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Keywords: Hydrogen energy; Decarbonization; Hydrogen source; Primary energy source; Carbon footprint; Cross-border carbon tax

Review Article

Roadmap for Greening the Economy of Turkmenistan

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Abstract

Over the past decades, interest in renewable energy has grown, this is due to the aggravation of climate change. The emerging trend of decarbonization of the world economy, including transport and energy, which are one of the main sources of air pollution with carbon dioxide emissions. The article discusses issues of climate change, decarbonization scenario, a road map for "greening" the economy, and presents a brief analysis of trends in the development of hydrogen energy and the importance of the development of "green" hydrogen in the world and in Turkmenistan. The main attention is paid to the prospects and scale of development of hydrogen energy to a certain extent will depend on the characteristics of the hydrogen sources proposed for use , primary energy sources and hydrogen production technologies, environmental consequences when using different approaches to hydrogen production, expected costs for hydrogen production, potential consumers and volumes of hydrogen consumption within the country and abroad, technologies for storing and delivering hydrogen to consumers, the competitiveness of hydrogen as an energy carrier in the domestic and foreign markets, taking into account all the necessary costs and a potential "transboundary carbon tax".

Introduction

Over the past decades, interest in hydrogen energy has increased; in the last century, its development fluctuated significantly. The current round of development is associated with increased concern about climate change and the emerging trend of decarbonization of the world economy, including transport and energy, which are some of the main sources of air pollution with carbon dioxide emissions, as well as with the widespread introduction of Renewable Energy Sources (RES) with a stochastic nature in a number of countries power output that requires redundancy and the use of efficient energy storage devices to regulate energy generation and consumption schedules [1].

In his speech, the President of Turkmenistan Serdar Berdimuhamedov at the 78th session of the UN emphasized that in the coming year, the country will consider solving intense climate and environmental problems. Introduction and use of modern environmentally friendly and resource-saving technologies in energy, industry, and transport.

At the 28th Conference of the Parties to the UN Framework Convention on Climate Change in Dubai in December of this year. The major forum brought together numerous delegates from around the world, including heads of state and government, relevant government agencies, international organizations, experts, representatives of civil society, business circles, youth, the media and many other specialists [1].

At this Global Forum, the implementation of the Paris Climate Agreement was summed up and further action plans were outlined for the international community to achieve its goals. The subject of interesting discussion was issues related to adaptation to climate change, overcoming its consequences, and such interrelated topics as ensuring environmental and food security, healthcare, green energy, greening the economy, rational use of natural resources, recycling, waste disposal, and so on. In this context, one of the key aspects was the reduction of emissions that have a negative impact on the environment . The Global Methane Commitment (GMP) is intended to help address this challenge. Methane is the second acid gas after carbon, and with its increase in the atmosphere, the greenhouse effect intensifies, which leads to an increase in the temperature of the planet.

Based on the fact that the topic of climate change is at the top of the national agenda, Turkmenistan fully supports the efforts of the world community in this direction and is taking all steps to introduce low-carbon technologies.

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Among the promising vectors within the framework of the "green" economy, the implementation in our country of projects for the production of hydrogen from natural gas is also considered.

On the issue of "green" energy, the National Strategy for the Development of Renewable Energy until 2030 and the Law of Turkmenistan "On Renewable Energy Sources" have been adopted. The law defines the legal, organizational, economic, social, and financial framework, and mechanisms for regulating relations between the state, producers, suppliers, and consumers of renewable energy sources, production equipment, installations, and technology for the use of renewable energy sources [2,3].

Attention is paid to the prospects and scale of development of hydrogen energy, which to a certain extent will depend on the characteristics of the hydrogen sources proposed for use, primary energy sources and hydrogen production technologies, environmental consequences when using different approaches to hydrogen production ("carbon footprint"), expected e costs of hydrogen production, potential consumers and volumes of hydrogen consumption within the country and abroad, technologies for storing and delivering hydrogen to consumers, the competitiveness of hydrogen as an energy carrier in the domestic and foreign markets, taking into account all the necessary costs and a potential "transboundary carbon tax" [1,3-5].

Decarbonization scenario

Almost all decarbonization scenarios agree that the future lies with electrification as the main and most economical way to "green" economies. There are two main reasons for this. First, after decades of subsidized technological innovation, solar and wind energy are becoming the cheapest sources of electricity generation in much of the world. Secondly, technological advances make it possible to use electricity-powered and cheaper batteries, heat pumps, electric motors, and the like. in sectors where fossil fuels traditionally predominate as an energy source, such as transport, heating of housing and communal services and buildings, and industrial enterprises [3,6].

As global power systems become increasingly electrified, a key challenge for system operators will be to meet demand in real-time to prevent power outages. But as the share of solar and wind energy increases, this can become an increasingly difficult task: what to do when the sun doesn't shine or there's no wind?

Energy carrier: One of the main reasons why hydrogen is now "in vogue" as a chemical "energy carrier" is that it meets the need for storage and flexible use of renewable energy sources. It can also be used in hard-to-decarbonize sectors such as heavy industry, freight, aviation, or shipping.

Hydrogen appears to be an ideal complement to renewable energy sources on the path to decarbonization, but only if it is produced through electrolysis from renewable energy sources themselves (so-called "green" hydrogen) [6-8].

Demand for hydrogen: Since 1975, global demand for hydrogen has more than tripled to 70 million tons in 2018. Hydrogen is currently used in oil refining and ammonia production. Almost all hydrogen comes from fossil fuels, making it a source of 830 million tonnes of carbon dioxide per year, equivalent to the combined CO2 emissions of Indonesia and the UK.

However, hydrogen from renewable energy sources now looks like an increasingly viable prospect thanks to falling costs in wind and solar technologies. While the cost of producing hydrogen from fossil fuels for 2018 was estimated at 0.8 - 2.7 euros per kilogram, hydrogen from renewable sources can already be produced at 2.5 - 6.3 euros per kilogram at the projected further cost reduction. With this in mind, many countries are developing green hydrogen development strategies [6-9].

Development of "green" hydrogen in the world

Plans of the European Union, Great Britain, USA, China, and Japan to understand the current state of green hydrogen development strategies in the world.

Hydrogen ambitions The EU expects hydrogen to play a significant role in the 2030 – 2050 CO2 reductions needed to achieve carbon neutrality and is therefore focusing on hydrogen from renewable sources. At the same time, the EU envisages the temporary use of other forms of low-carbon hydrogen to decarbonise existing hydrogen production from fossil fuels. In general, the development of hydrogen in the EU is expected to be carried out in three stages: 2020–2024. – gradual decarbonization of existing hydrogen production, 2025–2030. – introduction of hydrogen into new production, 2031–2050. – implementation in sectors that are difficult to decarbonize. At the final stage, it is expected that the share of "green" hydrogen will be 10% of total final energy consumption in the EU (versus 1% at the second stage) [10-13].

Italy – adopted hydrogen development strategies in 2020. Countries have also pledged around €11.5 billion for hydrogen for 2021–2026. within the framework of the EU Next Project Generation, including 3 billion euros each - from Germany and Italy, 2 billion euros - from France, 1.5 billion euros - from Spain, and 1 billion euros each - from Poland and Romania. In addition, in 2020 the EU launched the Important Project of Common European Interest (IPCEI), designed to accelerate the creation of pan-European hydrogen value chains. The level of ambition of national strategies varies, but in some cases is clearly high.

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Thus, Germany aims to increase its electrolysis capacity to 5 GW by 2030. This is about 4% of the final energy consumption in the country, according to the EU climate program Fit for 55. To achieve this, Germany has committed €9 billion as part of its national hydrogen strategy. France's plans are even more ambitious: by 2030, electrolysis capacity should reach 6.5 GW, by the same date government funding for promoting the use of hydrogen in industry and transport will amount to 7 billion euros. Italy's national hydrogen strategy targets 5 GW of electrolysis capacity by 2030, or 2% of final energy consumption, increasing to 20% by 2050. Spain expects to reach 4 GW with €9 billion of public and private investment by 2030 [12-14].

UK hydrogen economy: The UK unveiled its strategy to develop a "world-leading hydrogen economy" in August 2021, citing hydrogen as a key element of its energy transition, primarily across the electricity, industrial, and transport sectors.

Like Germany and Italy, the UK plans to deploy 5 GW of low-carbon hydrogen production capacity by 2030, which should help ensure that 20% - 35% of the country's energy consumption comes from hydrogen by 2050. Hydrogen has an important role to play in the decarbonization of those sectors for which it is currently produced from fossil fuels (chemical industry, oil refineries, residential heating, and some forms of transport).

It is interesting to note that the UK has high hopes for hydrogen in domestic heating. By 2030, around 1 TWh of residential heating demand is expected to be met by hydrogen, which involves converting around 67,000 homes from gas to hydrogen each year. The strategy then sees hydrogen's share skyrocketing to 45 TWh by 2035, or 10% of residential heating needs.

At the same time, the strategy does not involve the use of hydrogen in road transport - only in those segments that are more difficult to electrify: shipping, aviation, cargo transportation, buses, and trains [11-16].

According to the strategy, the UK's hydrogen economy will be worth £900 million and create 9,000 jobs by 2030, growing to £13 billion and 100,000 jobs by 2050.

The US is seeking to leverage research and development investments to overcome technical barriers and application variations for hydrogen by providing grants for research and demonstration projects. While the Energy Department's hydrogen investment has been capped at about $150 million per year, the Infrastructure and Jobs Investment Act calls for $9 billion in investment between 2022 and 2026. Thus, the U.S. investment is similar to the EU investment under the Next Program Generation. $8 billion of that $9 billion will go toward regional clean hydrogen hubs using the fuel, and another $1 billion will go toward research, development, and electrolysis demonstration projects.

The US Department of Energy estimates that hydrogen consumption will increase 4-6 times by 2050. This will result in hydrogen accounting for 14% of total US energy consumption in 2050.

Hydrogen china: China is the world's largest producer of hydrogen, but not "green" hydrogen, since most of China's hydrogen is produced from coal. In addition to the widespread use of hydrogen in oil refining and ammonia production, the country also has targets for its use in the transportation industry.

The recently published 14th Five-Year Plan identifies hydrogen as a priority sector, with the goal of increasing the share of renewable energy-based hydrogen to 50% of total hydrogen production by 2050. This is a significant commitment given the country's current dependence on coal for hydrogen production. It is also expected that CCS technologies, like those in the US, will play an important role in China in decarbonizing hydrogen production.

It is expected that the future use of hydrogen will be outlined in a related national strategy, which has not yet been published. At the provincial level, for example, Shandong is striving to develop industrial hydrogen clusters, in which various possibilities for the use of hydrogen are intertwined. Pilot programs have also been launched to produce steel using hydrogen from renewable energy sources.

In addition, provincial plans include building hydrogen refueling stations and continuing to subsidize fuel cell vehicles.

Experts also expect current subsidies and investment programs in the transport sector to be extended to hydrogen delivery and storage infrastructure, as well as CCS and electrolysis technologies. However, the extent of this investment remains unclear until a national hydrogen strategy is defined [13-16].

Japanese strategy: "Basic hydrogen strategy" in 2017. This strategy provides for the use of hydrogen for both domestic and industrial purposes. Moreover, hydrogen is integrated into 10 of the 14 priority technology areas in Japan's Green Growth Strategy, published in 2020. Hydrogen is one way for Japan to achieve its long-standing aspirations of becoming independent from fossil fuel imports.

Japan aims to increase hydrogen consumption 20-fold by 2030, from the current approximately 300,000 tons to 6 million tons. Such expansion implies an increase in the

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share of hydrogen in primary energy consumption from the current 0.2% to approximately 4.5%. It is expected that increased demand will be met by domestic production of green hydrogen of 300,000 tonnes in 2030 and 5 - 10 million tonnes in 2050, as well as imports of both green and hydrogen-based hydrogen. natural gas. Although the target share of green hydrogen imports has not yet been determined, domestic hydrogen production will be based on 100% renewable energy by 2030.

Like China, Japan has been using hydrogen in the transport sector since the 2000s. It plans for 800,000 vehicles in the country to be fuel cell-powered by 2030, representing about 1% of all currently registered vehicles. Interestingly, Japan also intends to use hydrogen in the residential sector: by 2030, 5.3 million fuel cells are expected to provide electricity and heat to homes and the industrial sector.

To achieve this widespread economic adoption of hydrogen, Japan is setting quantitative targets for cost reduction and energy efficiency improvements, with extensive research and development programs tied to achieving these goals. Japan is making significant public investments in developing the country's hydrogen infrastructure, accompanied by regulatory reforms, subsidies, and the creation of international hydrogen supply chains [16-20].

In Russia: The understanding of the need to develop promising technologies for the use of renewable energy sources appeared later than in other countries. The development of the legislative framework for supporting renewable energy sources in the Russian Federation began in 2007, and the implementation of the state program in 2015. The main goals of the program are the accumulation in the country of scientific and technological competencies in promising technologies for the use of renewable energy sources and the prevention of technological lag behind advanced countries in this rapidly developing field of global energy; creation of domestic high-tech industrial production of the main components of renewable energy with a high share of localization of production, including the export of competitive products; creating prerequisites for the cost-effective use of renewable energy installations today to supply energy to consumers remote from centralized energy supply networks (Arctic, Far East, etc.). The program is quite modest in scope. Within its framework, in recent years, dozens of renewable energy facilities (mainly solar power plants) with a total installed capacity of about 1 GW have been introduced in the country. By 2035, it is planned to commission about 3 GW of wind power plants, 2.2 GW of solar power plants, and about 200 MW of light hydroelectric power plants in various regions of the country. At the same time, the share of electrical energy generated by renewable energy facilities in Russia's energy balance will be only about 1.5%. Longer-term forecasts for the development of renewable energy in Russia until 2050 and beyond indicate the feasibility (primarily economic) of developing renewable energy at a moderate pace, primarily due to the presence in the country of large reserves of relatively cheap hydrocarbon fuels and plans for the development of nuclear energy, supporting at the same time, a high scientific and technological level in this promising area [21-25].

Discussion

A road map for greening the economy of Turkmenistan

In his speech at the 28th session of the UN Framework Convention on Climate Change (COP28) in the United Arab Emirates in Dubai, President of Turkmenistan Serdar Berdimuhamedov noted that with accession to the Paris Agreement, a number of relevant national programs have been adopted, a number of specific initiatives have been put forward aimed at consolidating and approved a roadmap for international cooperation on adaptation and mitigation of climate change, and announced adherence to the Global Methane Commitment. In general, Turkmenistan is taking steps to introduce low-carbohydrate technologies. Among the promising vectors within the framework of the "green" economy, the implementation of projects for the production of hydrogen from natural gas is being considered. Turkmenistan is actively working to ensure environmental food security, healthcare, rational use of natural resources, recycling, and waste disposal [1-3].

By 2030, Turkmenistan aims to reduce greenhouse gas emissions by 20 percent compared to 2010 and also plans to achieve zero growth in greenhouse gas emissions in the medium term, starting in 2030, and in the long term, significant annual reductions.

On the issue of "green" energy, the National Strategy for the Development of Renewable Energy until 2030 and the Law of Turkmenistan "On Renewable Energy Sources" have been adopted. The law defines the legal, organizational, economic, social, and financial framework, and mechanisms for regulating relations between the state, producers, suppliers, and consumers of renewable energy sources, production equipment, installations, and technology for the use of renewable energy sources.

"Greening" the economy of Turkmenistan: Turkmenistan will implement the Roadmap for the development of international cooperation in the field of hydrogen energy for 2022-2023, which will allow the formation of a new industry in a short time. International analytical and research centers will participate in the

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implementation of the National Strategy for the Development of Hydrogen Energy.

One of the promising areas of the chemical industry is the production of products from hydrogen and the development of hydrogen energy in general. Hydrogen in its pure form remains almost unclaimed, despite the fact that it is the most common element on Earth. However, with the development of science, projects using hydrogen as fuel in all types of transport, from cars to airplanes and ships, are gaining more and more popularity.

According to preliminary calculations, more than 68% of hydrogen is currently produced from natural gas, 16 percent from oil, 11 percent from coal, and 5% from water using electrolysis. The cheapest method of producing hydrogen is from natural gas; it is 5 times cheaper than electrolysis. Thanks to unlimited resources, high energy saturation, technological flexibility, and environmentally friendly energy conversion processes, hydrogen is considered the most promising energy carrier of the future.

Turkmenistan's hydrocarbon fuel reserves make it possible to develop the industrial production of the fuel of the future. Currently, most of the hydrogen produced is used in the chemical (hydrocracking of crude oil) and food (hydrogenation of vegetable oils) industries, due to the ability of hydrogen to enter catalytic hydrogenation reactions at elevated temperatures.

Our country has enormous potential in the production of hydrogen, which can give a significant impetus to the development of the "recovery" of the national economy. Hydrogen has been used in oil refining for many years. But the main source of energy for hydrogen production is natural gas - one of the main resources of our country.

Hydrogen, like electricity, is an energy carrier, and not an actual source of energy, since it does not occur in nature in its free form. As a source of chemical energy, hydrogen is potentially more efficient as a means of energy storage, especially when used in renewable energy systems such as solar and wind power [1,3,4].

Hydrogen, even among alternative fuels, seems to be the most promising in terms of possibilities of use. It makes a significant contribution to addressing three of the most important challenges related to energy use: reducing greenhouse gas emissions, improving energy security, and reducing air pollution. The development of efficient, cost-effective, competitive, and safe hydrogen production technologies is the basis of the future of hydrogen energy.

Hydrogen is used primarily in oil refining and the chemical industry, primarily in the production of ammonia and methanol. The use of hydrogen opens a unique path towards integrated "open energy systems" that meet all the key requirements for clean energy and environmental protection. In addition, in the near future, it may become a medium for storing energy, in particular electricity. One of its advantages is based on the fact that almost any energy source can be converted into hydrogen, making it possible to use it locally in different regions of the Earth.

Therefore, today hydrogen is one of the most effective ways to create long-term energy storage. By 2030, hydrogen, with a price of $2 per 1 kg, will begin to compete with coal and natural gas as an energy source in steel production, and by 2050, its price will eventually drop to $1 per kg, and hydrogen will be able to compete in world markets energy resources with the cheapest coal.

The main disadvantage of energy based on coal, oil, and gas is the annual release of about 30 billion tons of carbon dioxide into the atmosphere. It is the main greenhouse gas that negatively affects the environment.

This gas is recognized by the world community as one of the main factors causing the effect of global warming. It surpasses all other man-made factors and is comparable to powerful natural forces.

The global energy sector is undergoing a process of decarbonization—reducing carbon dioxide (CO_2) emissions. The urgency of decarbonizing energy systems has increased since the entry into force of the Paris Climate Agreement in 2016.

The intensive development of processes for processing hydrocarbons and solid fuels has confronted humanity with problems related to industrial safety and environmental protection. Current trends in solving environmental problems in the production and processing of oil and gas are the development of "clean technologies", which involve the development of environmentally friendly processes and waste disposal, purification of gas emissions from petrochemical production, wastewater from oil and petroleum products [2-4].

Currently, there are several methods for the industrial production of hydrogen, this increases energy security and reduces dependence on certain types of fossil raw materials. The main source of energy for hydrogen production is natural gas.

At the Turkmenbashi complex of oil refineries, installations are used that allow increasing the volume of production of hydrocarbon chemical products. In accordance with the "Program for the development of the oil and gas industry of Turkmenistan for the period until 2030", in the context of the rational use of hydrocarbon resources, work is underway to produce high-quality petrochemical products.

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Due to unlimited resources, high energy saturation, technological flexibility, and environmental friendliness of conversion processes, hydrogen should be considered the most promising energy carrier with the possibility of using various types of fuel.

When using hydrogen as a fuel, electricity is generated by its electrochemical oxidation with atmospheric oxygen in an electrochemical cell, in contrast to the traditional generation of electricity according to the classical three-stage scheme: chemical energy - thermal energy - electricity.

In the coming decades, the creation of fundamentally new types of industry and market is predicted, based on the carbon-free production of hydrogen, its large-scale storage and transportation over hundreds and thousands of kilometers using a system of pipelines and sea and land tankers.

The implementation of large-scale investment projects to produce competitive products is one of the strategic objectives of the development of the oil and gas industry. The economic policy initiated by the head of Turkmenistan, within the framework of which large-scale modernization of industrial facilities is being carried out, ensures the confident, dynamic development of the national economy.

The fuel and energy complex of Turkmenistan is a priority direction for the development of the national economy. High profitability, favorable macroeconomic situation, and investment climate attract foreign investors to our country. Projects for the production of products competitive on world markets are one of the strategic objectives for the development of the petrochemical industry.

Large-scale industrialization, the transition to a digital economy, the formation of an information society, the development of a market economy, and entrepreneurship are the main criteria of the socio-economic policy of the President of Turkmenistan, due to which the consistently high rates of "recovery" of the national economy are maintained, which means a stable increase in the standard of living of the people of the country [2-5].

The distribution of gross and technical potentials of solar energy during conversion into thermal and electrical energy in Central Karakum by months (kWh/m² per month) has been calculated; the histogram is shown in Figure 1.

Conclusion

The aggravation of climate change and the reduction of anthropogenic loads in the decarbonization of the world economy is the introduction of renewable energy sources. Producing hydrogen from renewable energy sources will become the most important tool for decarbonization in the "greening" of the economy.

Turkmenistan has adopted a number of strategic documents on climate change to implement the Paris Agreement. Our country has joined the Global Methane Commitment and envisages reducing greenhouse gas emissions by 20% in 2030 compared to 2010 levels.

In accordance with the "Program for the development of the oil and gas industry of Turkmenistan for the period until 2030", in the context of the rational use of hydrocarbon resources, work is underway to produce high-quality petrochemical products.

The development of hydrogen energy is being studied, a roadmap has been drawn up for the implementation of pilot demonstration projects, hydrogen transportation, storage conditions, participation in the hydrogen technology market, energy utilization of hydrogen-containing waste gases, and other key technological areas.

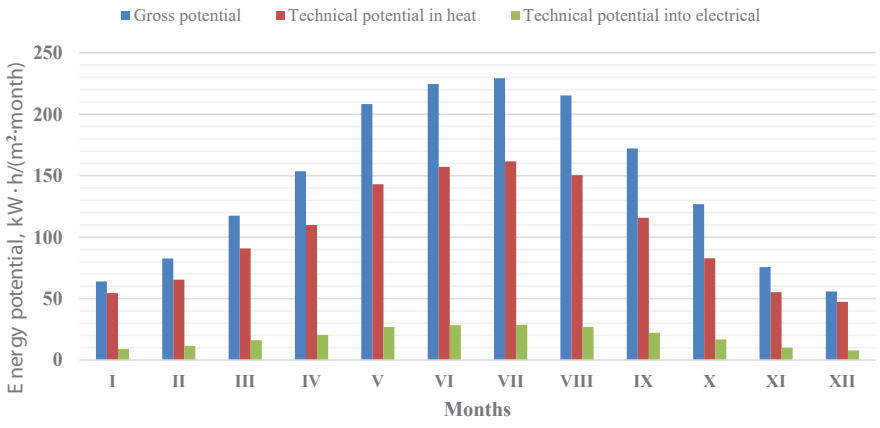

Figure 1: Distribution of the gross and technical potential of solar energy from conversion into thermal and electrical energy in the Karakum desert zone by month per 1 square meter during the year.

Author's contribution

The author analyzed global sources on climate change and renewable energy.

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