer of uranium (fifth largest in the world, according to the IAEA), that could create long-term opportunity for decarbonization if nuclear energy will develop beyond the Balkhash power plant project.

By default, it can be assumed that all available electricity from the new nuclear power plant will be used in the power sector. But if nuclear power generation targets do not be achieved – for example, due to grid constraints, more thermal power plants will remain in operation than planned – then hydrogen production near the site of the new nuclear power plant may be a solution. This issue requires further study.

A similar project is going to be implemented in Russia – Rosatom plans to supply electricity for pilot hydrogen production project from underloaded Kola nuclear power plant starting from 2023-2024.

2.9.1.3 Natural gas

According to BP (2021), proven natural gas reserves in Uzbekistan amounted to 800 bcm in 2021 - according to this indicator, the country is in fourth place among covered by this study.

According to Nexant World Gas Model, in 2020-2040 gas production capacity in Uzbekistan will not change significantly, remaining at the level of 60 bcm per annum with almost constant demand during this period. According to the IEA, by 2025 Uzbekistan plans to abandon gas exports, focusing on domestic gas consumption (similar point was given[27] in June 2022 by Uztransgaz's Chairman of the Board Mr. B. Narmatov). There is uncertainty on the side of long-term gas demand: for example, if part of gas-fired power generation is replaced by a new nuclear power plant, energy efficiency programs are implemented in households, in the power and industry sector, then demand for gas will decrease. Part of this potential can be used for hydrogen production – in case of outstripping development of the CCUS industry.

Gas processing is developed in Uzbekistan - the total gas processing capacity, according to the IEA, is 56.6 bcm per annum. In December 2021, the first gas-to-liquid (GTL) plant was launched in the country – Uzbekistan GTL, which produces liquid motor fuels from natural gas. The plant was built in collaboration with world leaders Sasol and Chevron. Uzbekistan GTL will be able to produce 307 thousand tons of jet fuel, 724 thousand tons of diesel fuel, 437 thousand tons of naphtha, 53 thousand tons of liquefied gas[28].

Oil refining facilities produce about 3.2 Mt of oil products per year, there are plans to modernize them.

Experience in gas and oil processing is essential for the successful implementation of projects in the field of steam methane reforming. In addition, gas and oil refineries can become centers for hydrogen economy development due to production of "grey" hydrogen already in place and demand for hydrogen for hydrocarbons processing. Thus,

27 https://www.uzdaily.uz/ru/post/69945

28 https://invest.gov.uz/ru/mediacenter/news/uzbekistan-gtl-set-up-its-own-hydrogen-production/

Uzbekistan GTL can produce up to 27 thousand tons of hydrogen per year - it is not low-carbon, but it can help in expanding the market.

2.9.1.4 Carbon dioxide capture and long-term storage (CCUS)

For low-carbon hydrogen production from natural gas, it is important to provide carbon dioxide capture and long-term storage (CCUS) that is produced during the steam methane reforming process.

There are no public assessments of CCUS potential in Uzbekistan yet. International oil and gas companies, including oilfield services companies, can help explore this potential. One of the possible options is the use of depleted deposits.

2.9.2 Resource potential for low-carbon hydrogen production

This section analyzes the main assumptions that shape the potential for low-carbon hydrogen production by various technologies analyzed, including in UNECE (2021 b).

2.9.2.1 Assumptions and estimates adopted for the analysis

Based on the analysis, Uzbekistan will have resources for hydrogen production by water electrolysis using renewable electricity (if renewable energy develops in the country), electricity from a nuclear power plant (after its commissioning until 2040), as well as for hydrogen production by steam methane reforming with CCUS (if the CCUS industry develops).

The resource potential of hydrogen production in 2040 is determined by:

- technical and economic potential for wind, solar and another renewables development;
- the share of renewable electricity that would be appropriate to use for hydrogen production instead of being used directly in the power sector of Uzbekistan or exported to neighboring countries;
- natural gas production potential;
- the share of natural gas that would be economically feasible to use for hydrogen production instead of direct use of gas in the national economy or its export;
- the CCUS potential for long-term storage of carbon dioxide produced during hydrogen production from natural gas.

With the current level of uncertainty, it is not possible to calculate these parameters, but it is possible to assess the resource potential by taking them at the minimum and maximum levels. In this study, two scenarios are adopted:

1) Minimum Scenario

- 30% of the increase in solar and wind electricity generation during 2020-2040 is used for hydrogen production,
- increase in renewable electricity generation until 2040 is determined based on linear extrapolation of trends set by the Electricity supply concept for 2020-2030;
- 5% of natural gas production in 2021 is used for hydrogen production;
- 5% of the annual output of the new nuclear power plant is used for hydrogen production (the rest electricity output will be used in the energy system by another consumers).

2) Maximum Scenario

- 50% of the increase in solar and wind electricity generation during 2020-2040 is used for hydrogen production,
- solar and wind electricity generation growth is determined by the installed generation capacity goal set by the Power sector carbon neutrality transition roadmap by 2050 (47 GW by 2040);
- 8.3% of natural gas production in 2021 is used for hydrogen production;

- 8.3% of the annual output of the new nuclear power plant is used for hydrogen production (the rest electricity output will be used in the energy system by another consumers).

In both scenarios, it is assumed that hydrogen production by electrolysis of water will require 55 kWh/kg H_2 of electricity, and hydrogen production by steam methane reforming will require 5.3 m^3/kg H_2 of electricity. The amount of CO_2 released during the reforming process, which must be stored, is estimated as 10 kg CO_2 / 1 kg H_2.

2.9.2.2 Resource potential

The results of the potential assessment are summarized in Table 10.

TABLE 10

Resource potential of hydrogen production in Uzbekistan by 2040

The evaluation results are shown in Figure 16. Thus, under the accepted assumptions, the main long-term

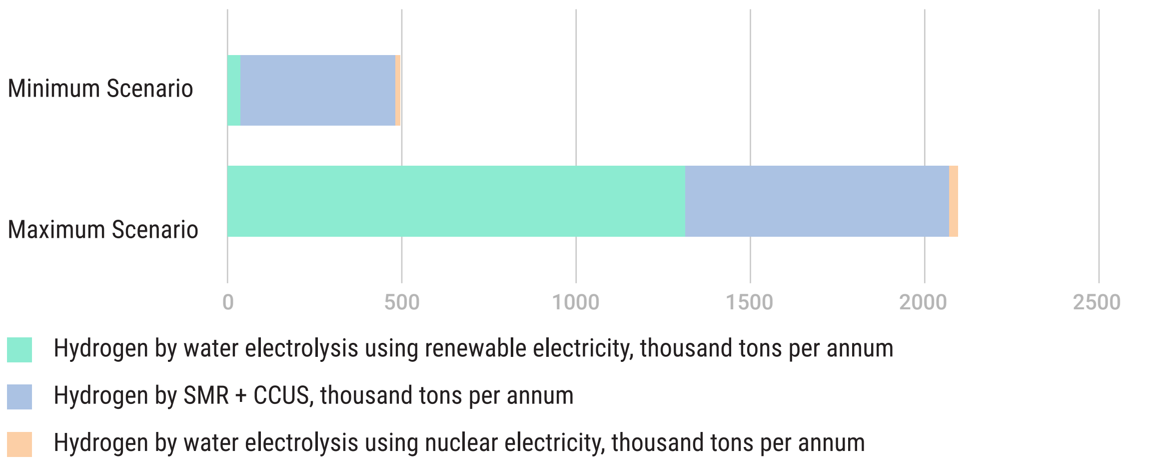
	MINIMUM SCENARIO	MAXIMUM SCENARIO
Renewable electricity for hydrogen, GWh per annum	1821	72051
Nuclear electricity for hydrogen, GWh per annum	900	1530
Natural gas for hydrogen, bcm per annum	2	four
Hydrogen by water electrolysis using renewable electricity, thousand tons per annum	33	1310
Hydrogen by water electrolysis using nuclear electricity, thousand tons per annum	16	28
Hydrogen from methane by SMR + CCUS, thousand tons per annum	444	755
Hydrogen total, thousand tons per annum	**494**	**2093**
Required capacity of CCUS systems, $MtCO_2$ per annum	4	8

opportunities for hydrogen production in Uzbekistan are water electrolysis using renewable electricity and steam methane reforming with CCS.

This is determined by the setting of ambitious goals and the accumulated dynamics in the field of renewables development in the country, by significant proven natural gas reserves, the possibility of reducing its consumption in other sectors through energy efficiency and the introduction of carbon-free power generation (renewables, nuclear power). The key constraint and condition is the outstripping development of the CCUS industry - even in the minimum scenario, it is necessary to create CCUS facilities with a total capacity of 4 $MtCO_2$ per annum, as well as implement combined renewables+electrolysis projects.

FIGURE 16

Resource potential of hydrogen production in Turkmenistan by 2040, thousand tons per year



2.9.2.3 Cost analysis

According to ERI RAS estimates (ERIRAS, 2022), the cost of low-carbon hydrogen produced using electricity from new nuclear power plants in Russia, considering their 60-year operation, can be more than $4 per kg. A nuclear power plant in Uzbekistan can be built according to Russian design in the same time as the new nuclear power units in Russia, so this estimate can be taken as the minimum for a nuclear power plant in Uzbekistan, since when the payback period is reduced from 60 years to in 20-30 years, the cost of electricity and hydrogen will increase.

The cost of solar and wind electricity from new power plants can be taken at the level of $0.027 per kWh[29]. According to IEA estimates, at this price of electricity, the number of electrolyzers capacity utilization hours of 1500-2000 hours per year, electrolyzers CAPEX of $450 per kW, and discount rate of 8%, the hydrogen present value will be about $2.5–3 per kg.

The cost of hydrogen from natural gas consists of the cost of raw materials (for Uzbekistan, as a gas producing country, this is the cost of natural gas production), as well as the cost of CCUS. According to the IEA (2019), for gas producing countries, the natural gas cost was approximately 30% of the blue hydrogen cost. With the gas production cost at the level of $100 per thousand m^3, the blue hydrogen production cost can be estimated at $1.5-2.0 per kg of hydrogen.

2.9.2.4 Logistical opportunities and barriers for export-oriented hydrogen projects

Uzbekistan has no access to the open sea. With a combination of land and sea transport, the distance from Tashkent to the port of Rotterdam (Netherlands) will be 17.7 thousand km, to the port of Kobe (Japan) - 11.1 thousand km. The distance from European ports is more than almost three times that for export-oriented hydrogen projects in the MENA region (such as the NEOM Green Hydrogen project in Saudi Arabia with a capacity of 4 GW - 6.5 thousand km to Rotterdam). The distance from the ports of Japan and Korea is comparable to the indicators of export-oriented projects in Australia (9 thousand km). The remoteness from future key markets and the overland part of the routes with a length of thousands of kilometers questions the competitiveness of similar projects in Uzbekistan.

The nearest capital of an EU member state is located at 5.5 thousand km from Tashkent by land transport (Sofia) with transit through Turkmenistan, Iran and Turkey - this is 2 times more than the same indicator of Azerbaijan, which also has existing TAP and TANAP pipelines transporting gas to the EU. Thus, Uzbekistan location relative

29 Corresponds to first solar PV plant in Uzbekistan indicators, see the "RES" section above.

to the future European hydrogen market (imports up to 10 Mt of hydrogen per year by 2030) can hardly be called competitive. During drafting an export strategy, these routes may need to be studied in more detail, considering Uzbek suppliers competitiveness in terms of cost, carbon footprint of hydrogen and its origin (green or renewable hydrogen has priority for the European market).

Uzbekistan does not have a common border with China, and the distance from Tashkent to Urumqi (the largest industrial center of the Xinjiang Uygur Autonomous Region of the PRC) by land transport is about 1.5 thousand km - the route runs through Kazakhstan. The Central Asia-China gas pipeline runs along the same route, which connects with the Chinese West-East gas pipeline in Khorgos on the border of Kazakhstan and the Xinjiang Uygur Autonomous Region of China. This creates opportunities for investigation of hydrogen export opportunities to China by pipeline, road, and rail transport.

2.9.3 Existing and prospective pilot projects in the field of hydrogen

2.9.3.1 Existing pilot projects

There are no implemented pilot projects in the field of low-carbon hydrogen in Uzbekistan yet, but Uzbek and international companies are beginning to consider this area under special agreements.

ACWA Power (Saudi Arabia) signed an $10 billion 5-years investment agreement and memorandum of cooperation with the Ministry of Energy of Uzbekistan. The goal is to investigate possible projects in the field of gas, renewables and green hydrogen.

In 2021, an Interdepartmental Commission for Renewable and Hydrogen Energy Development was established under the leadership of the Minister of Energy, which included representatives of all key ministries. In 2021, the National Renewable Energy Research Institute was established under the Ministry of Energy, with a Hydrogen Energy Research Center as a structural unit. A national renewable and hydrogen energy development strategy is drafting.

2.9.3.2 Possible promising projects

Uzbekistan has not yet set carbon neutrality goals, so local consumption of low-carbon hydrogen is not a priority for the country.

Large-scale low-carbon hydrogen production in the country will be possible subject to the development of low-carbon electricity sources (renewables, nuclear power plants), as well as CCUS (for hydrogen production from natural gas produced in Uzbekistan). For pilot projects, hydrogen associated with greenhouse gas emissions (for example, hydrogen from existing refineries, gas processing plants, Uzbekistan GTL) can be used - this will help to scale-up value chain by the time when low-carbon hydrogen production becomes possible.

Domestic hydrogen demand can start with pilot projects in the transport sector. The launch of pilot hydrogen fuel-cell electric buses, the phased development of hydrogen refueling infrastructure around hydrogen-producing enterprises (including oil refineries) are the first steps that begin the development of the hydrogen economy of countries around the world. Setting targets for achieving carbon neutrality and other energy policy measures related to the transport sector (ICE ban, environmental restrictions on emissions, preferential parking, priority travel, subsidies, tax incentives) can create a regulatory environment for such projects. If infrastructure develops and technologies become cheaper, the use of low-carbon hydrogen in industry (oil, gas refining) can be considered.

Transportation of hydrogen using the existing gas transmission infrastructure requires additional research, taking into account the experience of European, American, Chinese gas companies (Shell , Gasunie , Snam , etc.)

The large-scale export of hydrogen through the existing infrastructure (gas pipelines) will require collaboration with the gas companies of the importing countries (primarily China) and countries involved in operation and development of the Central Asia-China gas pipeline system. Russian Gazprom has no plans to use the gas transportation infrastructure to transport hydrogen. Among Uzbekistan's immediate neighbors, only Kazakhstan is

drafting a hydrogen strategy, and there is no explicit request for hydrogen imports in Kazakhstan. Chinese hydrogen strategy focuses on local hydrogen production rather than importing hydrogen.

It is important to consider the diversity of possible options for the development of the hydrogen economy in the national hydrogen strategy of Uzbekistan. International organizations can provide methodological assistance in this.

2.9.4 Conclusions

1. Uzbekistan is an energy-abundant country, a major natural gas producer and exporter with significant production of oil and coal to meet domestic demand. Economic growth and the use of fossil fuels determine the dynamic growth of greenhouse gas emissions. Natural gas-fired power plants made it possible to increase electricity production by 33% over 14 years and reduce electricity imports by 3-4 times over the same period.

2. The country is actively reforming the energy sector and is among the leaders in the region in terms of renewable energy deployment: about 10 utility-scale wind and solar projects are in different stages of development, the national hydrogen strategy is drafting.

3. Renewables potential in Uzbekistan is huge and many times exceeds its energy needs. Power sector's carbon neutrality could be achieved by 2050 with 97 GW of intermittent renewables. Technical potential of renewables, in contrast, stands for 2000 GW. In addition, the country is considering the first nuclear power plant construction project.

4. Natural gas reserves in Uzbekistan are sufficient to meet the local demand, there are plans to increase energy efficiency, which may lead to gas demand decrease and create possibility to use gas for hydrogen production. Outstripping development of the CCUS industry will be needed to allow this way of production.

5. The country's developed gas and oil refining industry provides experience that can be used in the deployment of steam methane reforming projects. In addition, gas and oil refining enterprises can become centers for hydrogen economy development - for example, the Uzbekistan GTL plant can produce and consume up to 27 thousand tons of hydrogen per year.

6. Considering resources and energy sources which will be available for hydrogen production, it is possible to estimate the resource potential for low-carbon hydrogen production in Uzbekistan at 0.49-2.09 Mt per annum.

7. Steam methane reforming in combination with CCUS is the most affordable low-carbon hydrogen production option in Uzbekistan in the medium-term.

8. The gas transportation infrastructure in Uzbekistan is used to transport gas within the country and transit to neighboring countries - the total capacity of export and transit gas pipelines to the countries of Central Asia, Russia, Europe and China in Uzbekistan reaches more than 120 bcm per annum. Transit routes start in Turkmenistan and pass through Kazakhstan. The use of gas transportation infrastructure for hydrogen transportation will require additional research involving all interested parties.

9. There are no implemented pilot projects in the field of low-carbon hydrogen in Uzbekistan yet, but the sector is already attracting the attention of international partners (for example, ACWA Power). It is possible to start local low-carbon hydrogen consumption from the transport sector, as well as in oil and gas processing.

10. To better understand the prospects for a hydrogen economy in Uzbekistan, the country may need a national hydrogen strategy, which international organizations can help develop.

2.10 General findings based on the cross-country analysis

2.10.1 Summary data by country

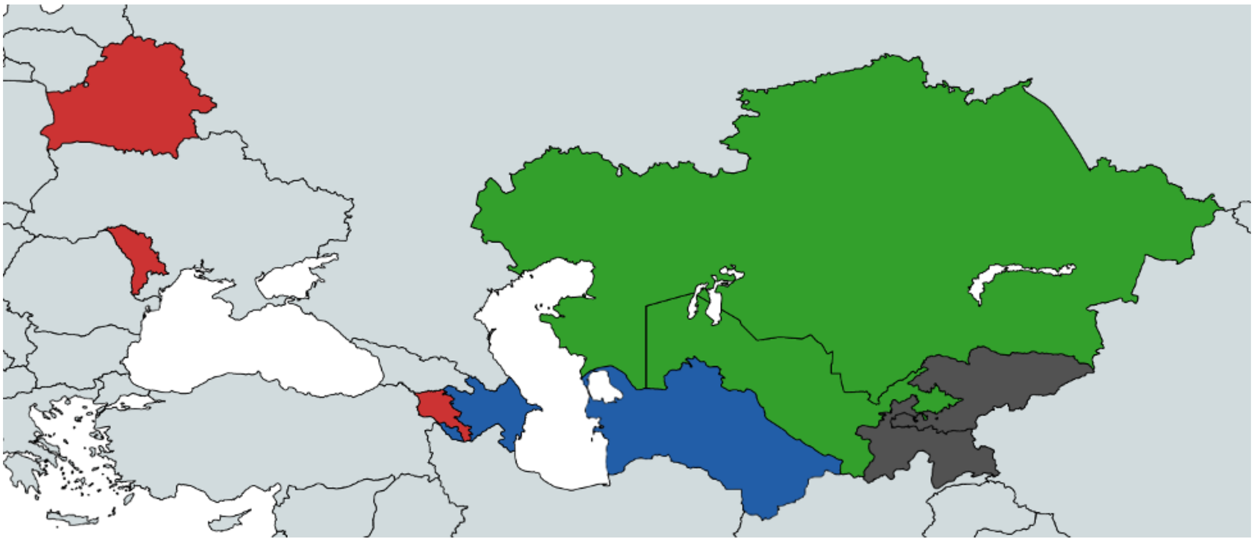
The data resulting from the analysis of the current state of the energy sector, energy and climate policies and low-carbon hydrogen potential for all countries are summarized in Table 11.

2.10.2 Grouping countries by geography and energy policy features

The countries' way towards low-carbon development and hydrogen economy is determined by their individual characteristics in energy and climate policy, in the current energy sector state, in economic growth rates, infrastructural opportunities and constraints. Cross-country analysis shows that for assessing the low-carbon hydrogen potential, they can be divided into four groups with similar features. (Figure 17).

FIGURE 17

Four groups of countries with similarities regarding low-carbon hydrogen potential assessment



Source: *UNECE using* www.mapchart.net*. The boundaries and any other information shown on the maps do not imply, on the part of the authors, any judgment on the legal status of any territory, or any endorsement or acceptance of such boundaries*

Armenia, Belarus and Moldova are united by the virtual absence of their own hydrocarbon resources, a serious dependence on energy imports and an orientation towards natural gas (30-60% of the total final energy consumption). Renewables have so far received limited development, but in Armenia and Belarus, the role of nuclear power plants is significant. The three countries' climate policies aim at cutting emissions by 2030, which can be achieved relatively easily without major decarbonization efforts. Under these conditions, there is practically no potential local demand for low-carbon hydrogen in countries over the next 10 years, and hydrogen economy development has not yet become a priority (as evidenced by the lack of public activities in drafting of hydrogen strategies or roadmaps). At the same time, on a longer-term horizon, subject to a reorientation to their own low-carbon energy sources, hydrogen can take its place in the energy sector of these countries. For Belarus and Moldova, proximity to a key market, the EU, could open additional opportunities, especially these connecting with renewable hydrogen.

Azerbaijan and Turkmenistan, located in the Caspian region, are, in contrast, major energy exporters towards the EU and China. Natural gas dominates in their energy consumption mix, the role of the oil and gas sector is great in the countries, significant competencies have been accumulated in the large-scale projects implementation in this area, and large foreign companies are operating. This opens opportunities to produce hydrogen from natural gas

in combination with CCUS, as well as to use the new gas transmission infrastructure for transporting hydrogen (oil and gas companies are engaged in similar projects in the world).

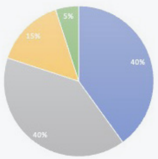
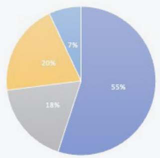
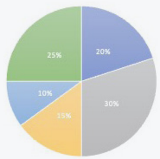
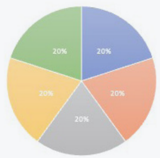
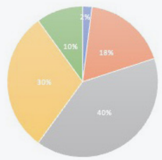
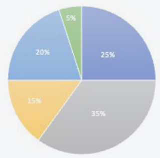
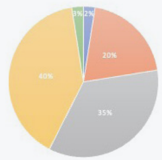
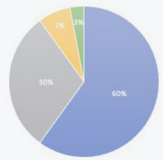
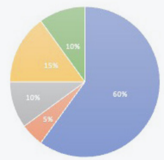
The same applies to realizing the offshore wind energy potential on Caspian Sea shelf. At the same time, the climate policy in these countries does not yet create significant incentives for decarbonization and low-carbon technologies deployment. Azerbaijan can reach its 2030 GHG emission reduction target while maintaining current levels of emissions, while Turkmenistan is increasing its GHG emissions and does not have a quantified reduction target. Both countries have started activities in the field of hydrogen. The key consumers of their natural gas - the EU and China - have adopted national hydrogen strategies and are actively developing a hydrogen economy, with the EU aiming, among other things, at up to 10 Mt per annum hydrogen imports on the horizon of 2030. This may create additional incentives for Azerbaijan and Turkmenistan.

Kyrgyzstan and Tajikistan, located in the south of Central Asia and having a common border, are united by energy shortage problem and a significant hydropower plants share in the energy mix. On the one hand, thanks to hydropower, these countries have the highest share of low-carbon energy sources in the energy mix among all the countries covered by this study, and on the other hand, this creates recurring seasonal problems associated with hydropower variability. Under these conditions, there is potential to produce hydrogen using "surplus" curtailed electricity from hydropower plants and use of this hydrogen, for example, to replace imported petroleum products. But in the medium term, the more urgent tasks in energy policy (compared to decarbonization) will be the modernization of outdated infrastructure and ensuring energy security.

Kazakhstan and Uzbekistan, located in the center of Central Asia and sharing a common border, together account for more than 60% of energy-related greenhouse gas emissions among all countries covered by this study. Both countries are showing impressive momentum in launching the low-carbon energy transition– despite being rich in and exporting their own fossil energy resources. Renewable energy is developing, supported by energy sector reforms and involvement of major international players. Kazakhstan aims to achieve carbon neutrality by 2060 and is already considering hydrogen as an opportunity to achieve this goal, while Uzbekistan has adopted a green economy transition strategy by 2030 (with an extension to 2050) and created a high-level commission responsible for hydrogen economy development. Both countries are drafting national hydrogen strategies with the support of international organizations. Considering serious institutional changes, strategic vision and a wide range of resources for low-carbon hydrogen production, it is Kazakhstan and Uzbekistan that can be called regional leaders in hydrogen economy development.

TABLE 11

Summary data for all countries covered by the study

	AZERBAIJAN	ARMENIA	BELARUS	KAZAKHSTAN	KYRGYZSTAN	MOLDOVA	TAJIKISTAN	TURKMENISTAN	UZBEKISTAN
Energy net-exporter /importer	exporter	importer	importer	exporter	importer	importer	importer	exporter	exporter
Energy mix									
Fossil energy resources	gas, oil	-	-	coal, gas, oil, uranium	coal	-	coal	gas, oil	gas, coal, oil, uranium
Energy infrastructure	developed	moderate	developed	developed	moderate	developed	moderate	developed	developed
GHG emissions, $MtCO_2e$ per annum	50	10	85	370	5	14	13	80	190
GHG emissions reduction goals	35% к 2030, 40% к 2050	40% к 2030	30% к 2030	Net Zero 2060	16% к 2025-2030	70% к 2030	30-40% к 2030	н/д	35% к 2030 (specific)
Max hydrogen production potential by 2040, MtH_2 per annum	2.36	0.042	0.046	2,56	0.145	0.052	0.204	5.76	2.09
Main potential source for hydrogen production	SMR+CCUS	electrolysis + RES	electrolysis + RES + nuclear	SMR+CCUS, electrolysis + RES	electrolysis + RES	electrolysis + RES	electrolysis + RES	SMR+CCUS	SMR+CCUS, electrolysis + RES
Priority potential domestic hydrogen applications	industry, transport	transport	transport	industry, transport	transport, power sector	transport	transport, power sector	industry, transport	industry, transport

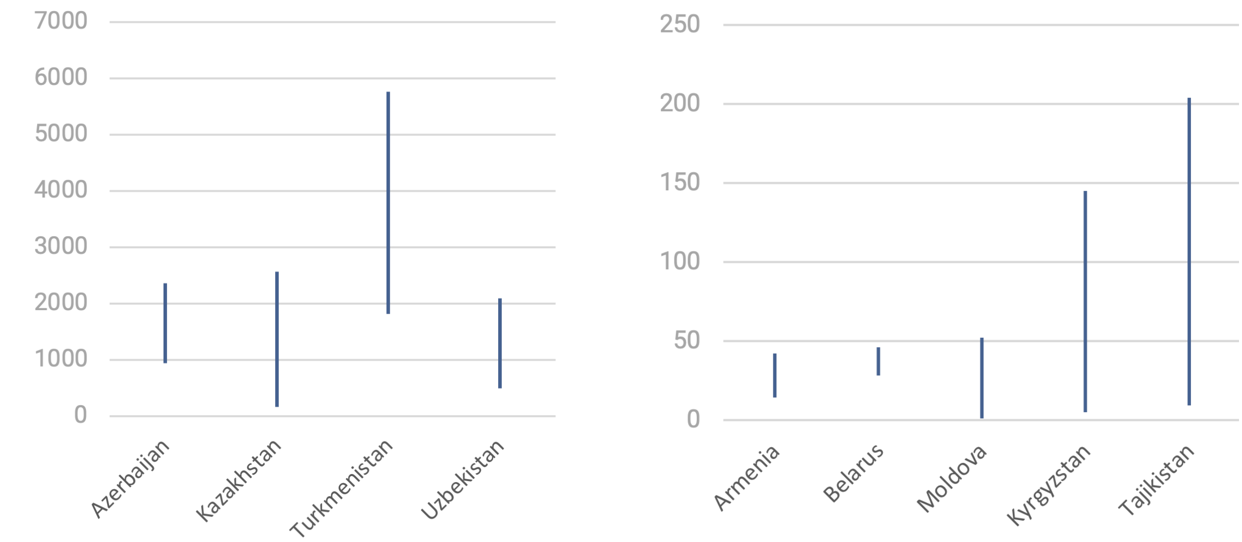
■ Gas ■ Coal ■ Oil ■ Electricity ■ Bio/waste ■ Heat

2.10.3 Resource potential for low-carbon hydrogen production by 2040: amounts and cost analysis

The resource potential for low-carbon hydrogen production by 2040 varies widely in all countries, reflecting uncertainties in the assessment of both the minimum and maximum scenarios (Figure 18).

FIGURE 18

Ranges of resource potentials for low-carbon hydrogen production by 2040 in the countries covered by the study (different scales are applied on the left and right sides), thousand tons of hydrogen per year

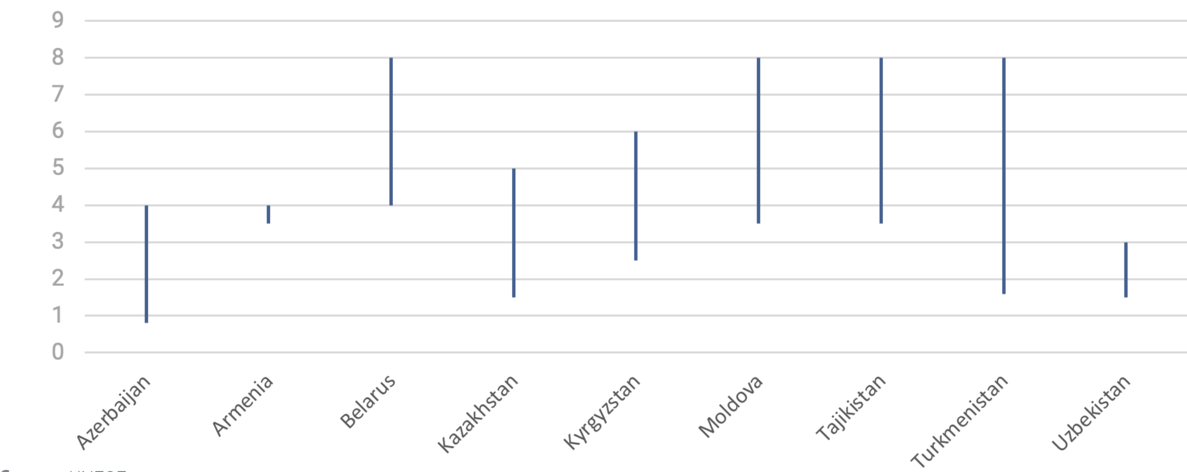


Source: UNECE

The order of values is determined, first, by the presence of the country's own reserves of natural gas and the pace of renewable energy development. They are highest in the group of Caspian countries exporting natural gas (Azerbaijan, Turkmenistan) and in the group of Central Asian countries actively reforming their economies towards low-carbon development (Kazakhstan, Uzbekistan). The maximum potentials of each of these countries are several Mt per annum. The potentials of energy-importing countries (Armenia, Belarus, Moldova, Kyrgyzstan, Tajikistan) are about 10-20 times less - primarily due to the low rates low-carbon energy sources development (except two countries in southern Central Asia that will have ability to use excess curtailed hydropower).

FIGURE 19

Cost ranges for low-carbon hydrogen by country, USD per kg of H_2



Source: UNECE

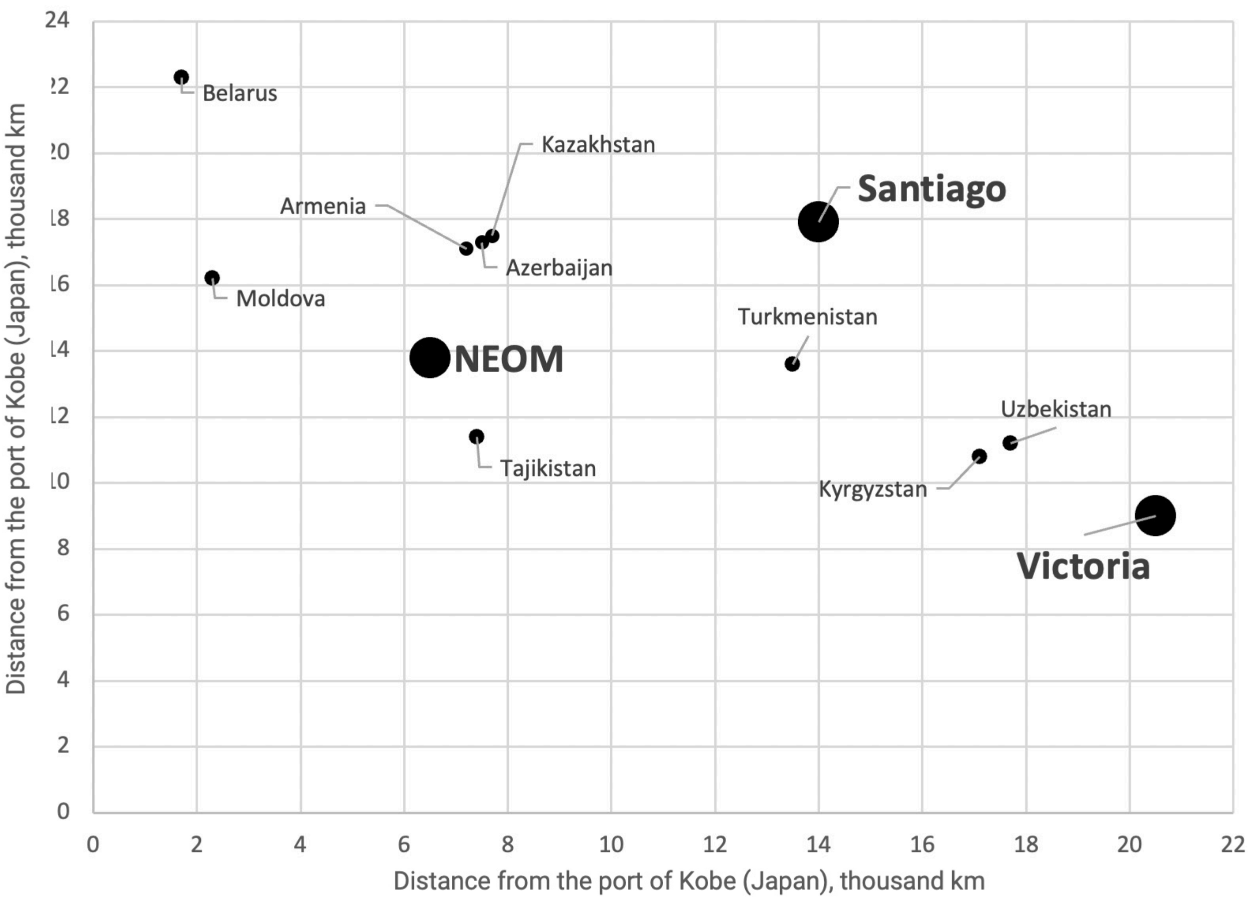
The projected cost of low-carbon hydrogen (Figure 19) also varies widely depending on the assumptions made. The key uncertainty factors are levelized cost of renewable electricity and cost of CCUS after unfolding their potential, as well as the technologies cost (primarily electrolysis). It is likely that gas producing countries will have an advantage in the medium term due to low cost of hydrogen produced using natural gas. In the long term, countries with high rates of renewable energy deployment can gain an advantage due to the electrolysis cost reduction as the global hydrogen economy develops. Countries with surplus (curtailed) renewable electricity generation will benefit faster than others, such as Kyrgyzstan and Tajikistan nowadays.

2.10.4 Logistical opportunities and constraints for export-oriented projects

Export-oriented hydrogen projects in all countries will face logistical constraints: none of them has access to the open sea, so potential exports to key hydrogen markets (EU, Southeast Asia) will most often require transshipment of cargo and land / sea transport combination with transportation for several thousand kilometers (Figure 20). Similar projects in the MENA region (such as NEOM Green Hydrogen) are located closer to key markets and have direct access to the Red or Mediterranean Sea. Several countries in Central Asia (Kazakhstan, Kyrgyzstan, Tajikistan, Turkmenistan, Uzbekistan) are located relatively close to China (1.5-2 thousand km from Urumqi) and may consider the possibility of exporting hydrogen to this country. At the same time, China's hydrogen strategy focuses on domestic hydrogen production rather than importing it. Belarus, Moldova and Azerbaijan have the potential to export hydrogen to the EU due to their relative proximity to the EU market and existing gas transport infrastructure but realizing this potential will require significant efforts.

FIGURE 20

Logistical opportunities and constraints for export-oriented hydrogen projects: distance from key future hydrogen markets (EU, Japan) compared to promising export-oriented projects in MENA, Australia and Chile



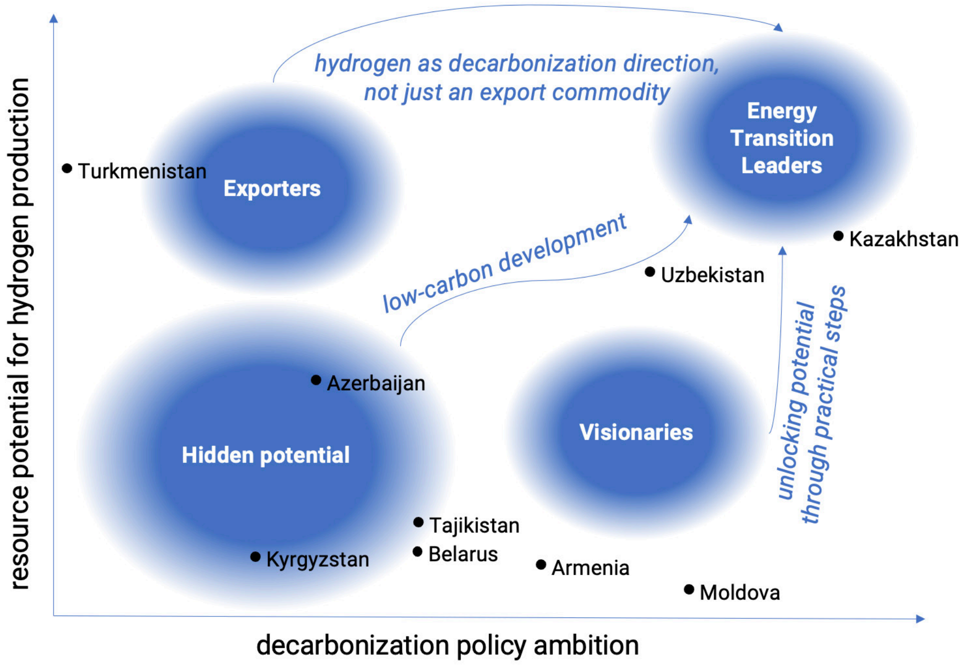
Source: *UNECE using searates.com, maps.google.com.*

2.10.5 Scenario models for the hydrogen economy development

The resource potential of low-carbon hydrogen production and decarbonization strategy ambitiousness are interconnected and form four scenario models for potential deployment of hydrogen economy in the countries covered by the study (Figure 21).

FIGURE 21

Possible typical scenario models for hydrogen economy establishment and deployment in the countries covered by the study, depending on their decarbonization policy ambition and resource potential for low-carbon hydrogen production.



Source: UNECE

The "Hidden Potential" model is implemented in the case of setting unambitious decarbonization targets and limited access to resources needed for low-carbon hydrogen production - for example, if the country lacks natural gas production and renewables deployment. In this model, there is no low-carbon hydrogen domestic demand (since there is no need for deep decarbonization), and hydrogen production possibilities (for example, for export) are limited due to the slow development in low-carbon sectors (RES, CCUS, nuclear power). Nevertheless, even in this case, the country has the potential to develop a hydrogen economy. Practical steps can be taken to realize the renewable energy technical potential (which exists in any country in the world without exception), by introducing of supporting framework inside decarbonization policy. Thus, the transition to low-carbon development will make it possible to realize the hidden potential and transform the economy towards the "Energy Transition Leaders" model.

The "Exporters" model is typical for countries with low decarbonization ambitions that have resources for low-carbon hydrogen production (for example, natural gas production and CCUS potential in depleted oil fields). In this case, there is also no domestic low-carbon hydrogen demand (since there is no need for deep decarbonization), and the hydrogen potential can only be realized through hydrogen export to key future markets (the EU, Southeast Asia). As shown above, such a strategy for almost all countries covered by the study is associated with serious challenges due to remoteness from markets and lack of access to the open sea. In addition to logistical problems, there are risks associated with long-term hydrogen demand guarantees: in this sense, export-oriented projects are more vulnerable than projects focused on domestic hydrogen demand with a short transport leg. More ambitious decarbonization strategy in this case can become a serious incentive for emergence of hydrogen demand in industry (hydrocarbon processing, metallurgy), transport (hydrogen fuel-cell electric transport) and

energy infrastructure (hydrogen blending into gas pipelines). Domestic hydrogen demand will become the basis for realizing its production potential in the country.

The "Visionaries" model is implemented when a relatively ambitious decarbonization policy is not sufficiently supported by practical steps aimed at realizing the latent low-carbon economy potential in a country. The dynamic development of renewable energy sources and other low-carbon technologies is a necessary basis for building up and implementing the resource potential of low-carbon hydrogen production.

The "Energy Transition Leaders" model combines an ambitious decarbonization policy (and thus guaranteed future domestic demand for low-carbon hydrogen and related technologies) with significant resource potential for hydrogen production (even if the strategy involves future imports). All countries leading the low-carbon hydrogen economy deployment - such as members of the G7 - or future potential hydrogen exporters (Saudi Arabia, Chile, Australia) have adopted carbon neutrality goals, are intensively developing low-carbon technologies, have adopted or are drafting national hydrogen strategies. Thus, they implement exactly the scenario model "Energy Transition Leaders".

The listed scenario models do not have clear boundaries, and each country's way from one model to another is unique, depending on the national economy circumstances. The study showed that a significant part of the resource potential of hydrogen production in all countries is in a hidden state, as renewable energy and other low-carbon technologies deployment is at an early stage. The way of all countries away from the Hidden Potential model is different. For example, Turkmenistan is a prime example of the "Exporters" model due to the combination of high potential for low-carbon hydrogen production and lack of quantitative greenhouse gas emissions reduction targets. Armenia and Moldova, which have adopted relatively ambitious NDCs, have not yet gained momentum in low-carbon technologies introduction. Kazakhstan and Uzbekistan are showing clear movement towards the "Energy Transition Leaders" model.

Thus, this study shows that the hydrogen economy deployment pace in countries will be determined not so much by their resource potential as by the strategic focus on low-carbon development, building an appropriate regulatory framework, expanding markets, technological development and international cooperation.

2.10.6 Scope for international cooperation

International cooperation regarding hydrogen economy development is especially important in the areas of standards harmonization and joint pilot projects implementation. International standards for certification of hydrogen as a low-carbon energy carrier (methodologies for calculating and confirming the carbon footprint or the origin of hydrogen) are necessary for emergence of a global hydrogen market, therefore, dozens of organizations around the world are involved in the drafting and testing of such standards, offering various approaches. Relevant discussions are also taking place at UNECE[30]. The main barrier here is that hydrogen production technologies are diverse, technological pathways have a different carbon footprint depending on the energy resources and raw materials used (which, in turn, also have a carbon footprint). Unification of approaches to this issue at international scale is an important scope for cooperation.

Equally important is the unification of technical standards in the field of hydrogen technologies – the technical committee ISO / TC 197 is involved in that in the International Standards Organization[31].

The countries covered by this study have common borders, interconnections in the power grid, gas infrastructure, a long trade relations history in the energy sector - both in the supply of resources, equipment and the joint implementation of infrastructure projects. Many of countries together are part of international organizations such as the EAEU. Extending this cooperation to the new area of the hydrogen economy, implementing pilot projects, developing a joint strategy for export-oriented projects will be important to unlock potential of this sector.

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82. Updated Nationally Determined Contribution of the Republic of Moldova / 2020.

83. Updated Nationally Determined Contribution of the Republic of Tajikistan / October 2021.

84. Wind Energy in Armenia: Overview of Potential and Development Perspectives. March 2010

85. World Bank (2022). Offshore Wind Roadmap for Azerbaijan. World Bank, Washington, DC. License: Creative Commons Attribution CC BY 3.0 IGO

ANNEX - CURRENT STATUS OF THE ENERGY SECTOR BY COUNTRY

A1.1 Azerbaijan

The Republic of Azerbaijan (Azerbaijan) is located in the South Caucasus region, bordered by the Caspian Sea in the east, Armenia and Georgia in the west, Russia in the north and Iran in the south. Its population is 10.1 million people, and its area is about 86.6 thousand km^2; Baku is the capital and the largest city.

Key facts

Azerbaijan is an energy surplus country: according to the International Energy Agency (IEA), in 2017, with a total energy production of 54 Mtoe final consumption was approximately 14 Mtoe and energy exports were 42 Mtoe.

The basis of the energy sector is the oil and gas industry: natural gas share in energy supply in 2019 was more than 65%, oil share was almost 35%. Hydropower, biofuels, solar and wind energy shares in 2019 were, by contrast, insignificant. Azerbaijan is also a major crude oil exporter (approximately 31 million tons in 2019) and natural gas exporter (approximately 11 bcm in 2019).

The electric power sector is based on natural gas-fired thermal power plants – their share in electricity mix in 2019 reached 90%, the hydro power share was almost 10%, with a small share of other sources (solar, wind power plants and biomass sources).

Oil and gas account for over 90% of Azerbaijan's exports. Oil and gas production increased significantly in the 2000s after the Shah Deniz gas field discovery and reached a record high in 2010. The government and international companies have invested heavily in the energy sector, building several new power plants, and rehabilitating and upgrading gas pipelines and power grid, improving the reliability and security of energy supplies.

Despite the widespread economy privatization since independence, the energy sector in Azerbaijan remains predominantly state-owned. Only a few small hydropower plants are privately owned and account for less than 1% of electricity generation.

Key documents and regulators

The Presidential Administration, the Cabinet of Ministers and the Ministry of Energy are the main state institutions involved in the energy sector, while the State Oil Company of the Republic of Azerbaijan (SOCAR), AzerEnergy, Azerishiq and Azeristiliqtejizat are the main state-owned energy companies. The Ministry of Energy is the central executive body responsible for the state policy implementation and various regulations, orders and resolutions issued by the government for the energy sector. The State Agency for Renewable Energy under the Ministry of Energy[32] is involved in drafting and implementation of state policy in the field of renewable energy and energy efficiency.

The Azerbaijan State Commission on Climate Change was established in 1997. Azerbaijan ratified the Kyoto Protocol in 2000, became a member of the International Renewable Energy Agency (IRENA) in 2009. In 2016-17, Azerbaijan signed and ratified the Paris Agreement.

Azerbaijan's long-term energy strategy as of June 2022 is still in a drafting phase. There are no hydrogen related strategic state documents yet. According to the State Agency for Renewable Energy Sources, as of July 2022, a working group consisting of interested parties has been established to determine hydrogen energy development directions, and relevant studies are being carried out.

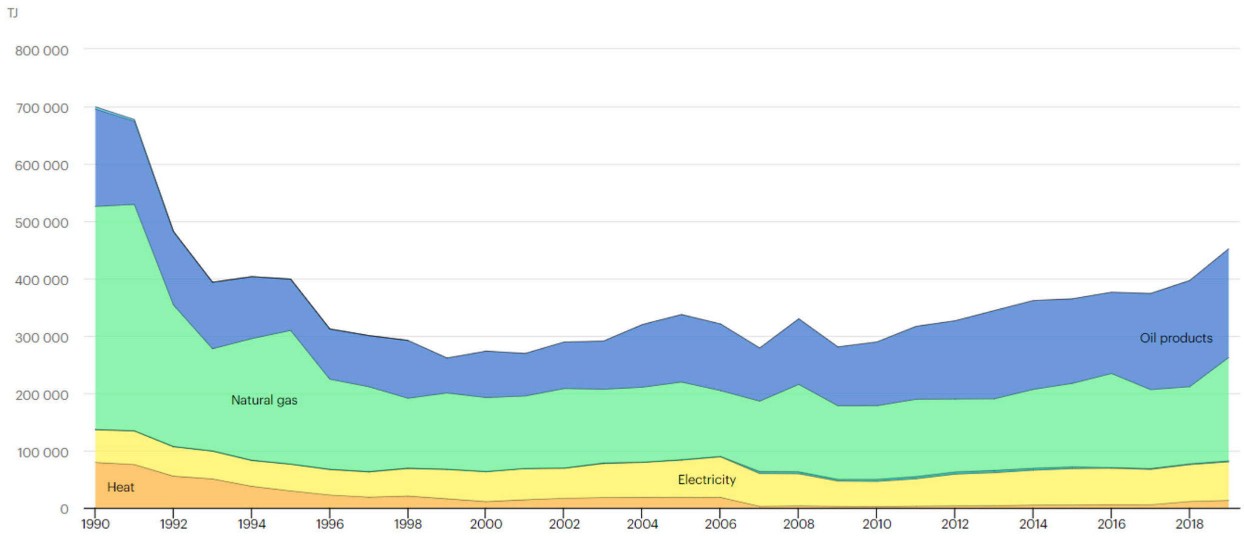
32 https://area.gov.az/en/page/haqqimizda

Balance of energy supply and demand

The total final energy consumption in Azerbaijan is provided by about 40% from oil products, 40% from natural gas, 15% from electricity and about 5% from heat (see Figure 22). Oil products are mainly used in the transport sector, while natural gas is used in the power sector.

FIGURE 22

Total final energy consumption in Azerbaijan in 1990-2019 by source

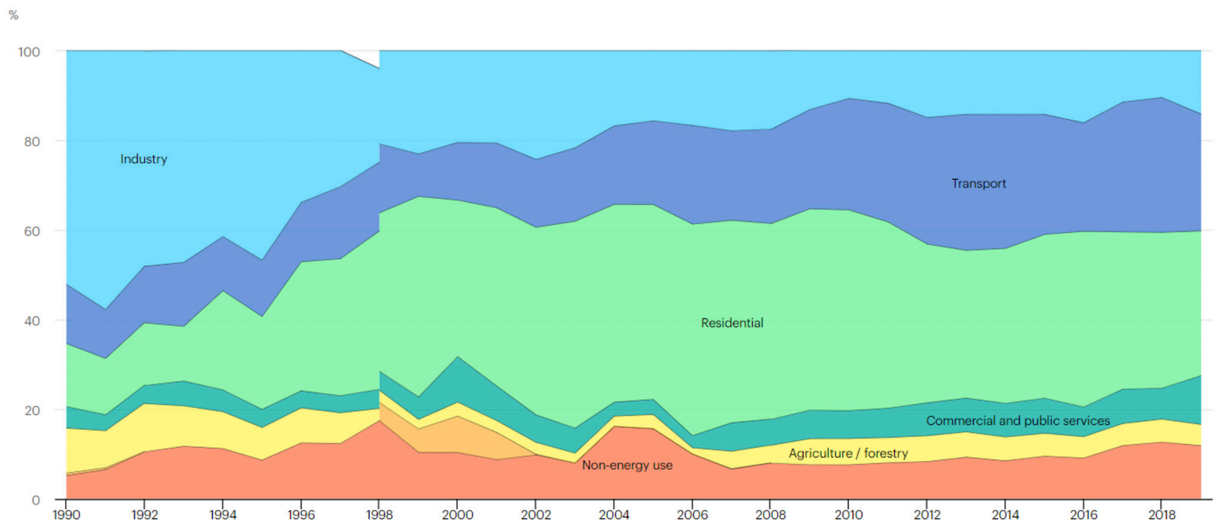


Source: *IEA World Energy Statistics*

Approximately 30% of final energy consumption is in the residential sector (buildings) and transport. The remaining 40% is split between industry, the services sector, non-energy use and agriculture / forestry (Figure 23).

FIGURE 23

Total final energy consumption structure in Azerbaijan in 1990-2019 by sector

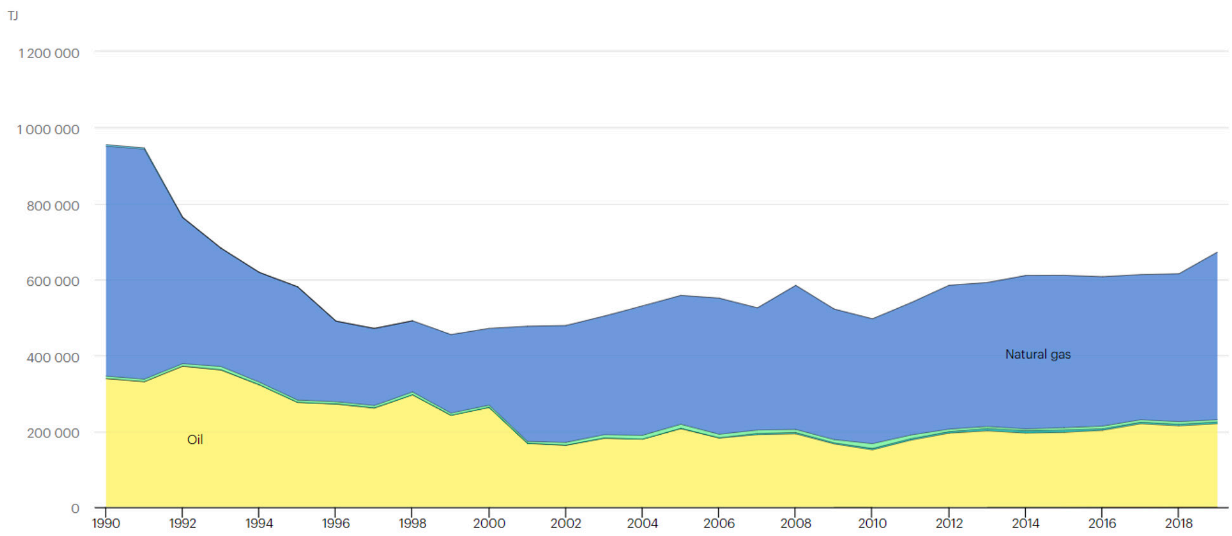


Source: *IEA World Energy Statistics*

Energy supply exceeds final energy consumption. Since 2010, energy supply has increased by almost 40%, primarily due to natural gas (Figure 24).

FIGURE 24

Energy supply in Azerbaijan in 1990-2019 by source



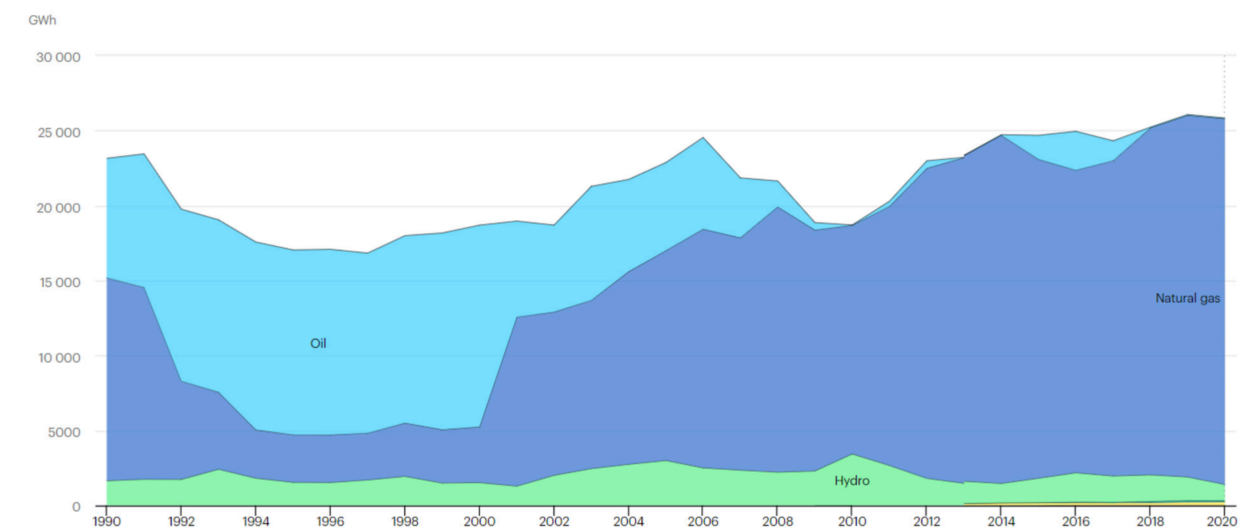
Source: *IEA World Energy Statistics*

According to BP, Azerbaijan in 2020 produced 0.8% of the world's oil (35.1 Mt), ranking 23rd in the world and second among the countries included in the study. The country's share in global natural gas production is 0.7% (25.8 bcm) – the 28th place in the world and the fourth place among the countries included in the study.

Azerbaijan's power sector is dominated by natural gas, which has almost completely replaced oil products since 2010. In 2013-2020, there is a slow increase in solar and wind power generation: from 1 GWh in the solar and 1 GWh in the wind in 2013 to 47 and 96 GWh in 2020, respectively.

FIGURE 25

Electricity generation in Azerbaijan by source in 1990-2020



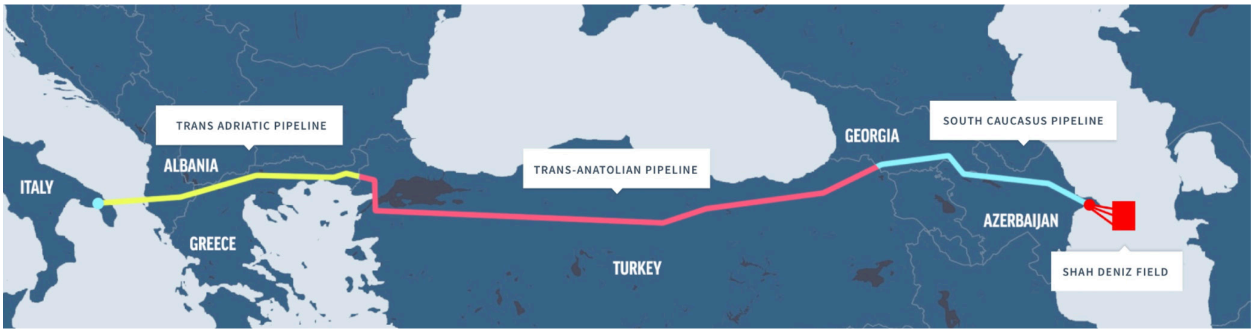
Source: *IEA World Energy Statistics*

Gas transportation infrastructure

Southern Gas Corridor is the main gas pipeline system for natural gas export from Azerbaijan (Figure 26).

FIGURE 26

Southern Gas Corridor layout



Source: *www.sgc.az*

It comprises the South Caucasus gas pipeline from Azerbaijan to Georgia, the Trans-Anatolian gas pipeline (TANAP, 16 bcm per annum) from Georgia through Turkey to the border with Greece, the Trans-Adriatic gas pipeline (TAP, 10 bcm per annum) through Greece, Albania, Adriatic Sea to Italy. The key stakeholders of the project are SOCAR and BP.

The throughput capacity of the gas pipeline can be increased through additional investments, and in the situation of reduced gas supplies from Russia to the EU markets, the attractiveness of these investments increases. In 2022, representatives of the European Union, Georgia, Italy, Serbia, Austria, Bulgaria, Turkey, Slovakia, Hungary, Moldova, Germany and other countries expressed their interest in increasing gas supplies from Azerbaijan (or extending existing agreements). In particular, an increase in gas exports to Europe from Azerbaijan from the current 8 billion m^3/year to 12 bcm/year (in the near future) and 20 bcm/year (in subsequent years) is being discussed[33]. The current agreement provides for exports of up to 10 billion m^3 annually for 25 years.

In the long term, it is possible to consider hydrogen export and an increase in the throughput capacity of the Southern Gas Corridor up to 31 bcm/year[34].

Greenhouse gas emissions

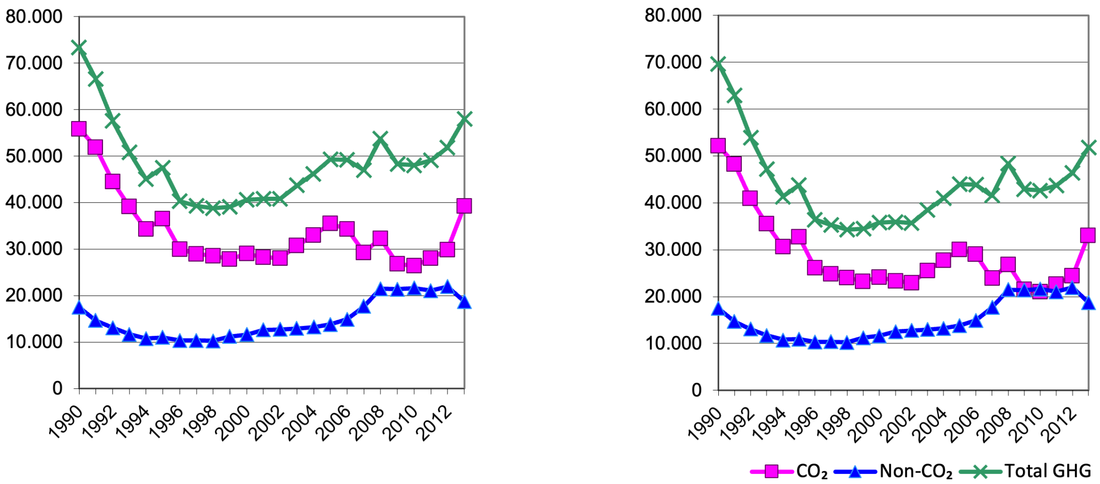
Greenhouse gas emissions in Azerbaijan, according to the official data of the National Inventory, continuously decreased from about 70 $MtCO_2e$ per annum between 1990 and 2000 (during the economic recession, as in most countries of the former USSR), after which they slowly and intermittently grew to about 50 $MtCO_2e$ per annum by 2013 (including CO_2 emissions of about 35 $MtCO_2e$ per annum) (see Figure 27).

33 https://report.az/en/energetika/socar-obsudil-s-es-perspektivy-rasshireniya-tanap-i-tap/

34 https://report.az/ru/energetika/afgan-isaev-sushestvuet-potencial-transportirovki-vodoroda-po-yugk/

FIGURE 27

Greenhouse gas emissions in Azerbaijan in 1990-2013 (left - excluding LULUCF, right - including LULUCF) in $GtCO_2e$/year



Source: *UNFCCC National Emission Inventory*

According to independent sources (Global Carbon Project, IEA World Energy Statistics), there were no significant changes in greenhouse gas emissions over the period 2013-2020. According to the IEA, in 2019, energy-related CO_2 emissions were about 35 $MtCO_2e$ per annum.

Existing forecasts and long-term energy policy goals

The long-term energy strategy of Azerbaijan is in drafting phase, so it is not possible to use long-term goals in the analysis.

Azerbaijan's Nationally Determined Contribution to reducing greenhouse gas emissions within the framework of the country's participation in the Paris Agreement assumes a 35% reduction by 2030 compared to the 1990 base level. In November 2021, in Glasgow, during the 26th session of the UN Conference of the Parties on climate change (COP26), Azerbaijan committed itself to 40% reduction in CO_2 emissions by 2050 and achieving net zero emissions by 2050 “in the territories liberated from occupation”.

In the long-term energy sector development forecasts issued by international agencies, incl. IEA, BNEF, Rystad, etc. Azerbaijan is considered as a part of the Caspian region. Unfortunately, this country is not singled out in the published forecasts. The only exception is in the IEA World Energy Outlook 2019: gas production in Azerbaijan in 2040 is assumed to be around 40 bcm per annum.

A2.1 Armenia

The Armenian Republic (Armenia) is located in the South Caucasus region, is landlocked and borders Turkey to the west, Georgia to the north, Azerbaijan to the east, and Iran to the south. The population of Armenia is 3 million people, its area is about 29.8 thousand km^2; Yerevan is the capital and the largest city (one third of the country's population).

Key facts

Armenia is an energy-deficient country: according to the IEA, its own energy production makes up no more than 25% of the country's needs.

The share of natural gas and oil in energy supply in 2020 was about 75%, the share of coal is insignificant. In terms of the share of natural gas in the total final energy consumption, Armenia is one of the world leaders (about 55%).

Nuclear energy (75%) and hydropower (approximately 25%) dominate in its own energy production. Electricity generation at hydropower plants has been stable over the past 30 years, while nuclear power generation has varied depending on the technical condition of the Armenian (Metsamor) nuclear power plant. The share of other (non-hydro) renewable energy sources is negligible, except for solar generation (3% of installed capacity in 2020, according to IRENA).

Key documents and regulators

The Ministry of Territorial Administration and Infrastructure is responsible for the formation of the entire energy policy in Armenia. The Ministry of the Environment is responsible for environmental policy, incl. in the energy sector, and coordinates Armenia's participation in the UNFCCC. In 2016-17, Armenia signed and ratified the Paris Agreement.

The Strategic Program for the Development of the Energy Sector of Armenia until 2040 was published in January 2021. A long-term low carbon development strategy is drafting, in early 2022 the UNDP selected the appropriate consultant.

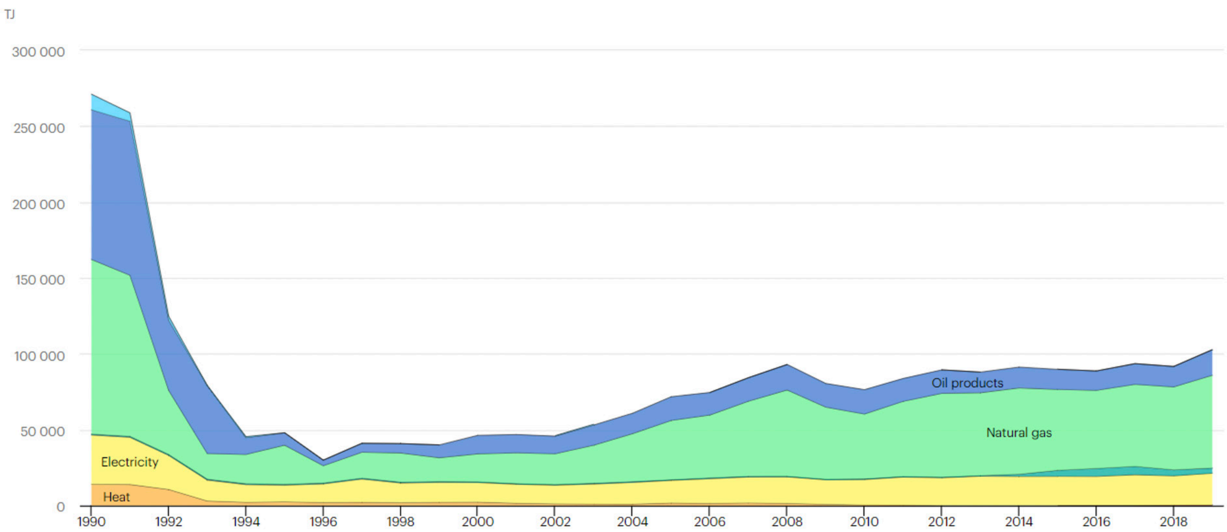
There are no strategic state documents in the field of hydrogen yet.

Balance of energy supply and demand

The total final energy consumption in Armenia is provided by about 55% from natural gas, 20% from electricity and about 18% from oil products (see Figure 25). Natural gas and oil products are used in the transport sector (natural gas is also used in the residential sector). During the period 2000-2019, energy demand almost doubled.

FIGURE 28

Total final energy consumption in Armenia in 1990-2019 by sourcer

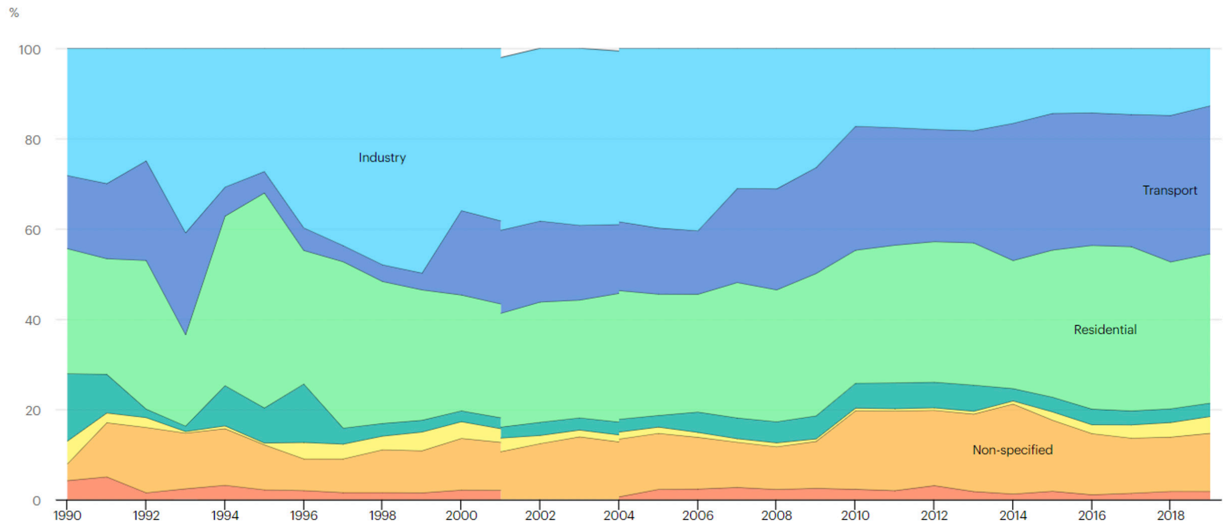


Source: *IEA World Energy Statistics*

Approximately 30% of total final energy consumption is in the residential and transport sectors. About 10% is in the industry. (Figure 28).

FIGURE 29

Total final energy consumption in Armenia in 1990-2019 by sector

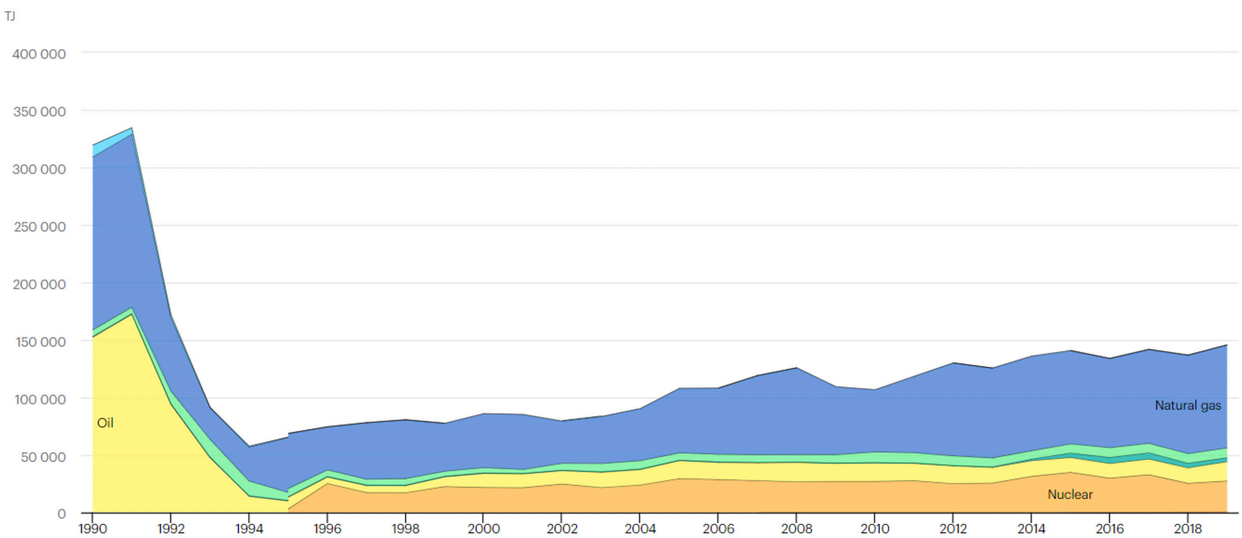


Source: *IEA World Energy Statistics*

Energy supply exceeds final energy consumption. Since 2010, energy supplies have increased by almost 30%, primarily due to natural gas (Figure 30).

FIGURE 30

Energy supply in Armenia in 1990-2019 by source



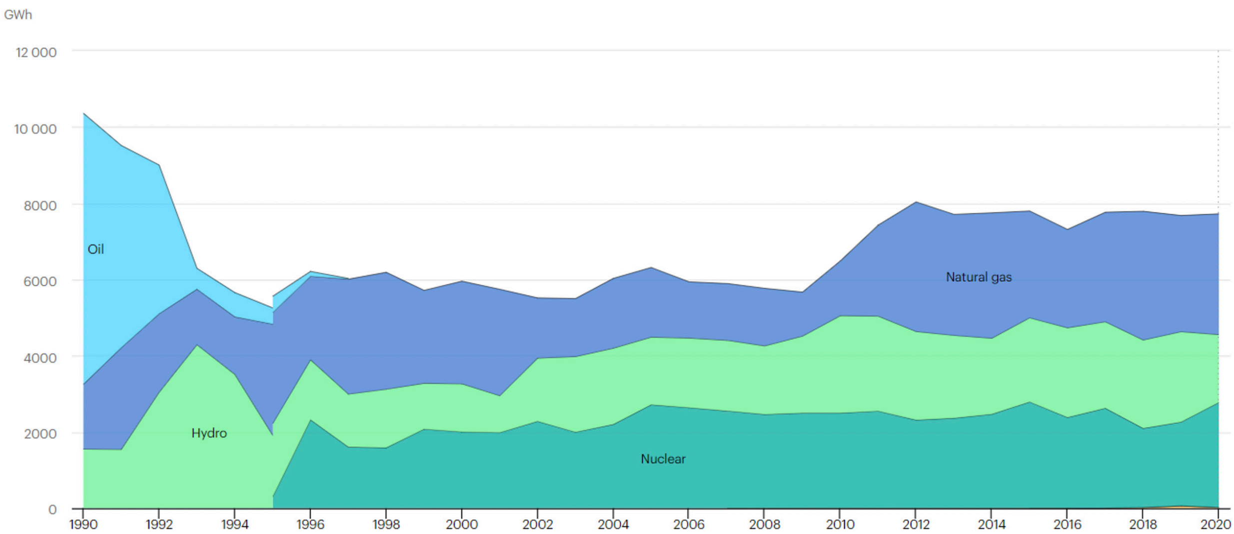
Source: *IEA World Energy Statistics*

The main source of natural gas and oil products supplies in Armenia is export from Russia. Crude oil is not exported, and an additional 15% of natural gas comes from Iran (although all of it is converted to electricity and sent back).

In the power sector of Armenia, natural gas, nuclear and hydropower shares divide approximately equally. The share of low-carbon electricity sources (hydropower, nuclear power plants) thus exceeds 50%, with nuclear power providing the base load, and hydropower and gas-fired thermal power plants cover the variable part of the demand curve. The share of other sources is insignificant (Figure 31).

FIGURE 31

Electricity generation in Armenia by source in 1990-2020



Source: *IEA World Energy Statistics*

Gas transportation infrastructure

The gas transportation infrastructure includes gas pipelines for importing gas from Russia and Iran (the Iranian gas pipeline is designed to supply gas to a power plant with subsequent export of electricity back to Iran). The entire gas transmission and distribution infrastructure is managed by the vertically integrated company Gazprom Armenia, a 100% subsidiary of Russia's Gazprom. As part of the Gas Transportation System (GTS), more than 1,683 km of main gas pipelines and branch gas pipelines are serviced. 1583.9 km of gas pipelines are involved in gas transportation.

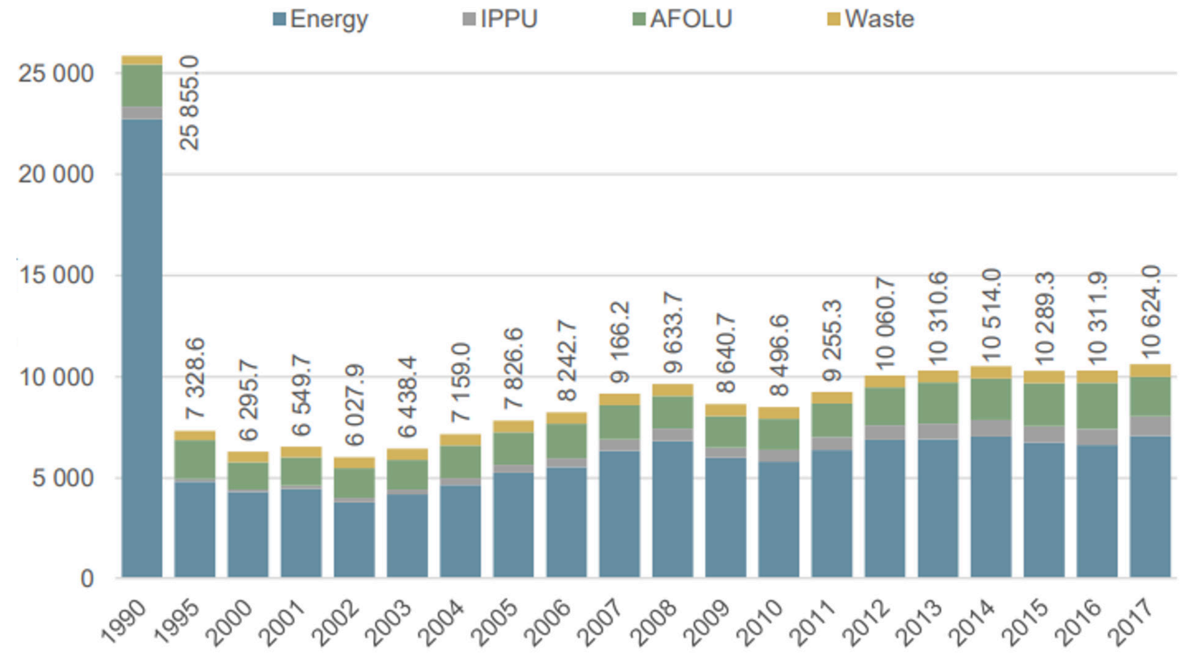
Gazprom Armenia, like the Gazprom Group, has no approved any plans to use the gas transmission infrastructure to transport low-carbon hydrogen.

Greenhouse gas emissions

Greenhouse gas emissions in Armenia, according to the official data of the National Inventory, decreased continuously and sharply from about 25 MtCO2e per annum between 1990 and 2000 (as the economic downturn, as in most countries of the former USSR), after which they slowly and inconsistently grew to about 10 MtCO2e per annum by 2017 (including CO_2 emissions of about 5 MtCO2e per annum and CH_4 emissions of about 4 MtCO2e per annum) (see Figure 32). Almost all the increase is due to energy-related emissions, both direct fuel combustion and methane leaks, as its use in the economy grows.

FIGURE 32

Greenhouse gas emissions in Armenia including LULUCF in 1990-2017 in GtCO₂e/year



Source: *UNFCCC National Emission Inventory*

Existing forecasts and long-term energy policy goals

The Strategic Program for the Development of the Armenian Energy Sector until 2040 was published in January 2021. It stated the benchmarks for the solar energy deployment - about 1000 MW by 2030 (including utility-scale and distributed ones), about 15% growth in the solar share in electricity generation. In addition, the document focuses on increasing energy efficiency, strengthening electricity interconnectors with neighboring countries and extending the nuclear power plant lifetime. It also mentions the possibility of 500 MW wind farms deployment by 2040.

Armenia's Nationally Determined Contribution to reducing greenhouse gas emissions within the framework of the country's participation in the Paris Agreement assumes doubling the renewables share in the energy sector "on the way to achieving climate neutrality by the middle of the century." The goal is 40% reduction of emissions by 2030 from the 1990 level.

In the long-term forecasts for the development of the energy sector issued by international agencies, incl. IEA, BNEF, Rystad, etc., Armenia is considered as a part of the Caspian region. Unfortunately, this country is not singled out in the published forecasts.

A3.1 Belarus

The Republic of Belarus (Belarus) is located in Eastern Europe, is landlocked and borders Poland to the west, Lithuania and Latvia to the northwest, Russia to the east and north, and Ukraine to the south. The population of Belarus is 9.4 million people, its area is about 208 thousand km^2; Minsk is the capital and the largest city (more than 20% of the country's population).

Key facts

Belarus is an energy-deficient country: according to the IEA, its own energy production account for about 15% of the country's demand. According to the National Statistical Committee (Belstat), the ratio of the primary energy production (extraction) to energy resources gross consumption (energy self-sufficiency) in 2019 was 16.5%, in 2020 - 17.1%. Belarus is one of the least energy-sufficient countries in the world. The natural gas and oil share in energy supply in 2019 was about 90%. Belarus is the largest importer of natural gas among all countries covered by this study.

Until the end of 2020, Belarus' own energy production was represented by fossil fuels extraction - peat and small amount of oil and gas (about 4.2 Mtoe in total). After commissioning of the new Belarusian nuclear power plant (planned in 2022), the country's own energy production may increase by about 37%.

The share of biofuels and waste in energy supply was 7% in 2019.

Key documents and regulators

The Ministry of Energy is responsible for the implementation of energy policy in Belarus (except for the oil sector, which is de facto controlled by the Belneftekhim concern, which is not subordinate to the Ministry of Energy but reports directly to the Council of Ministers). The drafting of key energy policy issues is in Council of Ministers responsibility. The Department for Energy Efficiency of the State Committee for Standardization is responsible for the implementation of the state policy in the field of energy efficiency and renewable energy. The Ministry of Natural Resources and Environmental Protection is responsible for environmental policy, including in the energy sector, and coordinates Belarus' participation in the UNFCCC. In 2016, Belarus signed and ratified the Paris Agreement.

The energy sector of Belarus includes state-owned companies and companies with state participation. Scientific support in this sector development is provided by the Energy Institute, other institutes of the National Academy of Sciences and the research institute BelTEI.

According to preliminary information, Belarusian long-term energy strategy as of June 2022 is drafting and has not been published. In 2015, the Energy Security Concept was approved with target indicators until 2035, but over the past 7 years since its adoption, the regulator has never made changes to it.

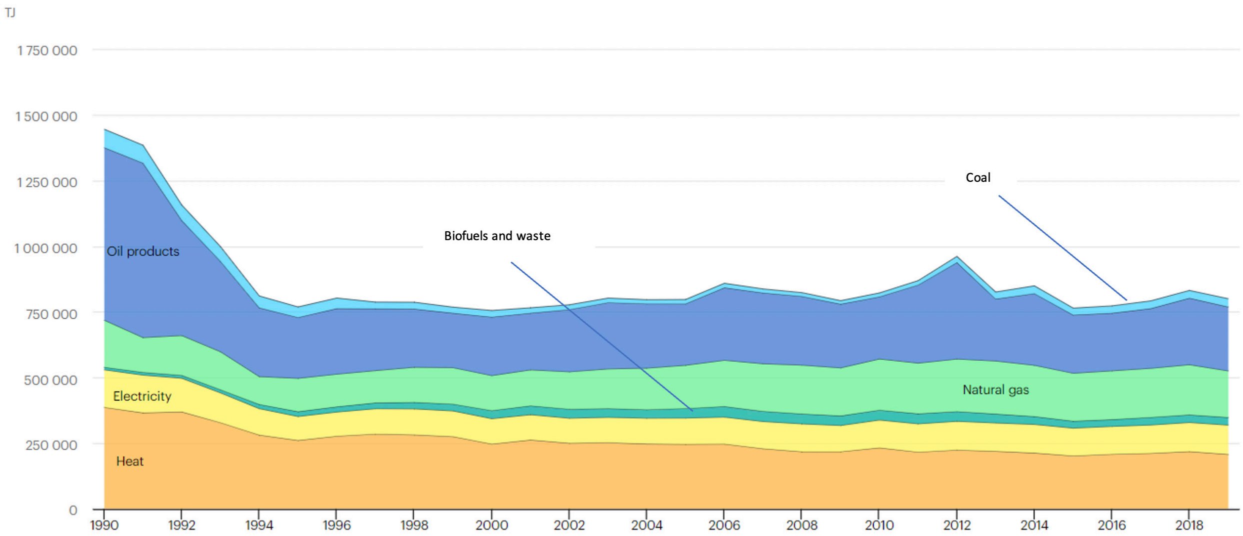
Strategic state documents in the field of hydrogen have not yet been published.

Balance of energy supply and demand

According to the IEA, the total final energy consumption in Belarus is provided by about 30% from oil products, 25% from heat, 20% from natural gas, 15% from electricity (see Figure 33). The share of other sources (including coal, biofuels and waste) is insignificant. According to the same data, natural gas is mainly used in the residential sector and for non-energy purposes (according to other data - in the manufacturing industry), oil products - in the transport sector. For the period 2000-2019, energy demand has not changed much.

FIGURE 33

Total final energy consumption in Belarus in 1990-2019 by source

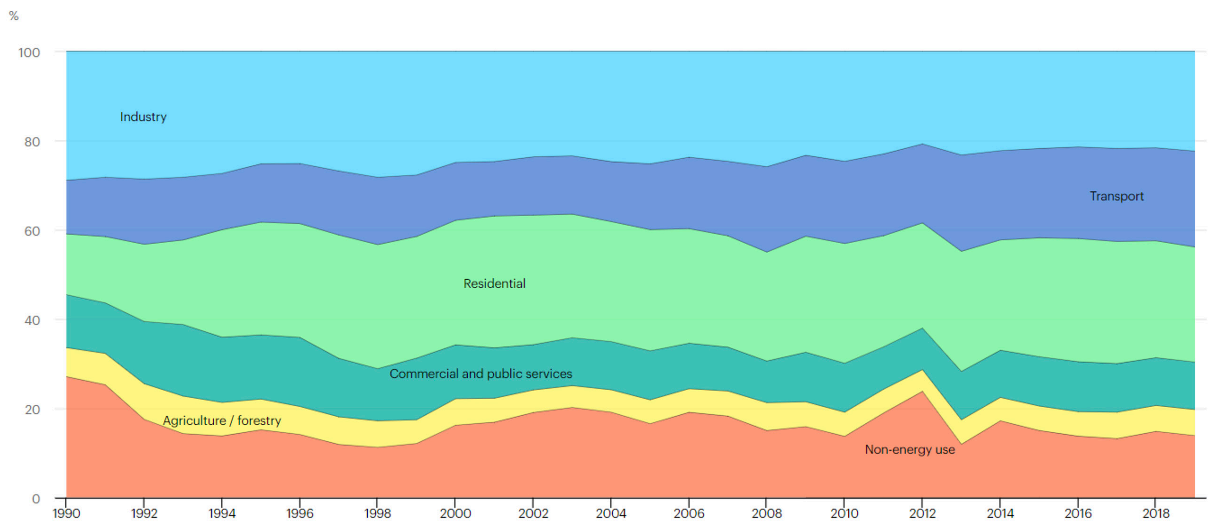


Source: *IEA World Energy Statistics*

Approximately 20% of total final energy consumption is in the residential, transport and industrial sectors. (Figure 34). According to Belstat, in 2020, industry accounted for 33.3% of the final energy resources consumption, 21.4% for transport, and 28.3% for the housing sector.

FIGURE 34

Total final energy consumption in Belarus in 1990-2019 by sector

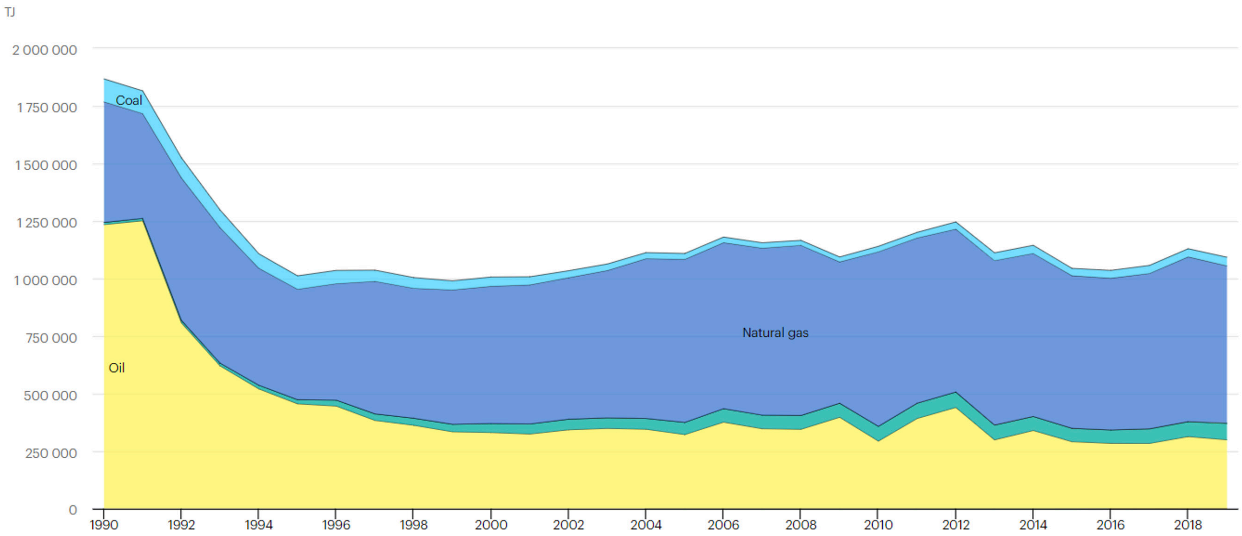


Source: *IEA World Energy Statistics*

Since 2010, the energy supply has practically not changed either in terms of the amount or the structure of sources - natural gas dominates (about 60%) (Figure 35).

FIGURE 35

Energy supply in Belarus in 1990-2019 by sourcer



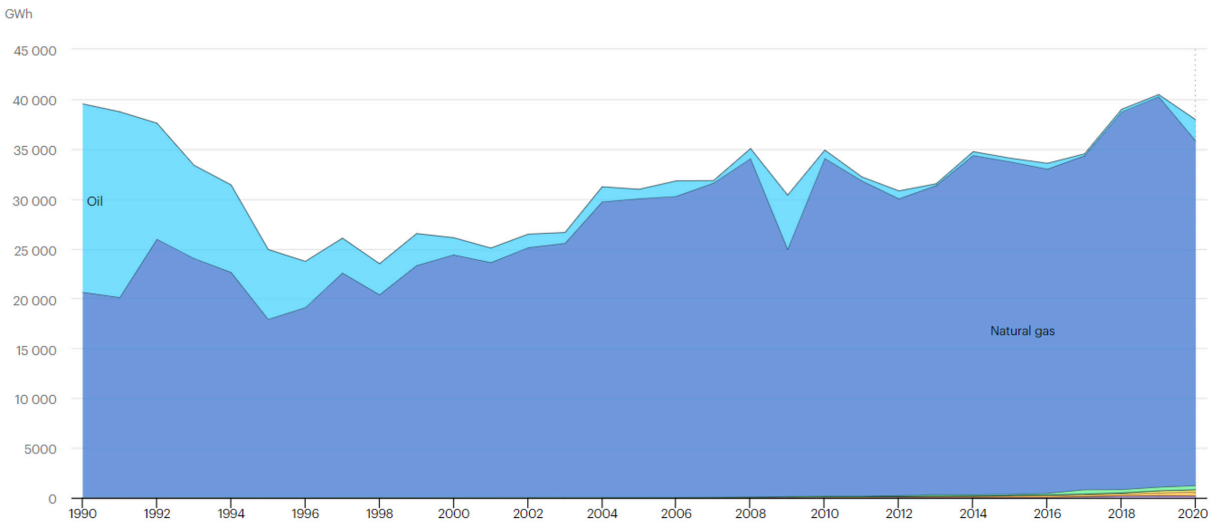
Source: *IEA World Energy Statistics*

The main source of natural gas and oil supply in Belarus is export from Russia. According to the IEA and Belstat, in 2020 Belarus processed an average of 320-360 barrels per day of oil - in terms of oil refining, the country is in second place among the countries covered by this study.

In the power sector of Belarus, natural gas was the only major and dominant energy source during 2000-2020. From 2021-2022, the situation will change due to the Belarusian NPP commissioning. (Figure 36)

FIGURE 36

Electricity generation in Belarus by source in 1990-2020



Source: *IEA World Energy Statistics*

Gas transportation infrastructure

The gas transportation infrastructure includes transmission and distribution gas pipelines with a total length of more than 7.9 thousand km. The main Yamal-Europe gas pipeline passes through Belarus, was built to import Russian gas by the EU countries. The entire gas transmission and distribution infrastructure is managed by Gazprom Transgaz Belarus, a 100% subsidiary of Russia's Gazprom.

The Belarusian NPP is located approximately 125 km from the main gas pipeline route.

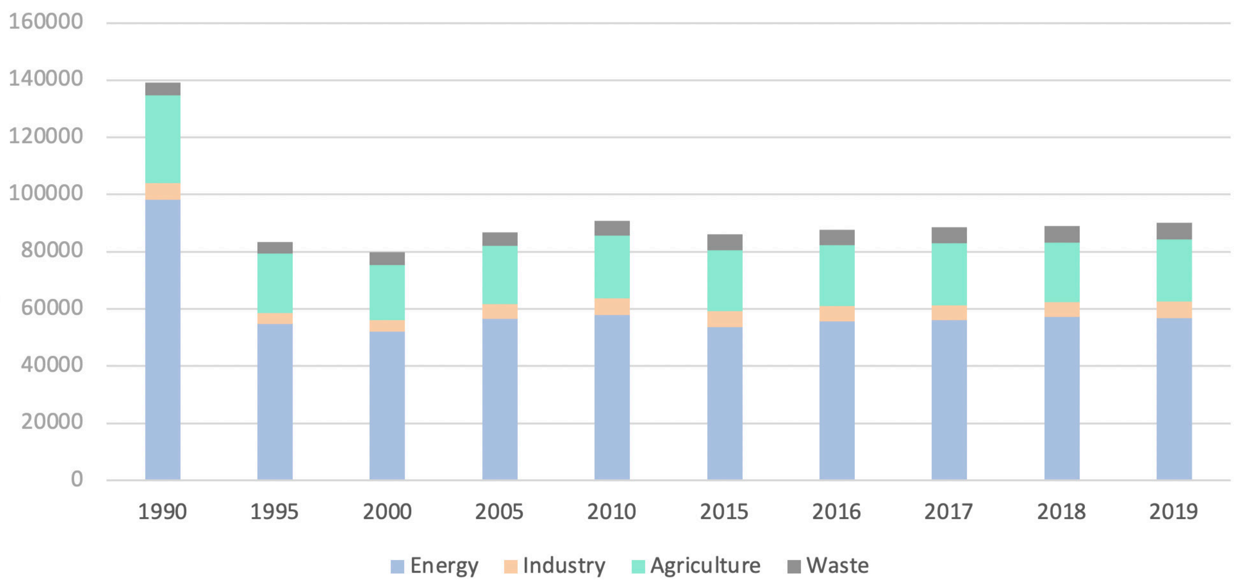
Gazprom Transgaz Belarus, like the Gazprom Group, has no any approved plans to use the gas transmission infrastructure to transport low-carbon hydrogen.

Greenhouse gas emissions

Greenhouse gas emissions in Belarus, according to the official data of the National Inventory, continuously decreased from about 140 $MtCO_2e$ per annum between 1990 and 2000 (during the economic recession and the increase in gas share in the fossil fuels used mix, as in most countries of the former USSR), after which they slowly and intermittently grew to about 85 $MtCO_2e$ per annum by 2019 (see Figure 37).

FIGURE 37

Greenhouse gas emissions in Belarus excluding LULUCF in 1990-2019 in Gt CO_2e/year



Source: *UNFCCC National Emission Inventory*

The share of CO_2 in 2019 accounted for 68% of emissions in all sectors, the share of the energy-related emissions - about 63%. Methane emissions and emissions from agriculture also play an important role.

Existing forecasts and long-term energy policy goals

The long-term energy strategy of Belarus is drafting, so it is not possible to use long-term goals in the analysis.

The long-term energy security concept Belarus (2015) provides guidelines for some indicators of the energy sector development:

- diversification of energy imports (reducing the share of the dominant supplier, i.e. Russia, between 90% in 2015 to 60% in 2035);
- energy diversification (reducing the share of natural gas in energy consumption from 60% to 50% and in electricity generation from 90% to less than 50% during the same period);

- a sharp increase in the nuclear power in electricity generation - from 0% to 41% during the same period;
- increase in the renewables share in electricity generation - from 0.7% to 6.1%.

Belarus's Nationally Determined Contribution to reducing greenhouse gas emissions within the framework of country's participation in the Paris Agreement assumes doubling the share of renewables in the energy sector "on the way to achieving climate neutrality by the middle of the century" and 35% emissions reduction by 2030, including LULUCF, and up to 40%, subject to access to international financing of the best available technologies (from the 1990 level).

In long-term forecasts of the energy sector development issued by international agencies, incl. IEA, BNEF, Rystad, etc. Belarus is considered as a part of Eastern Europe. Unfortunately, the country is not singled out in the published forecasts.

A4.1 Kazakhstan

The Republic of Kazakhstan (Kazakhstan) is located in the northern part of Central Asia and is bordered by Russia to the north, China to the east, Kyrgyzstan and Uzbekistan to the south, and the Caspian Sea and Turkmenistan to the west. It has a population of 18.7 million and an area of about 2.7 million km^2 (the largest country included in the scope of this study); Astana is the capital and the largest city (about 1 million people).

Key facts

Kazakhstan is an energy surplus country: according to the International Energy Agency (IEA), in 2017, with a total energy production of 179 million toe, total final consumption was approximately 40.7 Mtoe and energy exports were 103.4 Mtoe (the largest producer and exporter of energy resources among the countries covered by this study).

The backbone of the energy sector is oil, coal, and gas, which Kazakhstan both produces and exports. The oil and gas sector share in the country's GDP is 17% (2020). Oil and gas production increased 2.5-4 times between 2000 and 2015, after which growth slowed down. The power sector is based on coal-fired thermal power plants - their share in electricity generation in 2019 reached 70%, the share of gas-fired thermal power plants was almost 20%, and the remaining 10% came from large hydropower plants and the emerging renewables.

Key documents and regulators

According to Kazakhstan's constitution, strategic decisions in the field of domestic and foreign policy are made by the president, and the senate has the right to formulate economy policy aspects. The energy sector of Kazakhstan is regulated by the Ministry of Energy. Industrial development (including in the coal industry) is supervised by the Ministry of Industry and Infrastructure Development. The Ministry of Ecology, Geology and Natural Resources is responsible for environmental protection, green economy, waste management, and the Ministry of National Economy is responsible for strategic planning.

In 2016 Kazakhstan signed and ratified the Paris Agreement, and in 2020 President Tokayev publicly called for carbon neutrality by 2060.

In September 2021, the "Doctrine (strategy) for achieving carbon neutrality of the Republic of Kazakhstan until 2060" was approved. In March 2022, the Ministry of Energy approved the "Energy Balance of the Republic of Kazakhstan until 2035", which is focused on electricity sector. As a follow-up to this document, by October 2022 it is planned to develop a "Concept for the development of the power sector until 2035 with the possibility of covering the period up to 2060". In July 2022, the government approved the Comprehensive Plan for Gas Industry Development in Republic of Kazakhstan for 2022-2026, within which the main goal was to develop a competitive gas market through deregulation and attract independent gas producers.

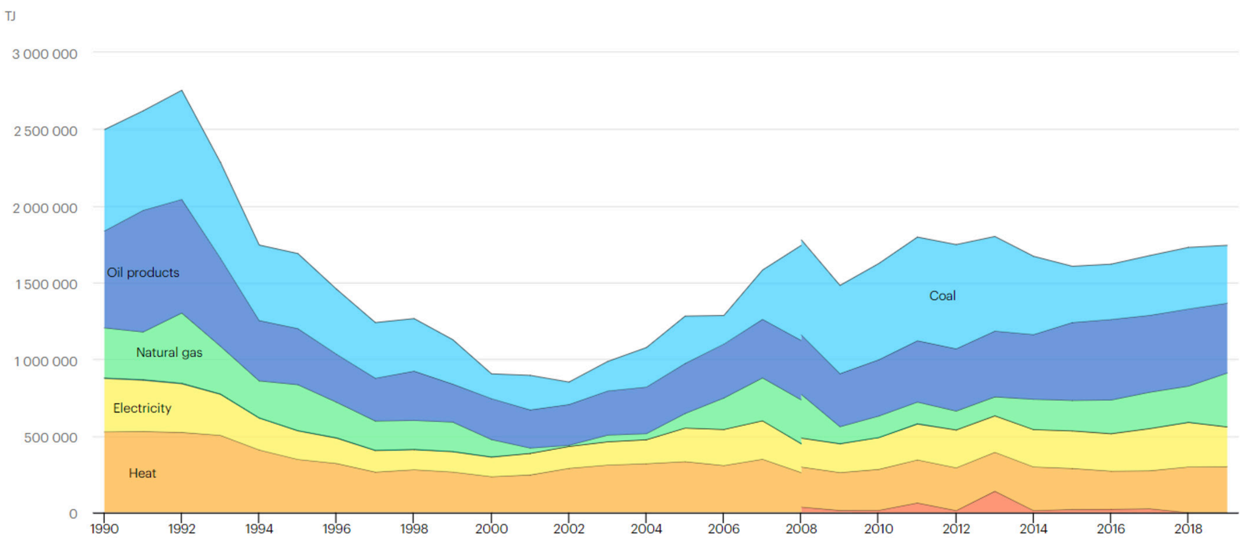
As of June 2022, the hydrogen strategy document is drafting, the planned date for its approval has not been published.

Balance of energy supply and demand

The total final energy consumption in Kazakhstan is almost equally provided by coal, oil products, natural gas, electricity and heat (see Figure 38). Coal is mainly used directly in the residential sector and in industry, oil products are mainly used in transport, and natural gas is used in the residential sector.

FIGURE 38

Total final energy consumption in Kazakhstan in 1990-2019 by source

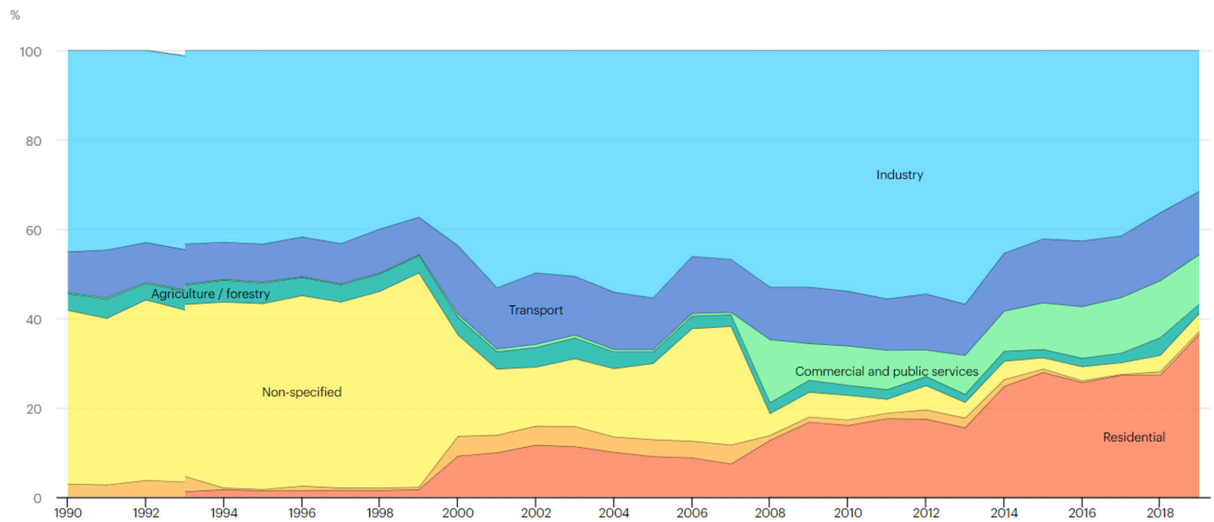


Source: *IEA World Energy Statistics*

Approximately 35% of total final energy consumption is in the residential and industrial sectors, transport accounts for about 15% (Figure 39).

FIGURE 39

Total final energy consumption in Kazakhstan in 1990-2019 by sector

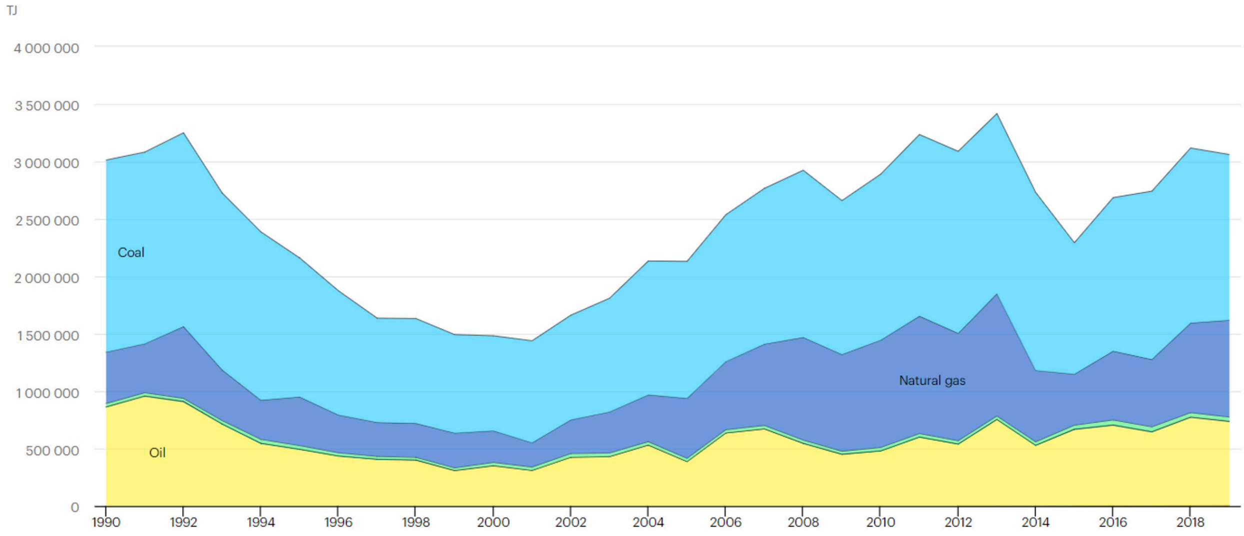


Source: *IEA World Energy Statistics*

From 2000 to 2013, energy supply nearly doubled, driven primarily by oil and gas. After the economic recession (2015-2016), deliveries began to grow again and almost reached the level of 2013 (Figure 40).

FIGURE 40

Energy supply in Kazakhstan in 1990-2019 by source



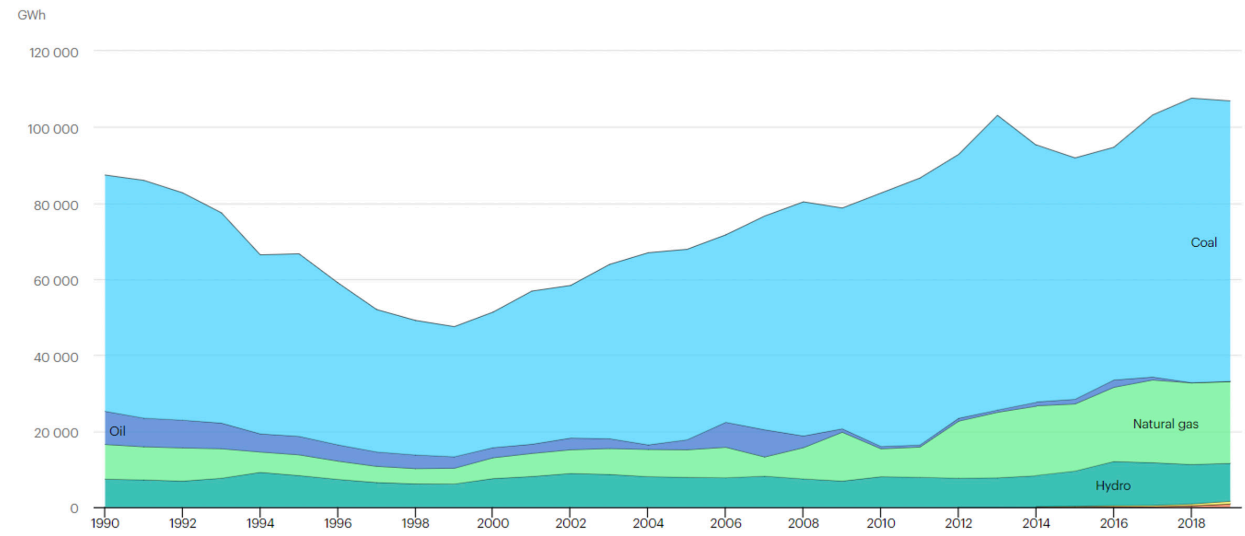
Source: *IEA World Energy Statistics*

According to BP (2021), Kazakhstan in 2020 produced 2.1% of the world's oil (86.1 Mt), ranking 14th in the world and first among the countries covered by this study. The country's share in the world natural gas production was 0.8% (31.7 bcm) - the 22nd place in the world and the third place among the countries covered by this study. In 2020, 113.2 Mt of coal was produced (1.5% of world production, 8th place in the world and first place among countries covered by this study).

Coal is dominating fuel in the power sector of Kazakhstan, although the natural gas share has doubled to 20% over the past 10 years. (Figure 41). Renewables share (excluding hydropower) is still insignificant - the growth in this sector began in 2016.

FIGURE 41

Electricity generation in Kazakhstan by source in 1990-2020



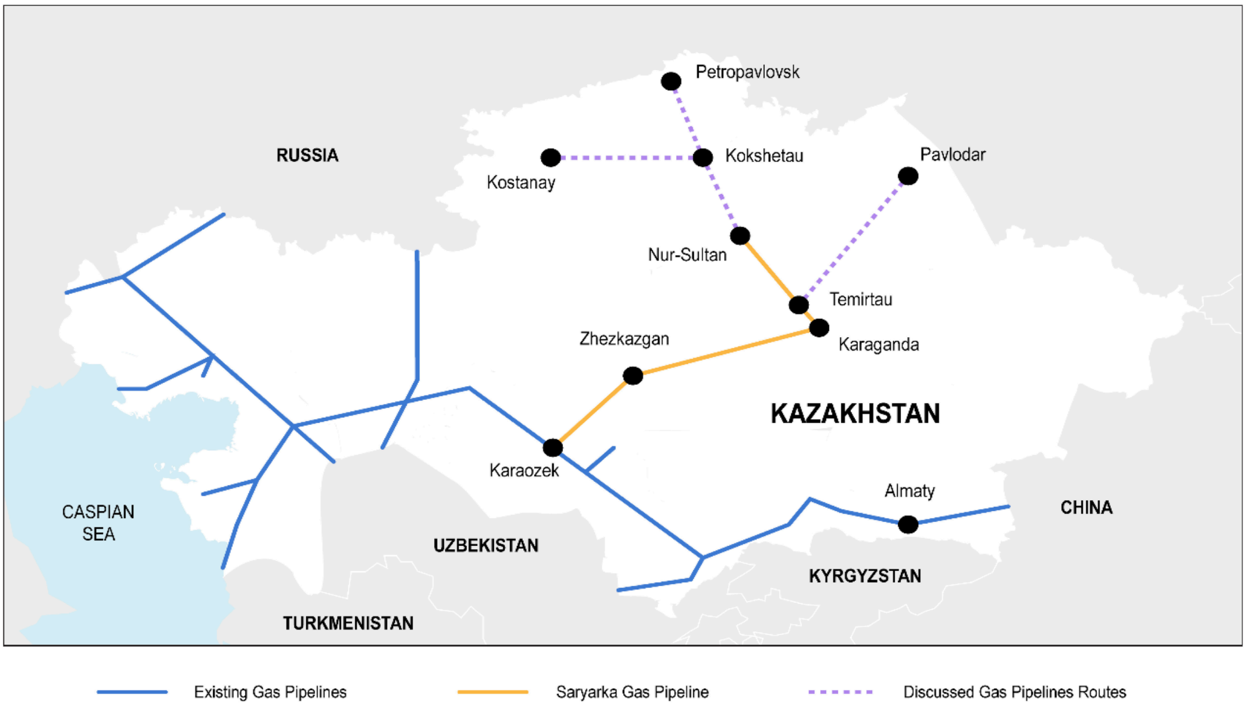
Source: *IEA World Energy Statistics*

Gas transportation infrastructure

The gas transportation infrastructure of Kazakhstan is used, among other things, to transport gas from Uzbekistan and Turkmenistan to Russia and China. (Figure 42).

FIGURE 42

Layout of gas transportation infrastructure in Kazakhstan



Source: *IEA, Aiymgul Kerimray*

Domestic gas demand is growing rapidly: over the past 10 years it has grown by 90%, and the share of households connected to the centralized gas supply has increased from 30% in 2013 to 55% in 2021. The western and northeastern parts of the country receive gas from local suppliers. The southern part of Kazakhstan (Turkestan, Shymkent, Almaty, Zhambyl, Kyzylorda regions) used to receive gas only from Uzbekistan, but since 2019 they have been connected by a gas pipeline to gas producing regions in the west of Kazakhstan. The eastern and northern regions of the country are still less connected to the gas infrastructure but introducing of new gas pipelines is aimed at solving this problem.

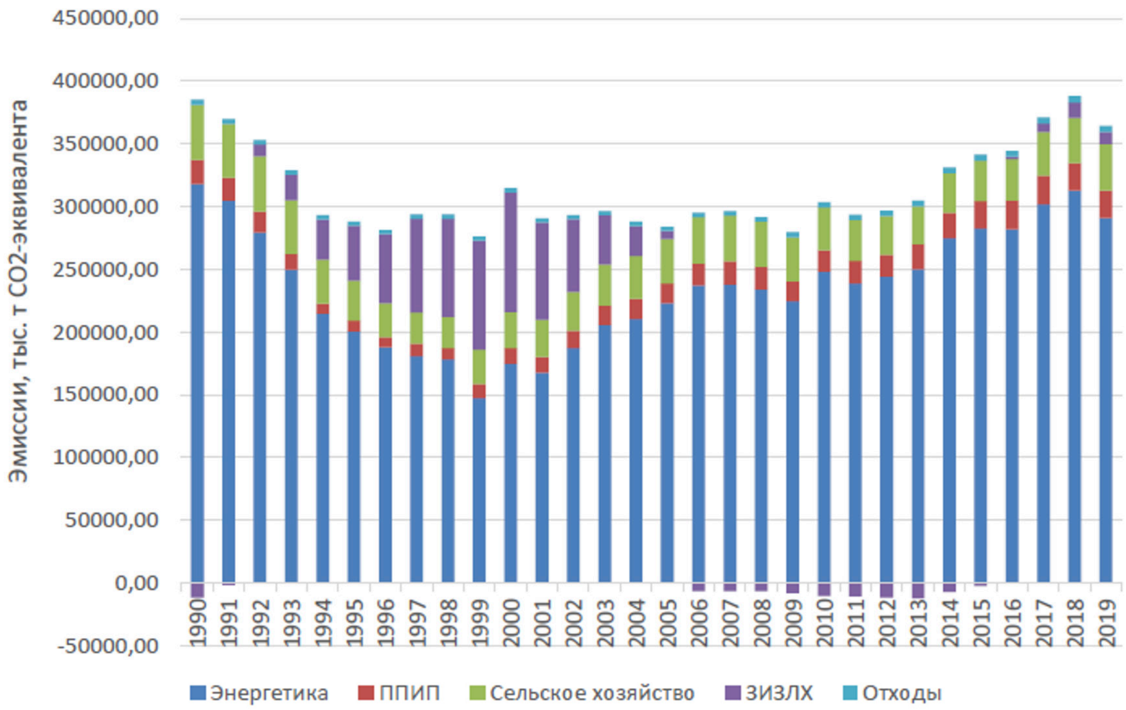
The gas transmission and distribution infrastructure are managed by QazaqGas. In July 2022, with the participation of this company, an agreement was signed to create the Green Hydrogen Alliance. In the public domain, there is no data yet on QazaqGas' plans regarding the use of gas transmission infrastructure for low-carbon hydrogen transportation, this issue will require further study - both in relation to gas consumers within Kazakhstan and in relation to export-oriented gas pipelines to Russia and China.

Greenhouse gas emissions

Greenhouse gas emissions in Kazakhstan (excluding LULUCF), according to the official data of the National Inventory, decreased continuously from about 400 $MtCO_2e$ per annum between 1990 and 2000 (as the economic downturn, as in most countries of the former USSR), after which it slowly and increased intermittently to around 370 $MtCO_2e$ per annum by 2019 (see Figure 43).

FIGURE 43

Greenhouse gas emissions in Kazakhstan in 1990-2019, thousand tons of CO_2e/year



Source: *UNFCCC National Emission Inventory*

Energy-related emissions account for more than 85%. An important source of emissions in this segment is coal combustion for electricity and heat generation.

Since 2013, a greenhouse gas emissions trading system has been operating in the country - Kazakhstan was the first country in Central Asia to launch such a system. By 2021, the emissions trading system regulated about 40% of domestic CO_2 emissions in Kazakhstan from 225 large enterprises covering power sector, district heating, mining and processing industries, each of which emit over 20,000 tons of CO_2 annually.

Existing forecasts and long-term energy policy goals

The most important energy policy goal that will affect the potential and prospects of hydrogen in Kazakhstan is intention to achieve carbon neutrality by 2060, adopted in the Carbon Neutrality Doctrine in September 2021.

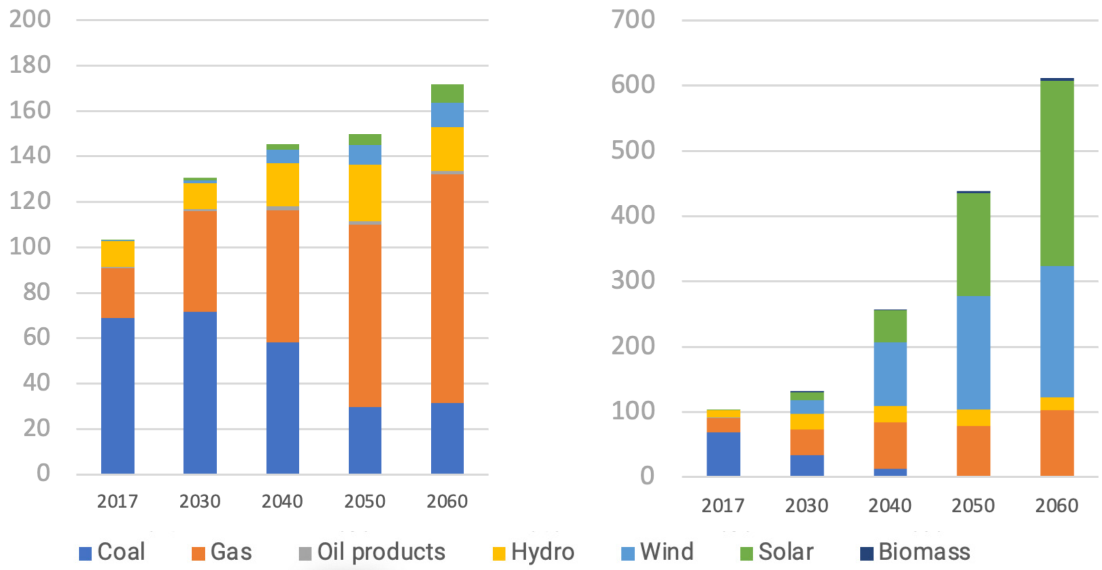
The Energy Balance of the Republic of Kazakhstan until 2035, approved in March 2022, has not been published as of June 2022. According to the press service of the Ministry of Energy, it contains the following information:

- forecast values of electricity generation and demand (demand of 153 TWh by 2035),
- new power generating capacity to be built (about 10 GW by 2035, including 6.5 GW of renewables and 2.4 GW of nuclear power),
- it is planned to introduce requirements for combine renewables with energy storage systems;
- building of new coal power plants will be limited.

The Doctrine of Achieving Carbon Neutrality provides forecast data on the electricity generation mix by 2060 (Figure 44)

FIGURE 44

Electricity generation in Kazakhstan by source according to the Doctrine of achieving carbon neutrality, TWh/year (on the left - the Baseline scenario, on the right - the Carbon neutrality scenario)



In the Baseline scenario, renewable electricity generation (including hydropower) is projected to grow by 2.2 times (by 15.6 TWh) during 2017-2040, and in the Carbon neutrality scenario, by almost 15 times (by 161 TWh).

In contrast with Energy Balance 2035, Doctrine of Achieving Carbon Neutrality does not consider any nuclear power. At the same time, the target electricity generation in 2035 at the level of about 135 TWh is the same in both scenarios of the Doctrine and in the Energy Balance 2035.

IHS Markit in the forecast made for Kazenergy (2021) shows estimates close to the Baseline scenario of the Doctrine: the total renewable electricity share of 15% by 2030, 18% by 2040 and 20% by 2050. Intermittency of renewable generation and high cost of electricity storage systems are among barriers for renewable energy development mentioned in this report.

According to Nexant World Gas Model, during 2020-2040 gas production in Kazakhstan will grow to 50 bcm per annum. Natural gas demand, in contrast, will be almost constant (which means growing opportunities for hydrogen production from natural gas). IHS Markit, on the contrary, proceeds from a gradual increase in gas imports to Kazakhstan from Russia and Central Asian countries until Kazakhstan becomes a net gas importer. This will largely depend on the pace of petrochemistry development and switching from coal to gas in the power sector and by industrial enterprises.

Kazakhstan's Nationally Determined Contribution to reducing greenhouse gas emissions within the framework of the country's participation in the Paris Agreement assumes a 15-25% reduction by 2030 compared to the 1990 base level.

A5.1 Kyrgyzstan

The Kyrgyz Republic (Kyrgyzstan) is located in Central Asia and borders Kazakhstan in the north, Tajikistan in the south, China in the east and Uzbekistan in the west. The population of Kyrgyzstan is 6.5 million people, and its area is about 200 thousand km^2; Bishkek is the capital and the largest city (17% of the country's population).

Key facts

Kyrgyzstan is an energy-deficient country: according to the International Energy Agency (IEA), in 2017, with a total energy production of 2.1 Mtoe total final energy consumption was about 3.5 Mtoe and net energy import was 1.9 Mtoe.

The energy sector plays a relatively small role in the national economy - about 4% of GDP - compared to agriculture. Energy sector features are vast hydropower resources and significant coal reserves. Kyrgyzstan generates electricity almost entirely from hydropower (one of the highest share in the world), but imports of oil products and gas (from Russia and Kazakhstan) are of great importance, especially during winter, when hydropower generation is reduced.

Historically, energy and water supply not only in Kyrgyzstan, but also in neighboring states (Uzbekistan, Tajikistan, Kazakhstan) depended on the operating modes of large hydropower plants and filling of water reservoirs, which were determined by difficult-to-predict river flows. After getting independence of these countries in the early 1990s, mutual interests coordination in these areas became more difficult. Today, both progressive aging of infrastructure and climate change, which leads to changes in river flows, create an additional challenge. Overcoming this difficult situation is one of the important tasks that all these countries must solve.

The main priority of Kyrgyzstan's energy policy in recent years has been energy security through local energy resources development (thus, coal mining has increased dramatically), modernization of existing energy facilities and the strengthening of power interconnections with neighboring countries.

Key documents and regulators

The State Committee for Industry, Energy and Subsoil Use of Kyrgyzstan is responsible for the development and implementation of state policy in the entire energy sector, including water, energy and fuel resources and the country’s industrial potential. In 2016, the National Energy Holding was created - a company that manages state shares in energy companies.

The Ministry of Natural Resources, Ecology and Technical Supervision is responsible for environmental protection and the implementation of climate projects. The State Committee for Ecology and Climate oversees the assessment of greenhouse gas emissions and drafting of relevant reporting documents. Kyrgyzstan has a Coordinating Council on Climate Change, Ecology and the Development of a Green Economy, chaired by the Prime Minister, which coordinates the country's participation in the UNFCCC (the republic joined the Paris Agreement in November 2019). In October 2021, the Updated Nationally Determined Contribution of the Kyrgyz Republic was approved, drafted with the support of UNDP and several international organizations.

Key current long-term documents determining the energy sector development are the National Development Strategy for 2018-2040, the National Development Program until 2026 (approved in October 2021), the National Energy Program for 2008-2010 and the Fuel-energy Sector Development Strategy until 2025 (NEP).

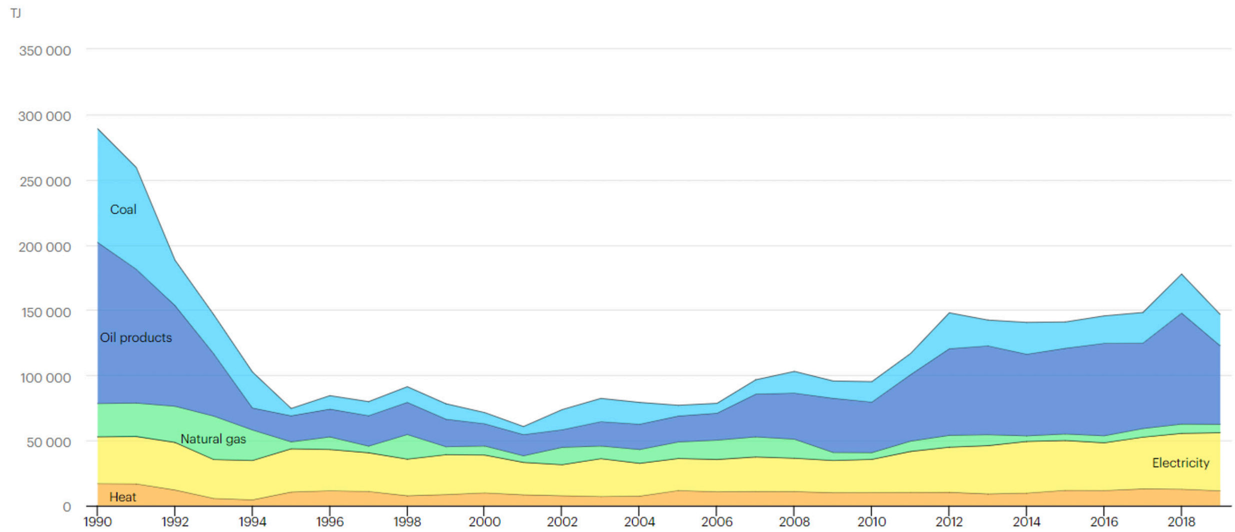
A strategic document in the field of hydrogen has not been drafted as of June 2022.

Balance of energy supply and demand

The total final energy consumption in Kyrgyzstan is primarily provided by oil products (40%) and electricity (30%) (see Figure 45). Petroleum products are used in the residential and transport sectors, coal is used in the residential sector.

FIGURE 45

Total final energy consumption in Kyrgyzstan in 1990-2019 by source

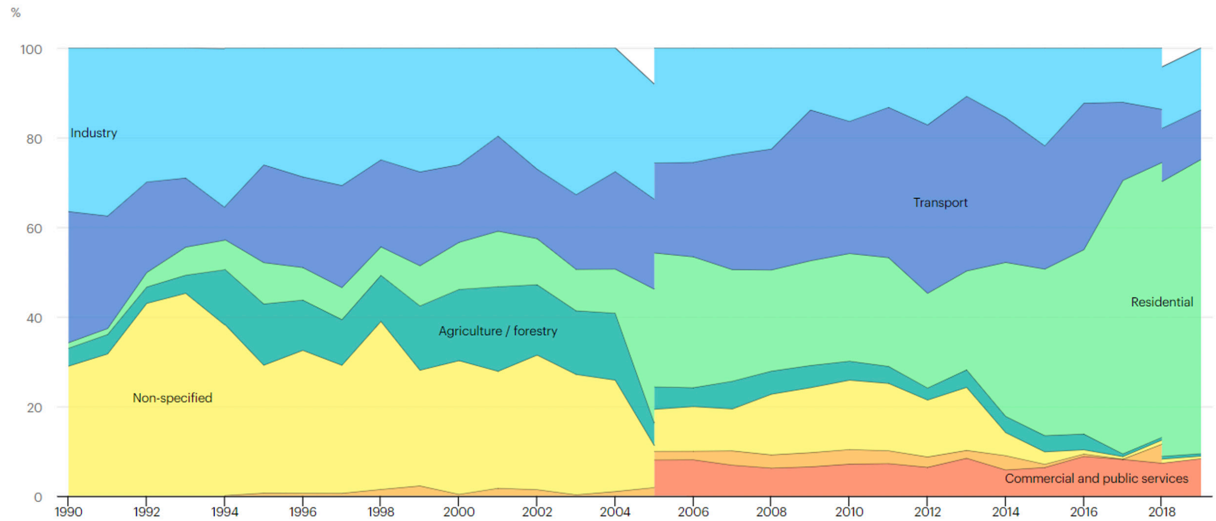


Source: *IEA World Energy Statistics*

The residential sector dominates in total final energy consumption - more than 60% (Figure 46).

FIGURE 46

Total final energy consumption in Kyrgyzstan in 1990-2019 by sector

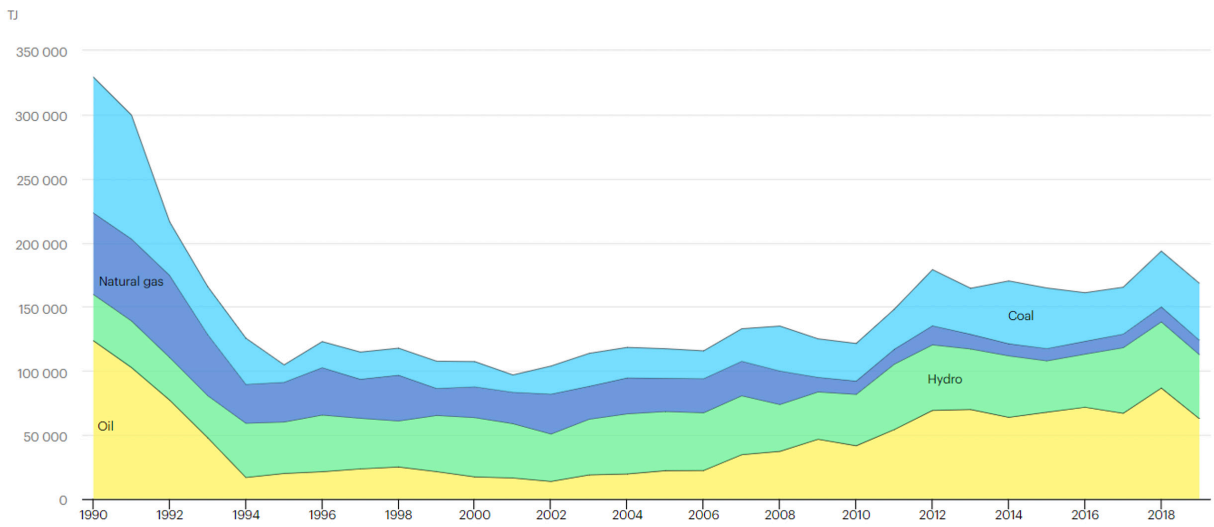


Source: *IEA World Energy Statistics*

From 2000 to 2018, the energy supply almost doubled, primarily due to oil products (Figure 47).

FIGURE 47

Energy supply in Kyrgyzstan in 1990-2019 by source



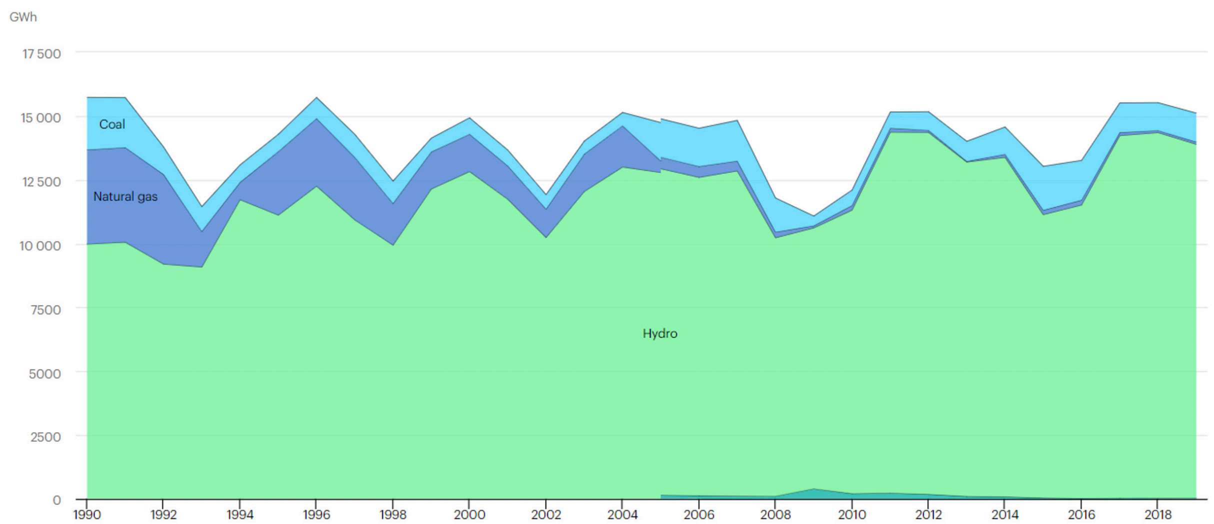
Source: *IEA World Energy Statistics*

Hydropower dominates Kyrgyzstan's power sector, with coal accounting for a constant share of just under 10% over the past 10 years (Figure 48). Fluctuations from year to year in electricity generation is explained by energy system dependence on hydropower plants and, accordingly, on rivers stream conditions, which objectively changes every year. The total electricity generation has hardly changed over the past 30 years, remaining within the range of 11-16 TWh/year.

At the same time, according to the IEA, over the past 10 years, electricity demand in Kyrgyzstan has been growing by an average of 5.8% every year, mainly due to households.

FIGURE 48

Electricity generation in Kyrgyzstan by source in 1990-2020



Source: *IEA World Energy Statistics*

Kyrgyzstan's energy sector dependence on rivers flow conditions creates energy supply problems during peaking energy demand - especially during winter, when household's electricity demand grows because of air temperature decrease (by turning on electric heating, lighting) and may exceed the energy system capacity (especially in a situation of increased infrastructure wear-out) – this is energy supply deficit situation. According to the Minister of Economy and Finance of Kyrgyzstan in October 2021[35], more than 80% of the energy sector in Kyrgyzstan have critical wear-out rate of no more than 30%, and the annual electricity shortage is about 6 TWh.

The imbalance between electricity production and demand can be reduced by increasing generation capacity, developing power interconnections with neighboring countries (for example, the Central Asia-South Asia power project, CASA -1000 is aimed at this), increasing energy efficiency, demand response (for example, by tariffs), developing seasonal energy storage systems (depending on possibilities - pumped storage power plants, battery storage, hydrogen-based storage systems).

In contrast, during the summer months, there may be a problem of excess electricity generation capacity due to increased river flows and declining electricity demand as ambient temperature increase. Reservoirs dampen this imbalance, but no-operation discharge of water can occur, including to regulate the water level in rivers after dams for water supply purposes. This issue requires additional study for the specific conditions of Kyrgyzstan.

Gas transportation infrastructure

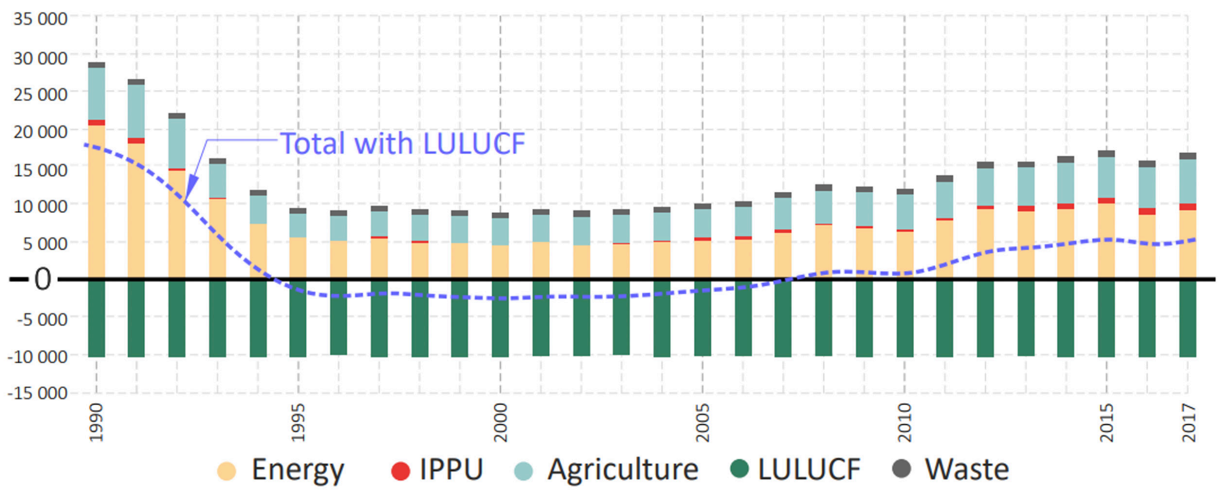
The gas transportation infrastructure ensures the import of natural gas to Kyrgyzstan (about 0.3 bcm per annum) from Uzbekistan and its transit to Kazakhstan via the Bukhara-Tashkent-Bishkek-Almaty gas pipeline. The infrastructure needs to be modernized (it's over 35 years old) and more efficient. It consists of almost 800 km of transmission gas pipelines and more than 3.4 thousand km of distribution (medium and low pressure) gas pipelines. The infrastructure is owned and operated by Gazprom Kyrgyzstan, a 100% subsidiary of Russia's Gazprom. Both companies do not plan to use the existing gas transmission infrastructure for hydrogen transportation. For Kyrgyzstan, this issue may not be so relevant, given system's wear-out.

Greenhouse gas emissions

According to the "Updated Nationally Determined Contribution of the Kyrgyz Republic" (October 2021), greenhouse gas emissions in the country were continuously decreasing from about 30 $MtCO_2e$ per annum between 1990 and 1995 (as the economic downturn, as in most countries of the former USSR), after which they remained constant for more than 10 years until they switched to growth.

FIGURE 49

Greenhouse gas emissions in Kyrgyzstan in 1990-2019, in thousand tons CO_2e/year



Source: *Updated NDC of the Kyrgyz Republic, October 2021. (IPPU stands for Industrial processes and product use)*

35 https://rus.azattyk.org/a/31503109.html

A feature of Kyrgyzstan is constant natural carbon sinks of 10 $MtCO_2e$ per annum, which significantly reduce the net emissions. During 1995-2007, net emissions were generally negative. (Figure 49). The key segments of emissions are energy (about 2/3 of all emissions in 2017) and agriculture.

Existing forecasts and long-term energy policy goals

Kyrgyzstan does not yet have long-term (until 2035 and beyond) strategic energy policy documents whose targets could be taken as a basis for assessing the hydrogen production prospects.

The existing short-term documents reflect such energy policy priorities as:

- reducing dependence on hydrocarbons;
- development of hydropower (including small-scale): both the modernization of existing capacities and the construction of new ones (including the Kambarata HPP-1, hydropower cascades of the Upper Naryn, the Suusamyr-Kokomeren and the Kazarman);
- development of electrical interconnections with neighboring countries (CASA 1000 project, etc.), including within the framework of the future EAEU united electricity market, export of excess electricity (including to East Asia);
- improving energy efficiency;
- transition of heating in cities to small coal-fired and gas-fired boilers;
- electric transport development.

There are practically no quantitative indicators in the documents.

The updated Nationally Determined Contribution of the Kyrgyz Republic (October 2021) contains a target of 16% GHG emissions reduction by 2025-2030 and – subject to international support – by 36% (2025) and 44% (2030). A list of measures for the energy sector decarbonization is included in this document with a focus on (more than 4 $MtCO_2$ per annum by 2030) coal-to gas transition in households, ICE-to-EV transition in transport, and energy efficiency increasing of house stoves and small boilers. In the field of renewables deployment (up to 1.4 MCO_2e per annum by 2030), biogas plants and expansion of existing hydropower plants are mentioned.

In the long-term forecasts for the development of the energy sector issued by international agencies, incl. IEA, BNEF, Rystad, etc. Kyrgyzstan is considered as a part of the Caspian region. Unfortunately, this country is not singled out in the published forecasts.

A6.1 Moldova

The Republic of Moldova (Moldova) is located in Eastern Europe, is landlocked and borders Romania to the west and Ukraine to the north, east and south. The population of Moldova is 2.6 million people, its area is about 33.8 thousand km^2; Chisinau is the capital and the largest city (more than 26% of the country's population).

Key facts

Moldova is an energy-deficient country. About 75% of the energy consumed in the country comes from imports: according to the IEA, in 2017, the production of primary energy resources amounted to 0.79 Mtoe, imports – 3.149 Mtoe. According to the National Bureau of Statistics of the Republic of Moldova, in 2020, the production of primary energy resources amounted to 0.689 Mtoe, imports – 2.214 Mtoe. (including supplies from Transnistria).

Domestic energy production in Moldova is represented mainly by bioenergy (solid fuels), hydropower and a small share of other renewable energy sources. Almost the entire amount of fossil fuel consumed is imported, as is most of the electricity consumed in the country. The key sector of total final energy consumption is households.

Key documents and regulators

The Ministry of Economy and Infrastructure is responsible for energy strategy and policy drafting and implementation. The Ministry of Agriculture, Regional Development and Environment is responsible for drafting of the environment and natural resource management strategy and policy. The Energy Efficiency Agency deals with national programs in the field of energy efficiency and renewable energy sources.

The Institute of Energy, subordinated to the Ministry of Education, Culture and Research, conducts research in the field of energy systems.

In 2013, the 2030 Energy Strategy was adopted. Moldova joined the Paris Agreement in 2017, and as part of the country's participation in the UNFCCC, the Low Carbon Development Strategy until 2030 was adopted.

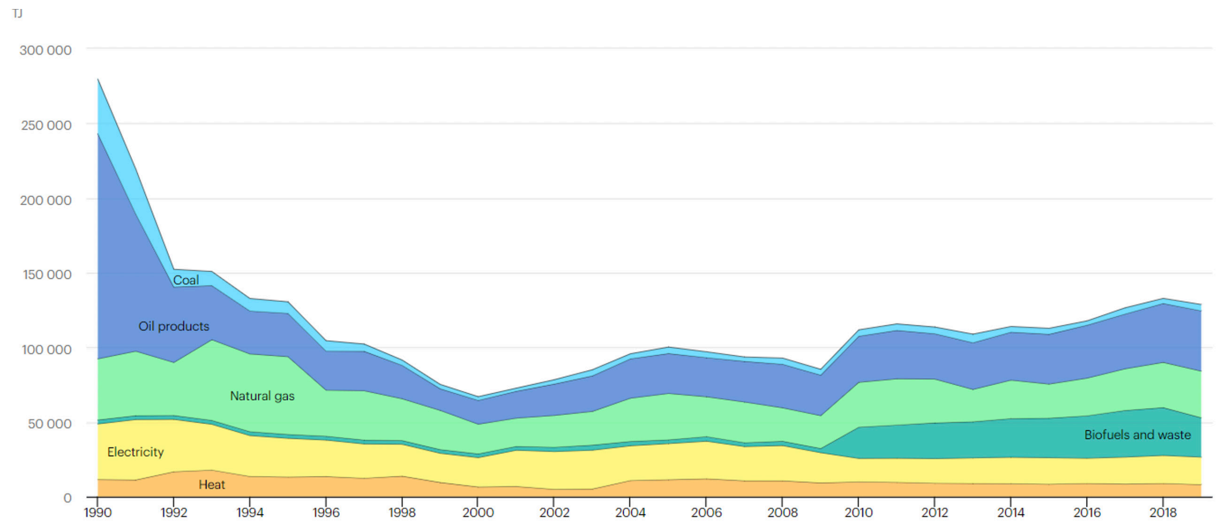
Strategic state documents in the field of hydrogen are not yet being drafted.

Balance of energy production and demand

The total final energy consumption in Moldova is mainly provided approximately equally by oil products, natural gas, biofuels and electricity (see Figure 50).

FIGURE 50

Total final energy consumption in Moldova in 1990-2019 by source

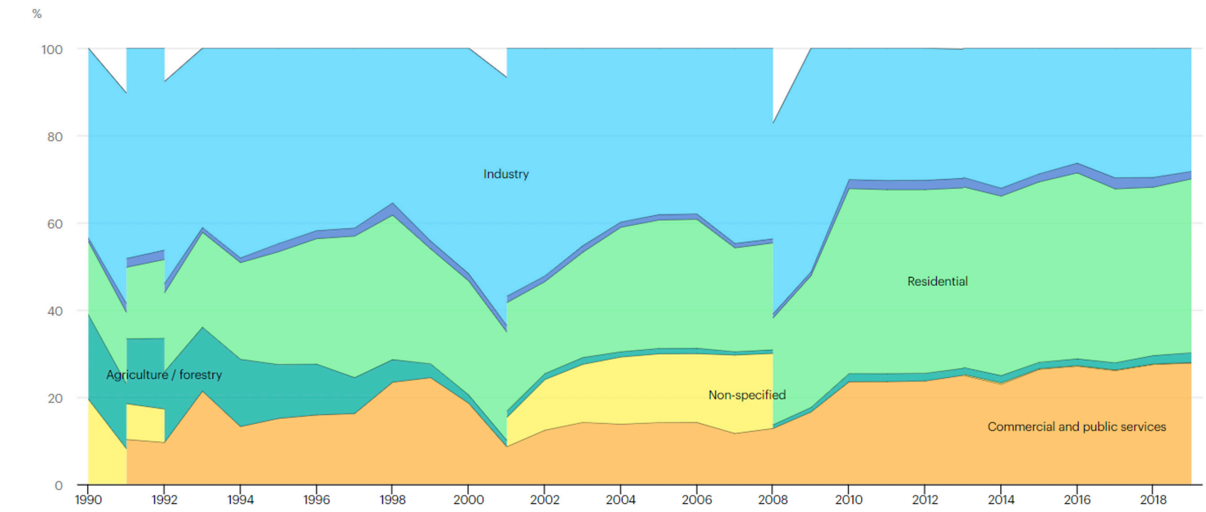


Source: *IEA World Energy Statistics*

Oil products are mainly used in transport, natural gas - in industry and the residential sector, and electricity - in industry, residential and commercial sectors. During the period 2010-2019, energy consumption increased by about 20%.Approximately 40% of total final energy consumption is in the residential sector, with another 25% each in industry and the commercial sector (Figure 51)

FIGURE 51

Total final energy consumption in Moldova in 1990-2019 by sector

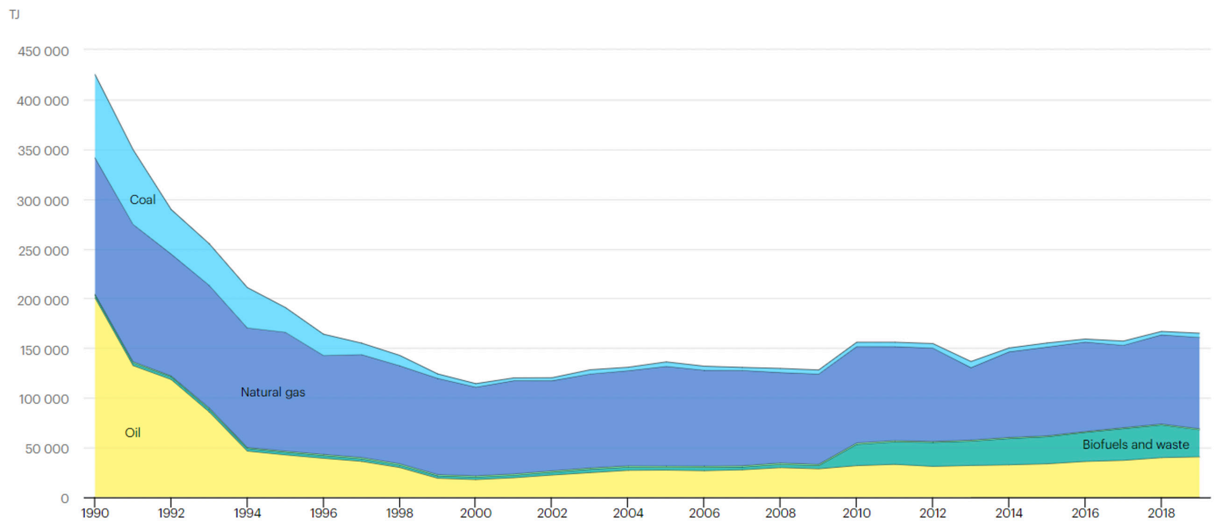


Source: *IEA World Energy Statistics*

Since 2010, energy supply has practically not changed either in terms of the amount or the structure of sources - natural gas dominates (more than 50%), biofuels and oil products occupy 20% each (Figure 52).

FIGURE 52

Energy supply in Moldova in 1990-2019 by source



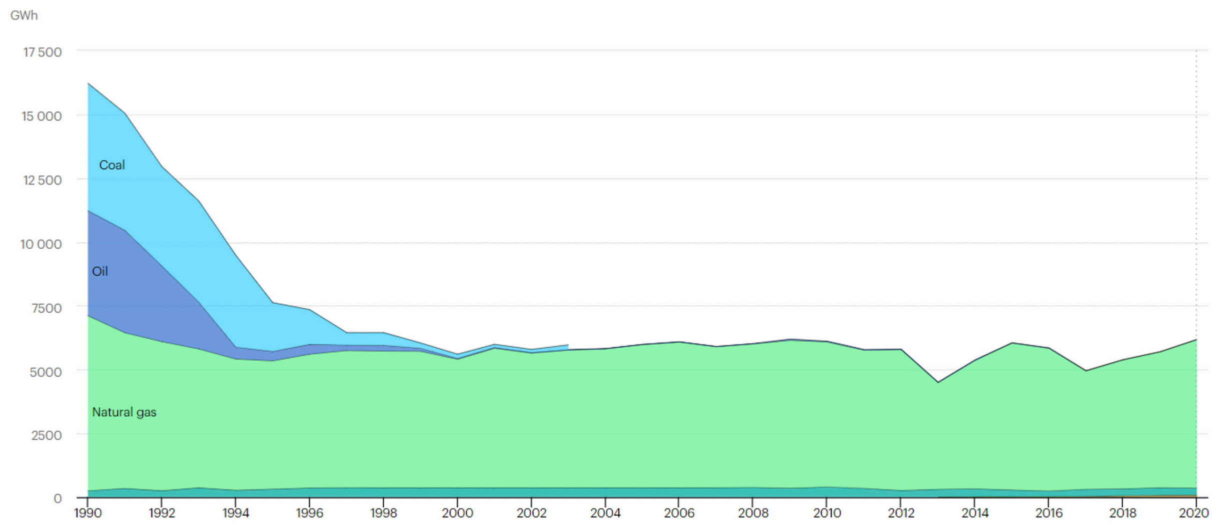
Source: *IEA World Energy Statistics*

The main source of natural gas supplies to Moldova is exports from Russia, although imports from Romania began at the end of 2021. Oil products are imported mainly from Romania (except for LPG, which is primarily supplied by Russia and Kazakhstan).

In power sector of Moldova, natural gas was the only major source during 2000-2020 (Figure 53), accompanied with practically constant amount of annual electricity generation.

FIGURE 53

Electricity generation in Moldova by source in 1990-2020



Source: *IEA World Energy Statistics*

Gas transportation infrastructure

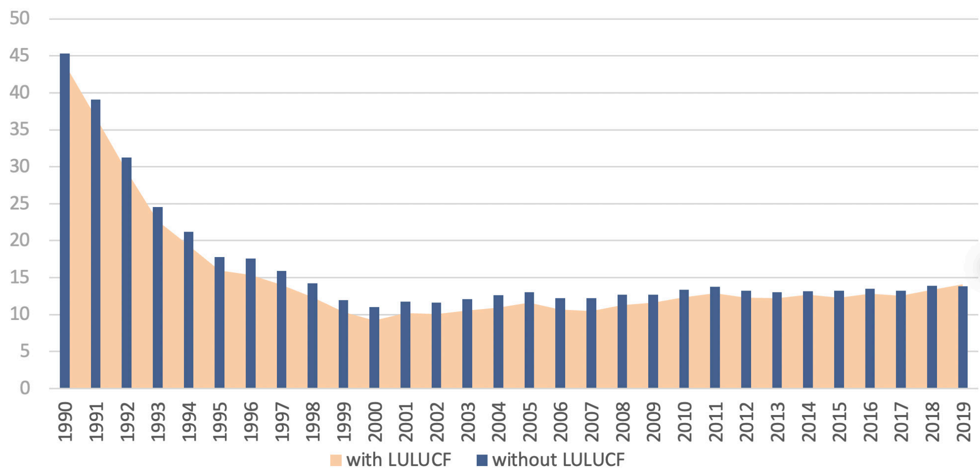
Natural gas is the second energy source in Moldova after oil products. The infrastructure is distributed between the right-bank part of the country and Transnistria with a large gas-fired power plant - Moldavskaya GRES – located in this territory. The infrastructure in Transnistria is not controlled by Moldovan companies and authorities. The gas transmission infrastructure in Moldova is mainly managed by Moldovagaz owned mainly by Russian Gazprom (50%) and the Moldovan government (35%). The infrastructure includes about 800 km of transmission gas pipelines, and the total length of gas pipelines reaches about 25,000 km. It provides access to natural gas throughout the country.

Greenhouse gas emissions

Greenhouse gas emissions in Moldova declined continuously from around 45 $MtCO_2e$ per year between 1990 and 2000 (during the economic downturn, as in most countries of the former Soviet Union), after which they slowly and intermittently increased to around 14 $MtCO_2e$ per year by 2019 (see Figure 54).

FIGURE 54

Greenhouse gas emissions in Moldova in 1990-2019 in $MtCO_2e$ per annum



Source: *Third Biennial Update Report of the Republic of Moldova: Developed to be reported to the UNFCCC (2021)*

CO_2 share accounted for 68% of emissions in all sectors, energy-related emissions share stands for 67.5% in 2019. Methane emissions (19%) and agriculture emissions 14%) also play an important role.

Existing forecasts and long-term energy policy goals

Moldovan energy strategy until 2030 was approved in 2013. It identified two priorities - strengthening the transit state status (in terms of electricity and gas flows) and strengthening domestic power generating capacity - and outlined several tasks for the energy sector:

- ensuring energy security;
- energy efficiency increase;
- increasing the renewables share in total final energy consumption and electricity generation;
- reduction of greenhouse gas emissions.

Quantitative targets for 2020 were partially achieved (except for strengthening gas and electricity interconnections, increasing power generation capacity and increasing the renewables share in electricity generation). This document does not contain quantitative goals for 2030.

The 2030 Low Carbon Development Strategy, adopted in 2016, contains targets for reducing greenhouse gas emissions by sectors (Table 12). Final target included into the first Nationally Determined Contribution (NDC) involves 64-67% emission reduction and a conditional 78% reduction from 1990 level.

TABLE 12

Moldova's greenhouse gas emissions reduction targets from 1990 levels (percentage of 1990 levels)

SECTORS	BY 2025		BY 2030	
	unconditional	conv.	unconditional	conv.
Energy	76	82	74	82
Transport	41	48	thirty	40
Building	79	8 1	77	80
Industry	51	59	45	56
Agriculture	43	45	37	41
LULUCF	43	54	62	76
Waste	46	51	38	47
TOTAL	**69**	**76**	**64-67**	**78**

Source: *Low Carbon Development Strategy until 2030*

The third updated report within the framework of Moldova's participation in the UNFCCC (2021) contains an updated Nationally Determined Contribution (NDC) - an unconditional 70% emission reduction and a conditional 88% reduction from the 1990 level. This is the most ambitious target among all the countries covered by this study, except for Kazakhstan.

In long-term forecasts for the development of the energy sector issued by international agencies, incl. IEA, BNEF, Rystad, etc. Moldova is considered as a part of Eastern Europe. Unfortunately, this country is not singled out in the published forecasts.

A7.1 Tajikistan

The Republic of Tajikistan (Tajikistan) is located in the southeastern part of Central Asia, is landlocked and borders Kyrgyzstan in the north, China in the east, Afghanistan in the south, and Uzbekistan in the north and west. Its population is 9.5 million people, and its area is about 143.1 thousand km^2; Dushanbe is the capital and the largest city (less than 10% of the population). More than 70% of the population lives in rural areas.

Key facts

Tajikistan is an energy-deficient country (although its energy imports dependence is not as significant as in some other countries covered by this study): according to the International Energy Agency (IEA), in 2019, with a total energy production of 3.07 Mtoe, total final energy consumption was approximately 3.19 Mtoe and energy imports were 1.039 Mtoe. Oil products is almost only energy resource to be imported.

A feature of the energy sector of Tajikistan is its vast hydropower resources (mountainous terrain creates huge reserves of glaciers that feed rivers) and significant coal reserves. Tajikistan generates electricity almost entirely from hydropower (one of the highest rates in the world and one of the most powerful hydropower plants in the world), but oil products import is of great importance.

Historically, energy and water supply not only in Tajikistan, but also in neighboring states (Uzbekistan, Kyrgyzstan, Kazakhstan, Turkmenistan) depended on the operating modes of large hydropower plants and filling of water reservoirs, which were determined by difficult-to-predict river flows. After getting independence of these countries in the early 1990s, mutual interests coordination in these areas became more difficult. Today, both progressive aging of infrastructure and climate change, which leads to changes in river flows, create an additional challenge. Overcoming this difficult situation is one of the important tasks that all these countries must solve.

The main priority of Tajikistan's energy policy in recent years is to ensure energy security and efficient use of electricity. The main problem in the energy sector is the lack of electricity supply during winter, which affects up to 1 million people annually. Additional priorities are existing energy facilities modernization and strengthening of electrical interconnections with neighboring countries.

Key documents and regulators

The Ministry of Energy and Water Resources is responsible for implementation of energy, renewable energy and energy efficiency policies.

The Ministry of Industry and New Technologies regulates the coal industry, the Ministry of Economic Development and Trade is the main body responsible for drafting of socio-economic aspects of state policy. The Agency of Statistics under the President of Tajikistan process energy statistics and data necessary to estimate greenhouse gas emissions as part of reporting to the UNFCCC. The Committee for Environmental Protection under the government is responsible for environmental regulation.

In the electric power sector of Tajikistan, the dominant role is occupied by OJHC " Barqi Tojik" (BT). This company is responsible for most of the electricity generation, transmission and distribution. Pamir Energy is the main electricity supplier in the Gorno-Badakhshan Autonomous Region.

Tajikistan ratified the Paris Agreement in February 2017.

As of June 2022, no unified strategic documents setting long-term energy policy goals (energy strategy) have yet been published.

In 2013, the 2030 National Development Strategy was approved, setting the economy development goals. In 2017, the General Plan for Electricity Sector Development was drafted, which is a scenario-based feasibility study for power generation and grid development with economic consequences assessment. In 2019, the 2040 Concept for Coal Industry Development was approved.

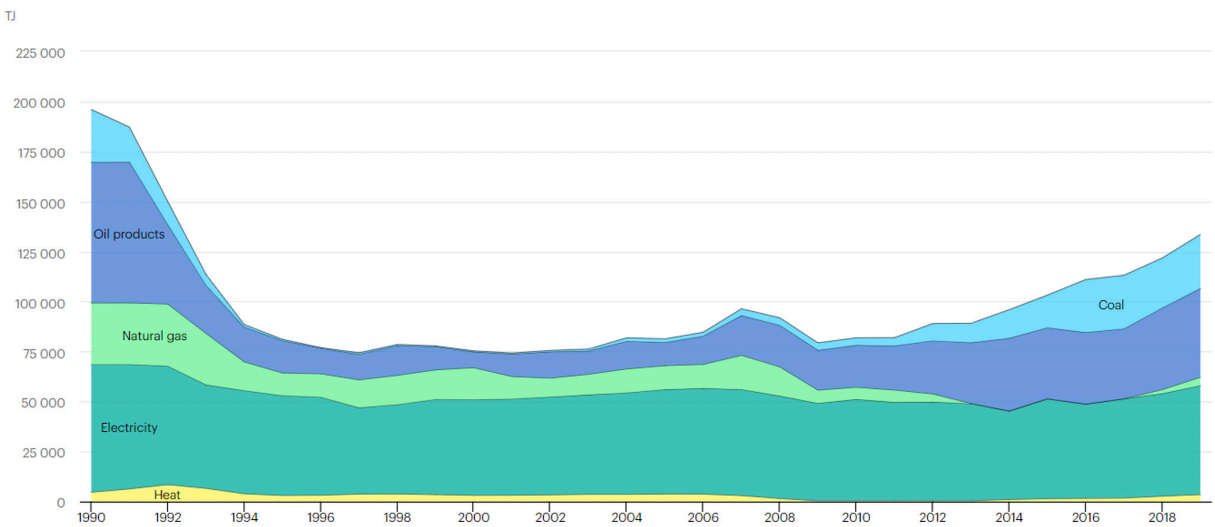
A strategic document in the field of hydrogen has not been drafted as of June 2022.

Balance of energy production and demand

The total final energy consumption in Tajikistan is primarily provided by electricity (40%), oil products (35%) and coal (20%) (see Figure 52). Electricity and coal are consumed primarily in the residential and industrial sector, while oil products are consumed in the transport sector. Between 2013 and 2018 there was a break in gas supplies due to gas pipelines shutdown on the side of Uzbekistan.

FIGURE 55

Total final energy consumption in Tajikistan in 1990-2019 by source

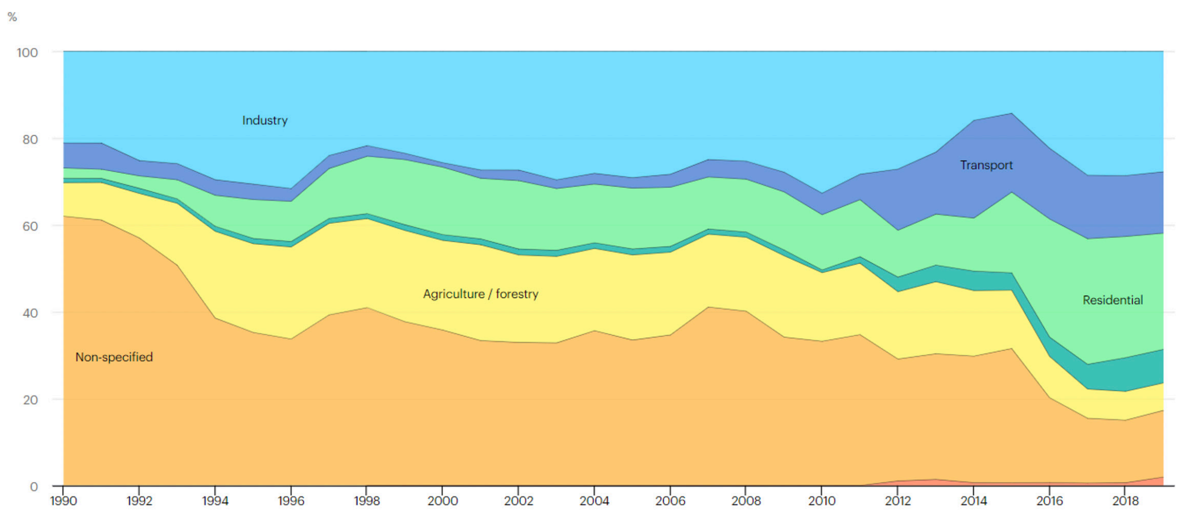


Source: IEA World Energy Statistics

Residential and industrial sectors dominate total final energy consumption, at about 30% each (Figure 56).

FIGURE 56

Total final energy consumption in Tajikistan in 1990-2019 by sector

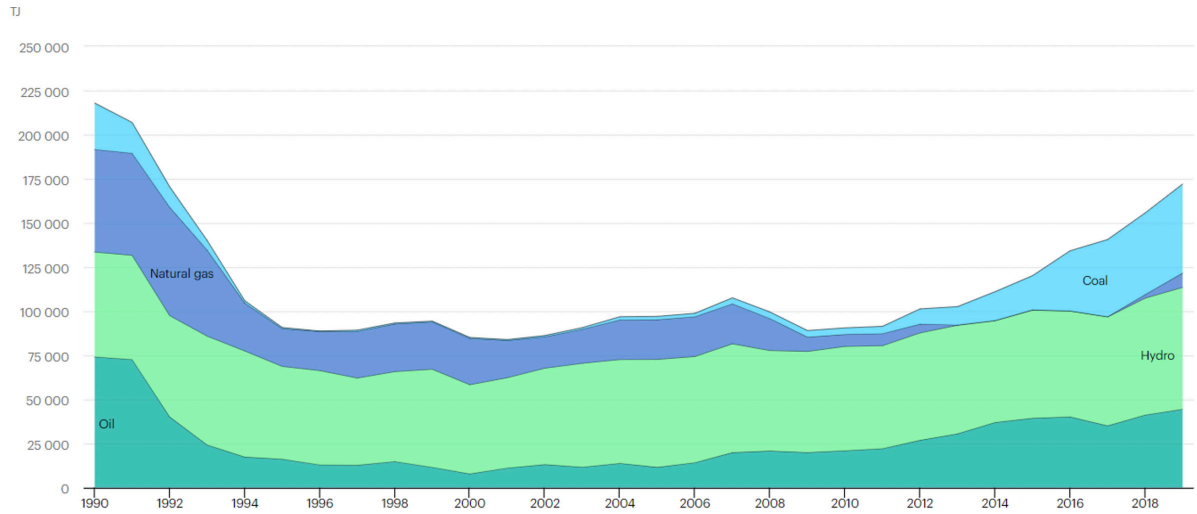


Source: IEA World Energy Statistics

Energy supply almost doubled during 2010-2019, primarily due to the coal and oil products supply growth (Figure 54). Natural gas imports have been interrupted for 5 years since 2013, and domestic production has not replaced it. According to BP, there were no significant proven oil, gas or coal reserves in Tajikistan as of 2020.

FIGURE 57

Energy supply in Tajikistan in 1990-2019 by source



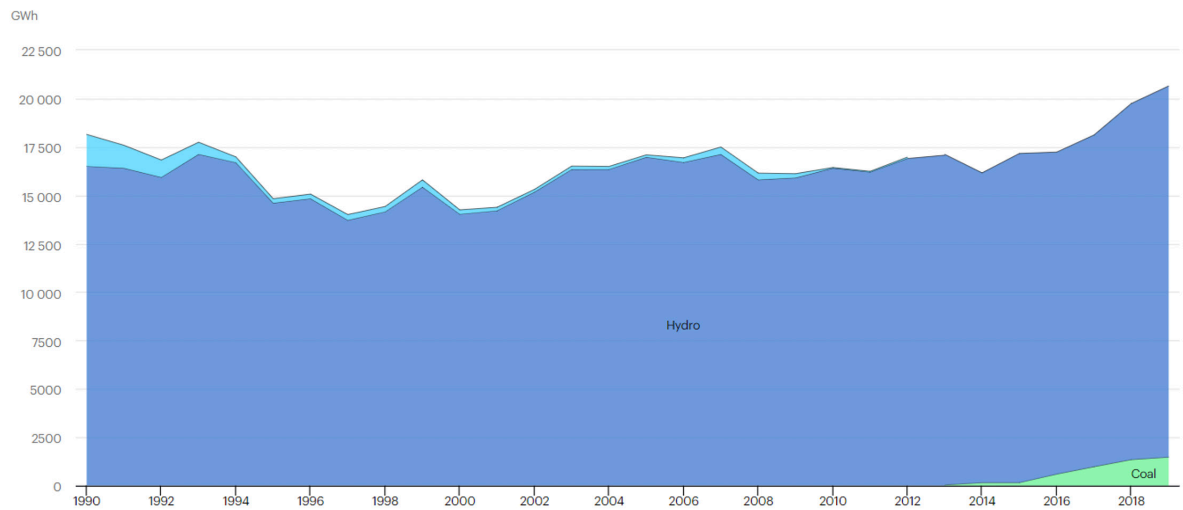
Source: *IEA World Energy Statistics*

Hydropower dominates Tajikistan's electricity sector, but coal has been able to take a small share of just under 10% over the past 5 years (Figure 58). The total electricity generation over the past 5 years has grown by about 30%. According to the IEA, during the same period electricity consumption has increased by 27% - mainly in households.

The largest electricity consumer in Tajikistan is TALCO, which operates the largest aluminum smelter in Central Asia.

FIGURE 58

Electricity generation in Tajikistan by source in 1990-2020



Source: *IEA World Energy Statistics*

Tajikistan's energy sector dependence on rivers flow conditions creates energy supply problems during peaking energy demand - especially during winter, when household's electricity demand grows because of air temperature decrease (by turning on electric heating, lighting) and may exceed the energy system capacity (especially in a situation of increased infrastructure wear-out) – this is energy supply deficit situation. It is repeated regularly in Tajikistan. The General Plan for Electricity Sector Development assumes that annual unmet electricity demand is about 2.4 TWh.

The imbalance between electricity production and demand can be reduced by increasing generation capacity, developing power interconnections with neighboring countries (for example, the Central Asia-South Asia power project, CASA -1000 is aimed at this), increasing energy efficiency, demand response (for example, by tariffs), developing seasonal energy storage systems (depending on possibilities - pumped storage power plants, battery storage, hydrogen-based storage systems).

In contrast, during the summer months, there may be a problem of excess electricity generation capacity due to increased river flows and declining electricity demand as ambient temperature increase. Reservoirs dampen this imbalance, but no-operation discharge of water can occur, including to regulate the water level in rivers after dams for water supply purposes. This issue requires additional study for the specific conditions of Tajikistan.

Gas transportation infrastructure

The gas transportation infrastructure in Tajikistan is used to import gas from Uzbekistan to supply it to key consumers - the Dushanbe gas-fired power plant and the TALCO aluminum smelter.

The infrastructure is managed by the state company Tajiktransgaz. The Line D transit gas pipeline as a part of Central Asian gas pipeline for transporting gas from Turkmenistan through Uzbekistan, Tajikistan and Kyrgyzstan to China is among the promising projects. Line D length will be about 1,000 km including 425 km to be laid in Tajikistan. The Chinese government plans to finance the project.

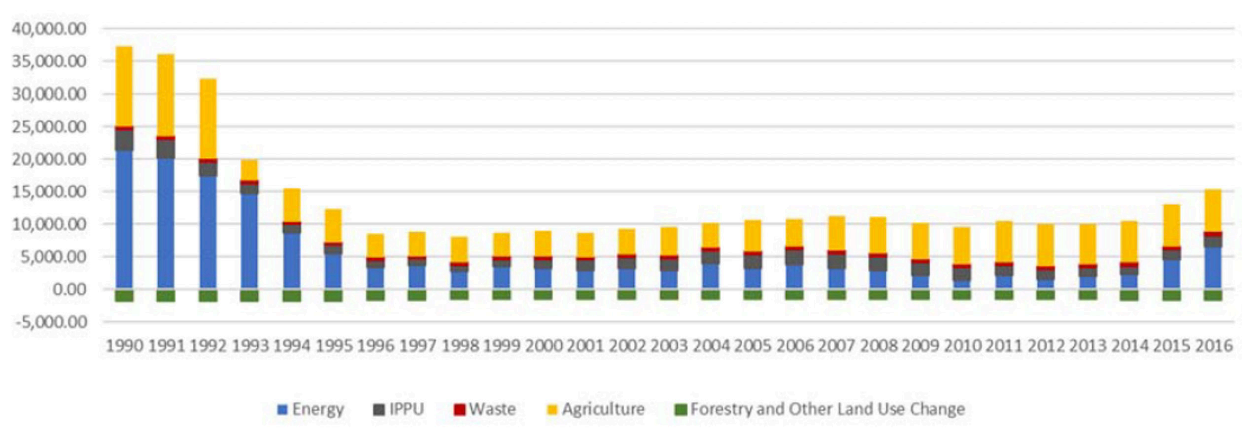
There are no published plans to use the existing and prospective gas transmission infrastructure in Tajikistan for hydrogen transportation.

Greenhouse gas emissions

According to official reporting data, greenhouse gas emissions continuously decreased from about 37 $MtCO_2e$ per annum between 1990 and 1996 (as the economic downturn, as in most countries of the former USSR), after which they remained constant for almost 20 years, until it started to rise in 2015. According to the IEA, energy-related CO_2 emissions almost doubled during 2014-2019, apparently due to rising energy consumption and an increase in coal and oil products share in the energy mix.

FIGURE 59

Greenhouse gas emissions in Tajikistan in 1990-2016, in thousand tons of CO_2e/year



Source: *Updated NDC of Tajikistan (2021)*

During the period 2004-2014, there was a change in the emissions sources mix: agriculture became the main source (50%), pushing energy into second place (23%). At the same time, CO_2 emissions dominate in the energy sector, while methane emissions dominate in agriculture.

Existing forecasts and long-term energy policy goals

Tajikistan has not yet published strategic documents defining long-term energy policy priorities and setting quantitative goals.

The 2030 National Development Plan (approved in 2013) sets “10/10/10/10” concept as a model for electricity sector development: to achieve 10 GW of the power system installed capacity, 10 TWh of annual electricity export, 10% share of non-hydropower electricity sources, 10% reduction in electricity transmission and distribution losses. The National Strategy also contains a plan for increasing electricity generation by 2025-2030 up to 37.5-40.7 TWh, an increase in oil, gas and coal production (with a focus on coal).

In 2017, the General Plan for Electricity Sector Development was drafted, which is a scenario-based feasibility study for power generation and grid development with economic consequences assessment on the horizon up to 2039. This document considers various options for power generation development (finishing of Rogun HPP construction project, commissioning of new hydropower and thermal power plants). It is concluded that the energy system does not have enough capacity to meet electricity demand during winter. To solve this problem, it will be necessary to commission new power generation plants with a capacity of 500 MW or more (in addition to the projects already approved for implementation). The option with the early Rogun HPP commissioning (until 2023) is recognized as optimal in terms of a combination of technical and economic indicators.

Tajikistan's Nationally Determined Contribution (October 2021) includes an unconditional 30-40% GHG emissions reduction goal from 1990 levels by 2030. The conditional goal is 40-50% reduction if financial support, technology transfer and technical cooperation are provided. Both goals seem achievable without a radical change in the energy mix, given the effect of the “high base” of emissions in 1990. At the same time, coal and oil products share increase in the energy mix, accompanied with energy consumption increase, may accelerate the growth trajectory of greenhouse gas emissions and require future additional energy and climate policy measures to meet NDC.

In the long-term energy sector development forecasts issued by international agencies, incl. IEA, BNEF, Rystad, etc. Tajikistan is considered as a part of the Caspian region. Unfortunately, this country is not singled out in the published forecasts.

A8.1 Turkmenistan

Turkmenistan is located in Central Asia, bordering Kazakhstan in the northwest, Uzbekistan in the north, east and northeast, Afghanistan in the southeast, Iran in the south and southwest. In the west it is washed by the Caspian Sea. Its population is about 6 million people, the area is about 488 thousand km^2; Ashgabat is the capital and the largest city (about 14% of the population).

Key facts

Turkmenistan is an energy surplus country: according to the International Energy Agency (IEA), in 2017, with a total energy production of 76.9 Mtoe, total final energy consumption was approximately 18 Mtoe and energy export was 48.8 Mtoe. Coal is not used in the economy; energy resources import is insignificant.

Oil and gas sector is the economy basis: oil, gas and oil products exports share in the export earnings of Turkmenistan is 90%, the share in gross national product is about 70%. Turkmenistan is a major natural gas exporter (about 45 bcm per annum), China is the most important consumer.

According to available data (IEA), 100% of electricity in Turkmenistan is generated by natural gas-fired thermal power plants. Gas production in Turkmenistan started in the late 1960s, reaching its peak in 20 years (about 90 bcm per annum).

Key documents and regulators

The President of Turkmenistan, among other things, approves the programs and main directions of the political, economic and social development (including documents related to energy and climate policy), and appoints ministers. The Ministry of Energy is responsible for the power sector development, its activities are directed and coordinated by the President. Oil and gas sector development is the area of responsibility of the state concerns Turkmennebit and Turkmengaz, as well as the Cabinet of Ministers.

The State Committee for Environmental Protection and Land Resources is responsible for environmental and climate policy implementation. Turkmenistan ratified the Paris Agreement in 2016.

Key current (as of June 2022) documents that determine the energy and climate policy in Turkmenistan:

- national social and economic development program for 2022-2052;
- the national program of the President of Turkmenistan for the socio-economic development of the country for 2019-2025;
- national climate change strategy (adopted in 2022);
- national renewable energy development strategy until 2030.

As of June 2022, these documents are not in the public domain and are not available for analysis.

There are no strategic state documents in the field of hydrogen yet, but a hydrogen energy international cooperation development roadmap for 2022-2023 was approved in January 2022 (not published).

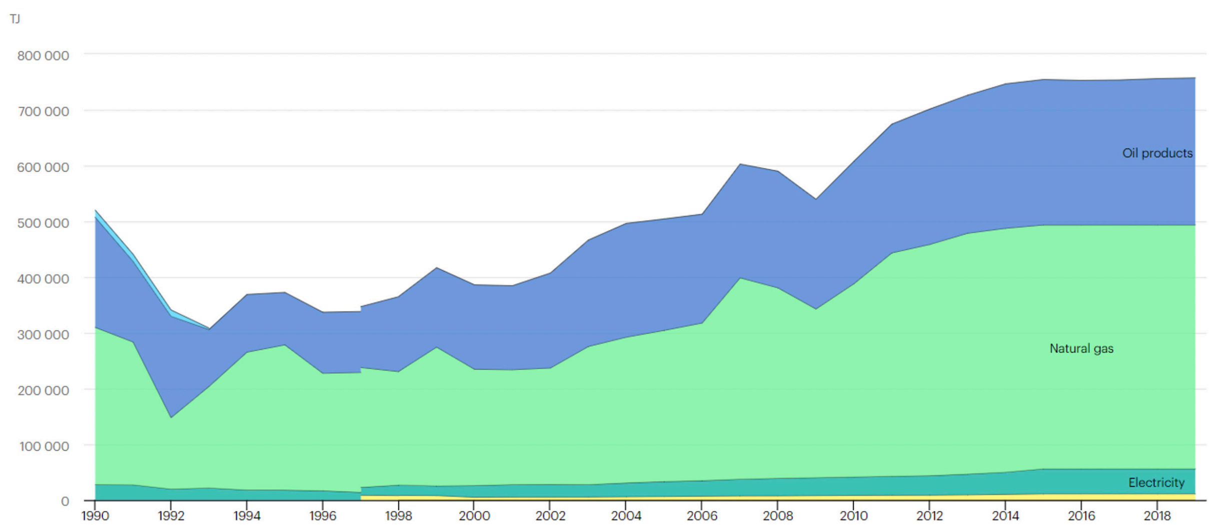
One of the features of Turkmenistan is the lack of access to the energy sector-related transparent statistical data.

Balance of energy production and demand

The total final energy consumption in Turkmenistan is provided by about 60% from natural gas and 30% from oil products (see Figure 60). Judging by the available data, these shares have not changed over the past 15 years.

FIGURE 60

Total final energy consumption in Turkmenistan in 1990-2019 by source

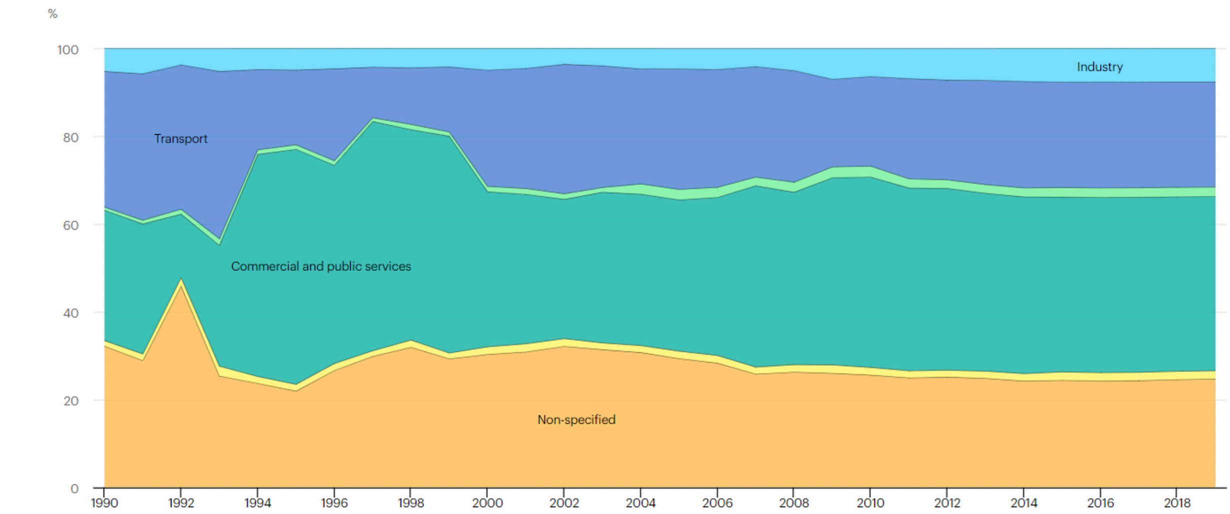


Source: *IEA World Energy Statistics*

Approximately 25% of the total final energy consumption is in the transport sector, 40% - in the commercial and public sectors. This structure has also remained unchanged over the past 15 years, according to the IEA (Figure 61).

FIGURE 61

Total final energy consumption in Turkmenistan in 1990-2019 by sector

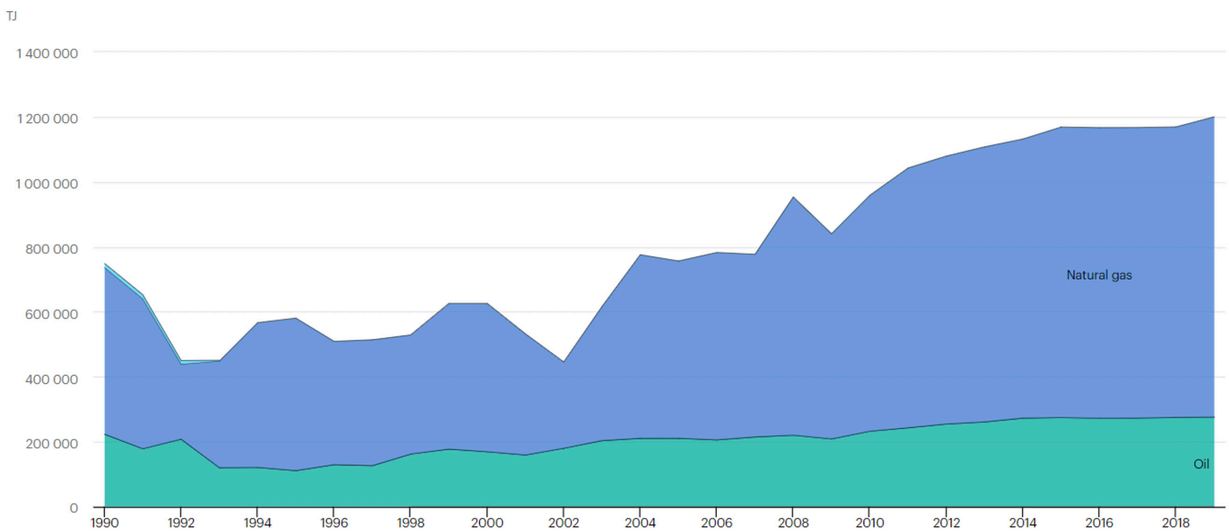


Source: *IEA World Energy Statistics*

Since 2010, energy supply has increased by almost 35%, primarily due to natural gas (Figure 62).

FIGURE 62

Energy supply in Turkmenistan in 1990-2019 by source



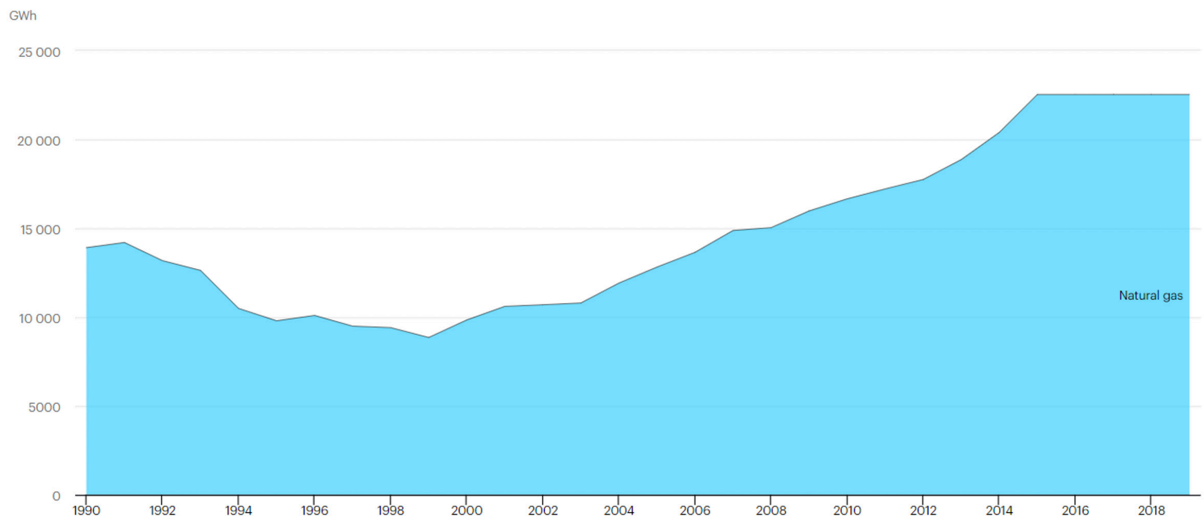
Source: *IEA World Energy Statistics*

According to BP, Turkmenistan in 2020 produced 0.2% of the world's oil (10.3 Mt), ranking 34th in the world and third among the countries covered by this study. Turkmenistan's share in the world natural gas production amounted to 1.5% (59 bcm) - the 13th place in the world and the first place among the countries covered this study.

100% of electricity in Turkmenistan's power sector is produced from natural gas. Electricity generation almost doubled during 2005-2015, after which it has not changed for several years (Figure 63), according to IEA. Physically, this is hardly possible - we can assume the lack of reliable data.

FIGURE 63

Electricity generation in Turkmenistan by source in 1990-2020



Source: *IEA World Energy Statistics*

Gas transportation infrastructure

As a major producer and exporter of natural gas, Turkmenistan has an advanced gas transportation infrastructure, including gas pipelines that were put into operation less than 10 years ago. According to the Ministry of Foreign Affairs, the Turkmenistan-Uzbekistan-Kazakhstan-China gas pipeline, connecting the Turkmen Malay field and the fields on the right bank of the Amu Darya River with the main industrial centers of China (Shanghai, Guangzhou, Hong Kong), has a total length of more than 9,000 km. Three lines of this gas pipeline operate on the Turkmenistan territory, each with a length of no more than 100-200 km. They are operated by the state concern Turkmengaz and China's China National Petroleum Corporation (CNPC). The gas pipeline capacity is up to 55 bcm per year.

The Dovletabad-Deryalyk gas pipeline system ensures natural gas export from Turkmenistan's eastern and western gas producing regions to the north. The Korpeje-Kurtkui (up to 8 bcm per annum) and Dovletabad-Serakhs-Hangeran (up to 12.5 bcm per annum) gas pipelines are built to export gas to Iran. The East-West gas pipeline connects large eastern fields with the country's western regions.

The 33 bcm per year Turkmenistan-Afghanistan-Pakistan-India potential gas pipeline with a length of 1800 km is among the promising projects. Underwater Trans-Caspian gas pipeline towards Baku and the Line 4 (Line D) gas pipeline as a part of Turkmenistan-China pipeline are also among the future promising projects.

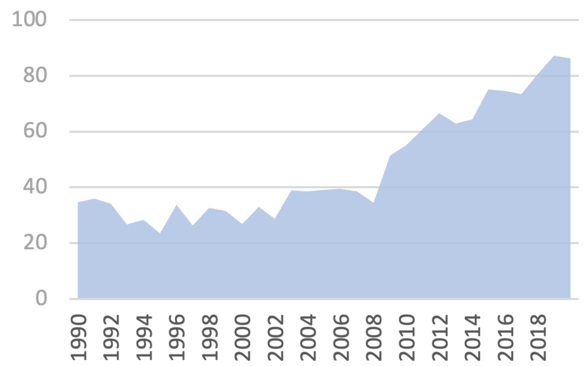
There is no information in the public space that gas transmission corridors operators in Turkmenistan have considered using their assets to transport hydrogen.

Greenhouse gas emissions

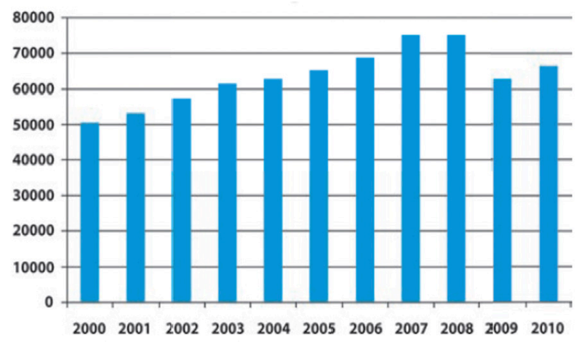
Greenhouse gas emissions in Turkmenistan continuously increased from about 50 $MtCO_2e$ per annum between 2000 and 2008 – by almost 50%, after which they rapidly decreased due to the crisis (see Figure 64), according to the official data of the national reporting in 2015. According to BP, CO_2 emissions in Turkmenistan continued to grow after that, exceeding 85 $MtCO_2e$ per annum.

FIGURE 64

CO_2 emissions in Turkmenistan in 1990-2020 in $MtCO_2e$/year and all greenhouse gases emissions during 2000-2010 in thousand tCO_2e/year



Source: *BP*



Source: *The Third National communication of Turkmenistan under the UN FCCC, 2015*

Energy-related emissions contribute the main part in Turkmenistan (85% in 2010), with a large share of methane emissions (41% in 2010) due to fugitive emissions from the gas industry.

The main difference in greenhouse gas emissions trends in Turkmenistan from most other former USSR and Eastern Europe countries is that the 1990 emissions level did not become the maximum, and the level of 2020 exceeds the level of 1990 more than twice.

Existing forecasts and long-term energy policy goals

Turkmenistan's long-term energy strategy does not exist as a separate document, and strategic documents of a different level (the 2022-2052 national socio-economic development program, etc.) have not been published and are not available for analysis.

First Nationally Determined Contribution was approved in 2016, and the updated NDC was approved in May 2022. It includes greenhouse gas emissions reduction by 2030 without specifying a quantitative value.

In the long-term forecasts for energy sector development issued by international agencies, incl. IEA, BNEF, Rystad, etc. Turkmenistan is considered as a part of the Caspian region. Unfortunately, the country is not singled out in the published forecasts. The only exception is in the IEA World Energy Outlook 2019 mentioned Turkmenistan's gas production in 2040 of about 158 bcm per annum.

According to the Nexant World Gas Model, Turkmenistan's gas production capacity will grow to 200 bcm per annum, while domestic gas demand will have a slight increase between 32 and 53 bcm per annum during 2020-2040.

A9.1 Uzbekistan

The Republic of Uzbekistan (Uzbekistan) is located in the central part of Central Asia and borders on Kyrgyzstan in the east, Kazakhstan in the northeast, north and northwest, Turkmenistan in the southwest and south, Afghanistan in the south and Tajikistan in the southeast. Its population is 35.7 million people, and its area is about 449 thousand km^2; Tashkent is the capital and the largest city (about 8% of the population).

Key facts

Kazakhstan is an energy surplus country: according to the International Energy Agency (IEA), in 2017, with a total energy production of 50.7 Mtoe, total final energy consumption was approximately 22.8 Mtoe and energy exports were 17.9 Mtoe.

The basis of the energy sector is, first, natural gas, which Uzbekistan both produces and exports (although exports may cease by 2025). The country has coal and oil production for domestic consumption, and large uranium reserves. Hydropower share in power sector has not changed for 30 years (about 7%), solar and wind energy share is insignificant - the renewable energy sector is in its infancy.

The government of Uzbekistan plans to increase renewable electricity generation by about 5 times in 10 years (by 2030). Power sector is being reformed, international renewable energy auctions, supported by international development institutions and investors, have been arranged. In terms of the pace of new renewable energy sources deployment, Uzbekistan is one of the leaders in the region.

Uzbekistan is the only country covered by this study (as of June 2022) that has adopted a hydrogen energy development roadmap, officially started the national hydrogen strategy drafting and created a specialized state-owned renewable energy research center with a structural hydrogen-related unit.

Key documents and regulators

In 2019, an energy sector wide reform started in Uzbekistan, which is ongoing as of June 2022. According to the IEA (2022), this reform looks ambitious in scope compared to other countries.

The Ministry of Energy of Uzbekistan, created at the beginning of the reform, is responsible for regulating the entire chain (from extraction to end use or export) of electricity, heat, coal, gas and oil. The presidential administration and the Cabinet of Ministers govern the ministry, setting top-level energy policy priorities.

The Ministry of Economic Development and Poverty Reduction is responsible for macroeconomic forecasting, planning and long-term development of economic sectors, including the key energy sector. The Ministry of Innovative Development oversees the introduction of innovations, long-term scientific development programs (including related to renewables and hydrogen). The Ministry of Finance is involved in the tariffs regulation and in public-private partnerships development in the energy sector.

In 2017, Uzbekistan joined the Paris Agreement, and in April 2022 submitted an updated Intended Nationally Determined Contribution (NDC) to the UNFCCC. The Hydrometeorological Service Center under the Cabinet of Ministers (Uzhydromet) coordinates interaction with the UNFCCC on drafting of national greenhouse gas emissions reporting, etc. Uzhydromet's CEO heads the Interdepartmental Coordination Council, which includes representatives of other departments.

In 2021, an Interdepartmental Commission for Renewable and Hydrogen Energy Development was established under the leadership of the Minister of Energy, which included representatives of all key ministries. In 2021, the National Renewable Energy Research Institute was established under the Ministry of Energy, with a Hydrogen Energy Research Center as a structural unit. Scientific support in the energy policy drafting and implementation is provided by the Academy of Sciences.

Key documents defining the long-term energy policy in the country:

- "Green" economy transition strategy for the period of 2019-2030 (approved in 2019, its new version is being developed with a horizon of 2050);

- Electricity supply concept for 2020-2030 (approved in 2020).

Power sector carbon neutrality transition roadmap by 2050 and the National Renewable and Hydrogen Energy Development Strategy are drafting as of June 2022.

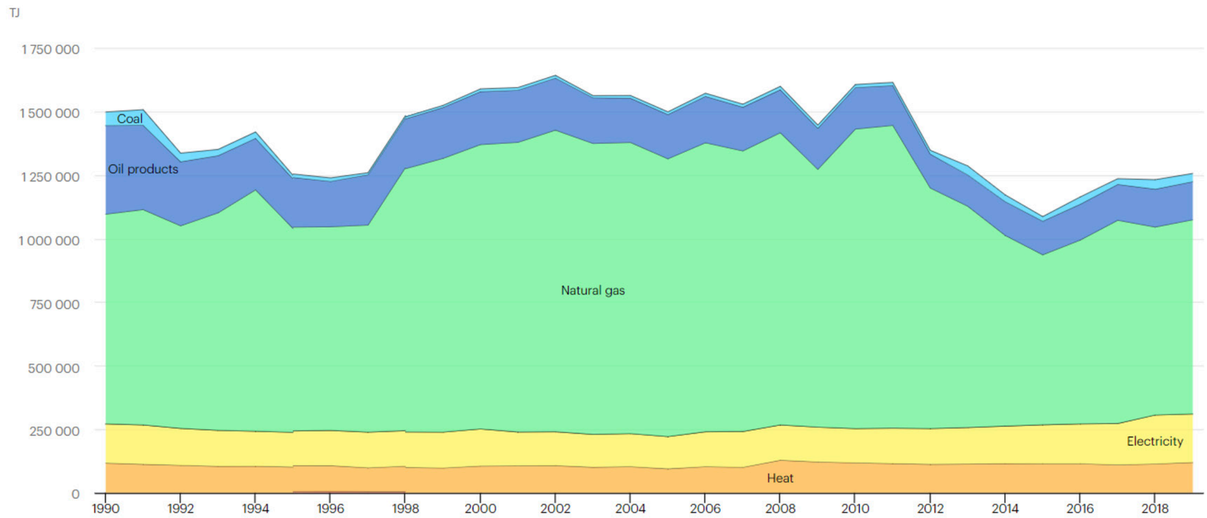
Uzbekistan, as of June 2022, has moved further than all other countries covered by this study towards creating an institutional framework for a hydrogen economy.

Balance of energy production and demand

The total final energy consumption in Uzbekistan is 60% provided by natural gas, the rest is approximately equally divided between oil products, electricity and thermal energy. The share of coal is insignificant (see Figure 65). Natural gas is used primarily in the residential and industrial sectors.

FIGURE 65

Total final energy consumption in Uzbekistan in 1990-2019 by source

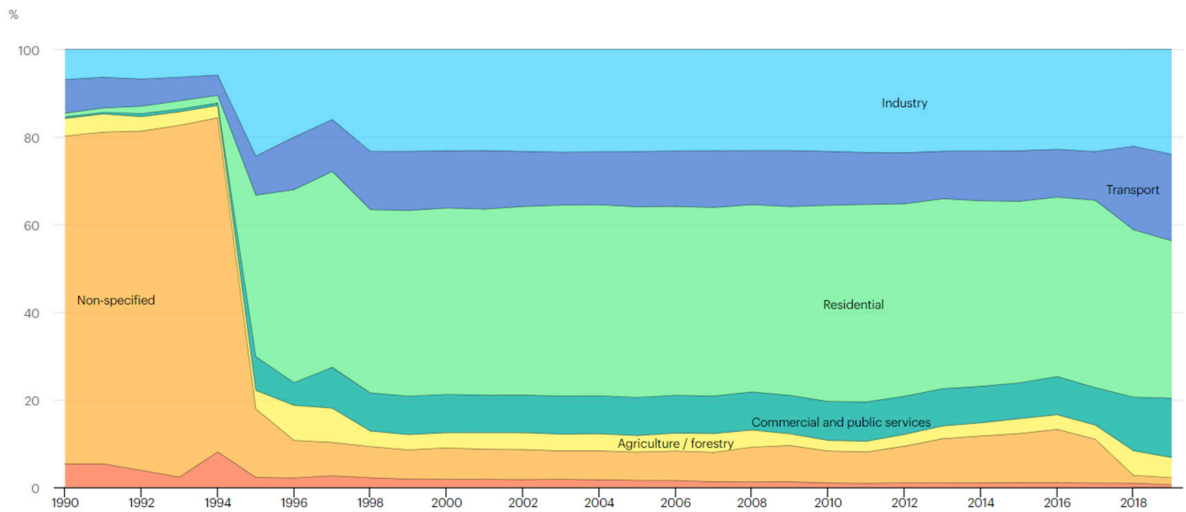


Source: IEA World Energy Statistics

More than 35% of total final energy consumption stands for the residential sector, about 20% each - on the industrial, transport and commercial sectors (Figure 66).

FIGURE 66

Total final energy consumption in Uzbekistan in 1990-2019 by sector

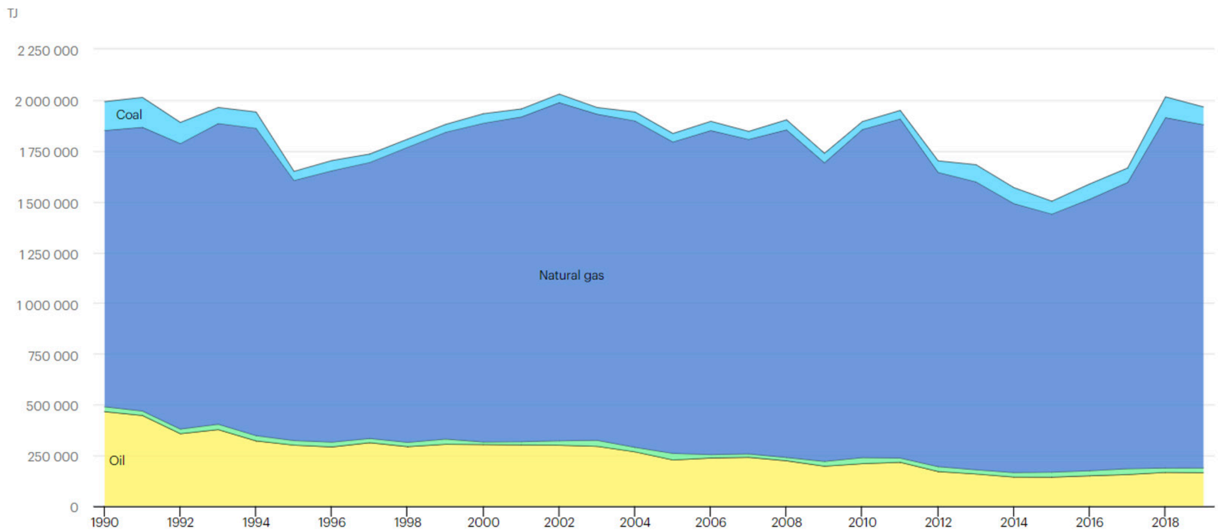


Source: IEA World Energy Statistics

Energy supply increased by almost a third between 2015 and 2019, primarily due to natural gas, reaching the level of 2002 (Figure 67).

FIGURE 67

Energy supply in Uzbekistan in 1990-2019 by source



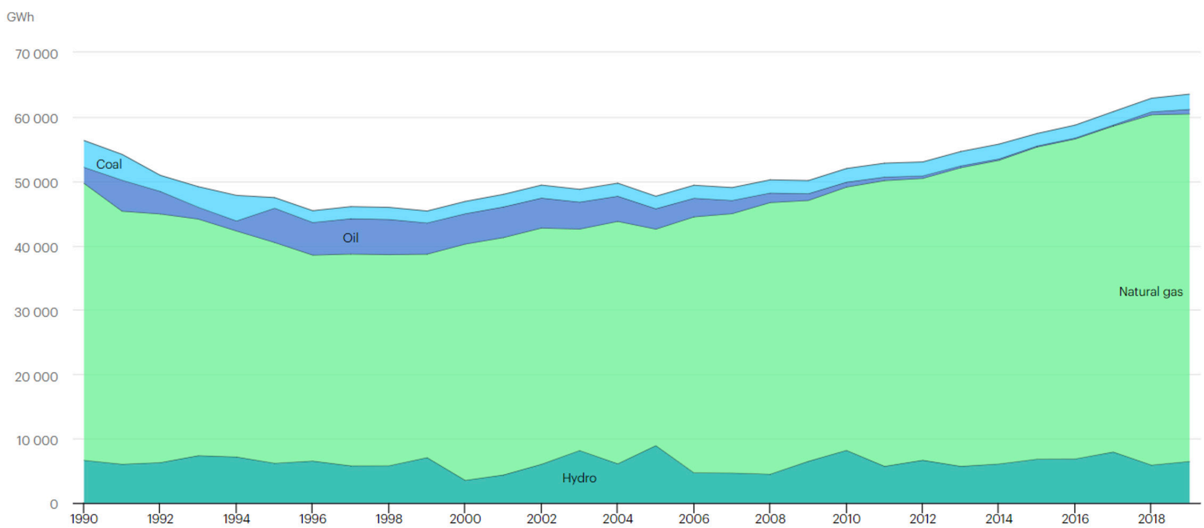
Source: *IEA World Energy Statistics*

According to BP, Uzbekistan in 2020 produced 0.1% of the world's oil (2.1 Mt), ranking 47th in the world and fourth among the countries covered by this study. The country's share in the world natural gas production was 1.2% (47.1 bcm) - 17th in the world and second among the countries covered by this study. Natural gas is exported to Russia, Kazakhstan and China, but by 2025 exports may stop due to raising domestic demand.

Natural gas dominates in Uzbekistan's power sector - it was due to gas-fired power plants that it was possible to increase electricity production by 33% over the period 2005-2019 and reduce electricity imports over the same period by 3-4 times. Coal-fired and hydropower electricity generation remained virtually unchanged over the same period (Figure 68).

FIGURE 68

Electricity generation in Uzbekistan by source in 1990-2020



Source: *IEA World Energy Statistics*

Solar and wind share in electricity generation is insignificant, solar and wind plants installed capacity was 5 MW in 2020, with a total installed capacity of about 16 GW, according to IRENA (2021). It is expected that starting from 2021-2022, renewable electricity generation will grow intensively as several solar PV projects (Navoi, Samarkand, Jizzakh, Bukhara, Namangan, Khorezm, Sherabad) and wind projects (Biruni and Karauzyak) are put into operation, which are now in different stages of development.

Gas transportation infrastructure

The Uztransgaz company mainly operates the gas transportation and distribution infrastructure in the country, which includes 13.5 thousand km of transmission pipelines, 23 compressor stations and 418 gas distribution stations. As the gas market in Uzbekistan is being reformed, other players will have possibility to become gas infrastructure operators.

The main gas pipeline in the country is Bukhara-Tashkent-Bishkek-Almaty with a capacity of 3.2 bcm per annum, which also used to transport gas to Kyrgyzstan and southern Kazakhstan. The Mubarek-Shurabad-Dushanbe gas pipeline is designed to supply gas to Tajikistan. According to the IEA, the total capacity of export and transit gas pipelines to the countries of Central Asia, Russia, Europe and China in Uzbekistan reaches more than 120 bcm per annum (including up to 55 bcm per annum to China and up to 70 bcm ber annum to Russia). Both transit routes start in Turkmenistan and pass through Kazakhstan.

Uzbekistan also has two gas storage facilities - Gazli (3 bcm, expandable to 10 bcm) and Khodjaabad (0.9 bcm).

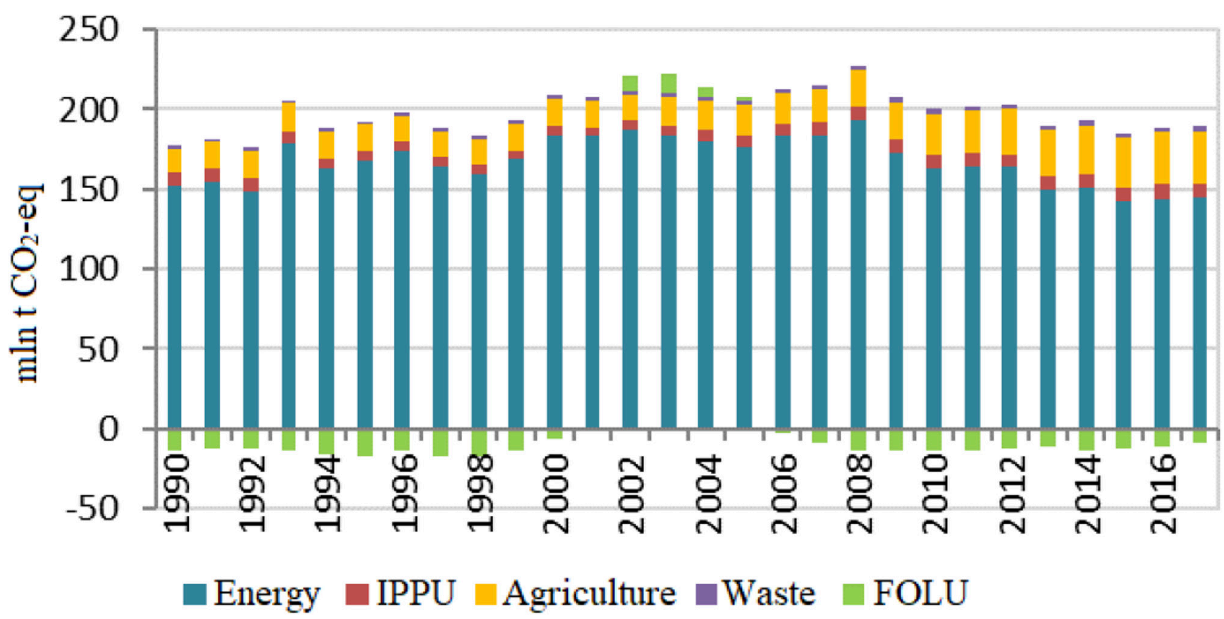
According to the IEA, it will take about $1.5 billion to modernize the decrepit gas transmission and distribution infrastructure. There are no published plans for the use of hydrogen transportation infrastructure.

Greenhouse gas emissions

Greenhouse gas emissions in Uzbekistan have grown slowly since 1990, peaking in the mid-2000s at around 230 $MtCO_2e$ per annum (Figure 69). After that, they began to slowly decline to about 190 $MtCO_2e$ per annum by 2017.

FIGURE 69

Greenhouse gas emissions in Uzbekistan in 1990-2017 in $MtCO_2e$ per annum



Source: *updated Nationally Determined Contribution of the Republic of Uzbekistan under the UNFCCC (2021). (IPPU stands for Industrial processes and product use, FOLU stands for forestry and other types of land use)*

Energy-related emissions account for about 80%, CO_2 emissions share is about 54%, while methane emissions share is 38%, and energy sector is the main source of both greenhouse gases emissions.

Existing forecasts and long-term energy policy goals

The key energy policy priorities are included in the "Green" economy transition strategy for the period of 2019-2030:

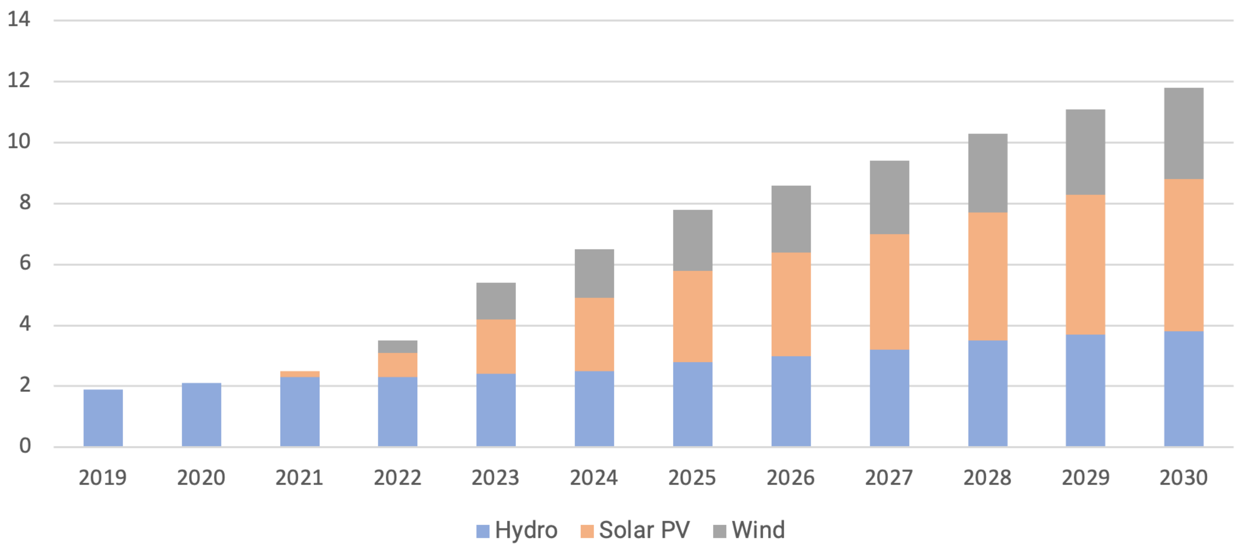
- 10% reduction in specific greenhouse gas emissions per unit of GDP compared to 2010 level;
- doubling the energy efficiency (compare to 2018 level) and reducing GDP energy intensity, increasing energy efficiency of industrial enterprises by at least 20%;
- 25% share of renewables in electricity generation;
- 100% access to modern, affordable and stable energy supply for all consumers;
- expansion of production and use of motor fuel and vehicles with increased energy efficiency, electric transport deployment.

Electricity supply concept for 2020-2030 includes the following guidelines regarding renewables:

- introducing 3 GW of wind, 5 GW of solar and 1.9 GW of hydropower plants;
- in the field of wind energy - wind farms with a project capacity of 100-500 MW, mainly in the North-Western region (Republic of Karakalpakstan and Navoi region);
- in the field of solar energy - solar parks with a project capacity of 100-500 MW mainly in the Central and Southern regions (Jizzakh, Samarkand, Bukhara, Kashkadarya and Surkhandarya regions);
- combining solar plants with energy storage systems;
- introducing of a 2.4 GW nuclear power plant.

FIGURE 70

Renewables installed capacity by 2030 in MW by source in Uzbekistan



Source: *Electricity supply concept for 2020-2030*

Renewables is planned to be deployed through parallel solar, wind and hydropower with a focus on solar PV (Figure 70).

New nuclear power plant construction could begin in 2022, according to the plan - preliminary agreements on this project have been reached with Rosatom (Russia). According to the Deputy Minister of Energy of Uzbekistan, as of June 2022, the planned cost of this project is being optimized in order to increase the economic attractiveness of the electricity generated in the future.

Uzbekistan's updated Nationally Determined Contribution includes a 35% greenhouse gas specific emission (per unit of GDP) reduction target by 2030 from the level of 2010.

According to Nexant World Gas Model, in 2020-2040 gas production capacity in Uzbekistan will not change significantly, remaining at the level of 60 bcm per annum with an almost constant demand during the same period.

Sustainable Hydrogen Production Pathways in Eastern Europe, the Caucasus and Central Asia

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