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RENEWABLE ENERGY SOURCES AND HYDROGEN IN ENERGY SYSTEMS: CHALLENGES AND ADVANTAGES

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The Monograph addresses the relevant issues of renewable energy sources integration into energy systems, including by switching to green hydrogen, and the challenges, related thereto. The examples of renewable energy sources functioning in the energy system in Germany are provided. Availability of resources and technologies, required for the energy transition in EU as part of the hydrogen strategy, is assessed. There is a comparison of volumes and dynamics of greenhouse gas emission in EU and Russia, of Russian and foreign methods of carbon footprint calculation.

The paper may be of interest for a wide spectrum of readers: research scientists, teachers, postgraduates, students and other interested persons.

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Abbreviations

Alkaline – alkaline electrolyser
BAT – best available technology
CBAM – Carbon Border Adjustment Mechanism
CCGT – combined cycle gas turbine unit
CHPP – combined heat and power plant
E – environment
EF – efficiency factor
EHB – European Hydrogen Backbone
EOH – equivalent operating hour
EU – European Union
FHUF – fuel heat utilization ratio
FL – federal law
FPC – fuel and power complex
GTE – gas-turbine engine
GTU – gas-turbine unit
HPP – hydropower plant
HTGCR – high-temperature gas-cooled reactor
ICUF – installed capacity utilization factor
IEA – International Energy Agency
LULUCF – land use, land-use change and forestry
NCRES – non-conventional renewable energy sources
NETC – nuclear electrotechnological complex
NPP – nuclear power plant
PDC – power delivery contract
PEM – polymer electrolyte membrane electrolyser
PSHP – pumped-storage hydroelectric plant
RDTE – research, development, testing and engineering
RES – renewable energy sources
RF – Russian Federation
SOEC – solid oxide electrolyser cell
SPP – solar power plant
SPU – steam power unit
SRFC – specific reference fuel consumption
TPP – thermal power plant
TPS – tidal power station
UES – Unified Energy System
UGS – underground gas storage
UN – United Nations
VAT – value added tax
WACC – weighted average capital cost
WF – wind farm
WTO – World Trade Organization

Introduction

In order to consider the ambiguous objectives and problems of non-conventional and renewable energy sources engagement in energy systems of various countries and regions one should apply diverse perspectives, including environmental friendliness and reliability, sustainability of operation and low-carbon solutions. Countries opt for various priorities of their energy systems development, based on core demands of the time, thus responding to the key contemporary challenges.

The United Nations Framework Convention on Climate Change adopted in 1992, pulls together the efforts of the countries aimed at prevention of hazardous climate changes. According to the Convention, every country adopts national policy aimed at limitation of greenhouse gases emission into the atmosphere. Commitments of countries to reduce emissions of greenhouse gases are recorded in the Paris Agreement [1] that has regulated the measures to mitigate carbon dioxide content in the atmosphere since 2020.

The hydrogen economy strategy [2] was presented on July 08, 2020 as part of the implementation of the Paris Agreement. This strategy will enable the European Union to achieve the objective of carbon neutrality by 2050. The priority of the EU is to develop renewable hydrogen sources, made largely with the use of wind and solar energy. Choice in favor of renewable hydrogen is based on the European industry leadership in electrolysers production technologies. The strategy states that “Investments in hydrogen will foster sustainable growth and job creation, which will be crucial in the context of recovery after COVID-19 crisis”.

The strategy encompasses the end-to-end cycle issues: from development of green hydrogen[1] production technologies to end use thereof, including storage, transportation; development of competitive green-hydrogen-driven technologies in industry, transport, power economy and construction; arrangement of conditions for investments; development of regulatory framework and tax environment; shaping of a demand for green hydrogen; development of market-based models, supporting renewable energy sources; establishment of mechanisms to protect native manufacturers. It is provided for a complex of organizational, regulatory, investment measures, ensuring competitiveness of EU economy.

The important aspect of the EU hydrogen strategy implementation is the commitment to extend it to foreign trading partners through economic relations and diplomacy, including through investments “in international cooperation in the area of climate, trade and research activities” [3]. The New Industrial Strategy for Europe provides for establishment of “global standards of high quality” to strengthen “the industrial competitiveness”. “The EU will continue efforts to uphold, update and upgrade the world trading system, so it is fit to address today’s challenges and tomorrow’s realities” [3].

The next step to promote the hydrogen and the New Industrial Strategy was a package of proposals, published by the European Parliament on July 14, 2021, to deliver the changes across the EU economy, making it possible to decrease emissions of greenhouse gases by at least 55% by 2030 compared to 1990 and for being the first climate neutral continent by 2050.

[1] Green hydrogen implies renewable-energy-source-based production; blue hydrogen is produced based on NPP and HPP, CO2 capture and storage technologies; grey hydrogen is derived from natural gas, coal oil products.

The package of proposals includes i.a. the Carbon Border Adjustment Mechanism (CBAM) [4]. It is expected that within the framework of the CBAM the price of CO2 emissions will be the same for the products of European manufacturers and imported goods. Thus, the European Union declares a non-discriminatory nature of CBAM and compliance thereof with the WTO regulations and the EU's other international obligations.

It is assumed that CBAM will be introduced gradually, at an early stage it will apply to a limited number of goods. The consequences of CBAM introduction for developing countries were considered and the countries most affected by introduction of this mechanism were determined as part of the UN Conference on Trade and Development [5] (Fig. 1).

According to the analysis data, obtained by the UN Conference on Trade and Development, the Russian Federation is at the most risk from introduction of CBAM in terms of the aggregate export value.

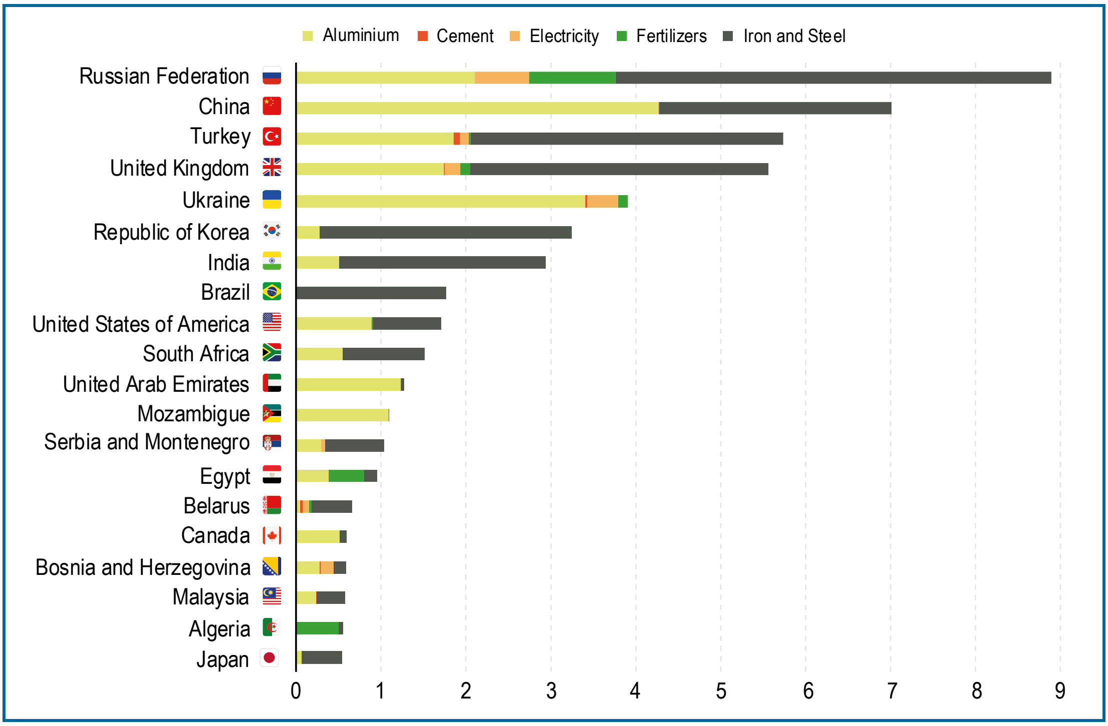

Figure 1. Countries' export to the European Union in 2019 from the perspective of individual sectors that may be subjected to CBAM, bln. US dollars [5]

The European Union is one of the key trading partners of the Russian Federation. Structural changes in the EU economy may lead to changes in conditions and structure of export (import) of goods and services from the RF, therefore, the analysis of reasons and consequences of transition to hydrogen economy is a relevant problem.

The Russian Federation joined the Paris Agreement on September 23, 2019. It is worth mentioning that at present a considerable share of HPP, NPP, combined CHPP generation and a minor share of coal power generation in the country's power balance makes it possible for the electric power industry of the Russian Federation to be one of the world leaders in terms of CO_2 emissions reduction. The rate of CO_2 emission from electric energy generation (gCO_2/kW·h) in general throughout the energy system of the RF is by 26% less than in the USA, by 30% less than in Germany, two times less than in China, by 41% less than the worldwide average and correspond to the level of Denmark [6]. A subsequent analysis confirmed these findings: the rate of CO_2 emission from electric energy generation in the energy system of the RF is lower than in the USA, Germany, Portugal, Mexico, the Netherlands, Japan, South Korea, China, Australia, Indonesia, India, Poland and RSA, slightly higher than in Denmark and slightly lower than in Italy [7]. The design of electric and heat energy systems development in terms of compliance of generating capacities structure with the pattern of consumption, increase in the proportion of combined electric power and heat generation, use of best available technologies (BAT) will result in further decrease of carbon dioxide emission ratio in our country.

It is important to note that the Russian Federation has vast experience in design and implementation of comprehensive development programs. For instance, one hundred years ago GOELRO (the plan for national economic recovery and development) was developed. This plan included the comprehensive program of generating capacities and industrial enterprises development, personnel training, research and development, increase of fuel efficiency, funding issues. The next step was a large-scale introduction of a heating system in cities and industrial hubs.

The Soviet (Russian) scientists laid the scientific foundation of energy systems design back in the last century [8, 9]. The issues of energy systems horizontal integration were addressed in late 70s of the last century by an international scientific panel, including Soviet scientists [10]. Unfortunately, following the launch of the electric power market in 2003, the domestic experience has barely been used in designing the electric energy system of the RF, for the most part, there is a direct copying of foreign fashion trends regardless of their applicability for Russian economy.

The Russian Federation has accumulated an extensive experience of hydrogen energy projects implementation, including green hydrogen production.

Initially, hydrogen technologies were used in rocket science and space sector. In 1971, 1.2 kW Volna electrochemical generator was developed as part of the Luna Program, in 1988, 10 kW Foton system was developed for Buran spaceplane. Later hydrogen found use in shipbuilding, machine building and aircraft industry. RAF car, driven by hydrogen alkaline fuel cell, was manufactured in 1982. The first experimental aircraft, powered by hydrogen TU-155 flew in 1988. There have been established units for stand-alone generation, driven by electrochemical generators, including marine generators with a capacity of 150 kW and more in Russia [11].

Nuclear and hydrogen technologies (hydrogen production through HTGCR, thermochemistry and water desalination, industrial energy technology complexes) proliferated during the USSR period under the guidance of academicians V. A. Legasov, N. N. Ponomarev-Stepnoy at the end of the 80s [12]. The Committee for the Food and Processing Industry adopted Technological Design Standards of Hydrogen Generation by Electrolysis in 1994 [13]. The design standards cover the issues of reliability, security, efficiency of hydrogen generation by electrolysis.

The major obstacle, hindering hydrogen application in the energy sector, is that the energy, generated upon hydrogen generation is less than, the energy consumed by the process [14]. The hydrogen generation process is considered a way of SPR and WF energy storage, characterized by inconsistency and low degree of production predictability. Currently, the efficiency of the water-electrolysis-based cycle makes approximately 60%.

The prospects and necessary conditions of Russian and EU energy systems transition to green hydrogen should be analyzed from the systemic (scientific) perspective.

It is relevant to analyze the feasibility of the goals, set by the EU as part of the hydrogen strategy and availability of the resources necessary to shift to green hydrogen: demand for WF and SPR electric capacity; the territory to place WF and SPP; required quality of water resources for electrolysis; irregular distribution of resources throughout the EU territory.

The important aspect of green hydrogen production is the utilization of energy and water resources, which are characterized by seasonal and daily irregularity. Transition to hydrogen economy will make it necessary to address a complicated challenge to ensure the balance of green hydrogen production and consumption subject to seasonal and daily irregularity of water resources and to take into account the risks of low water years [15]. Irregularity and low predictability of WF and SPP energy generation will require to establish comprehensive electric energy storage, source and distilled water and hydrogen storage systems.

It is essential to mention that subject to the Water Framework Directive absence of artificial barriers for free continuous water flow is a key to ensure good status of European waters. The cumulative impact of a large number of water barriers in Europe is one of the main causes of over 80% decline in biodiversity of freshwater resources and loss of 55% of monitored migratory fish population. The EU biodiversity strategy is aimed at restoration of at least 25 000 km of free flowing rivers by 2030 through removal of previously created barriers and rehabilitation of flood basins and wetlands [16].

It should be pointed out that the directives and the programming documents, adopted by the EU, lack consideration of possible risks, related to the impact, which may be produced by the transition to hydrogen economy in terms of climate changes, as such a transition will be accompanied by a sharp increase in air emissions of water vapor, the major greenhouse gas in atmosphere, and by the accompanying heat pollution of atmosphere [17].

Particular attention should be devoted to the issues, related to the assessment of how growing levels of hydrogen utilization in economy impact emission of nitrogen oxides (NOx), regulated by the protocols to the UNECE Convention on Long-Range Transboundary Air Pollution [18].

Transition of the Russian Federation to green hydrogen poses considerable risks to competitiveness of domestic economy. It is important to mention that according to the forecast of the International Energy Agency (IEA), the cost of hydrogen production in the Russian Federation will be one of the highest in the world [19].