CLEAN ENERGY AND HYDROGEN PERSPECTIVES IN RURAL REGIONS OF KAZAKHSTAN

Vladislav Zavadskiy[1], Gita Revalde[1, 2]
[1]Almaty University of Power Engineering and Telecommunication, Kazakhstan;
[2]Riga Technical University, Latvia
vladislav.zavadskiy@gmail.com, gita.revalde@rtu.lv

Abstract. The paper describes the results of our study about the perspectives of clean hydrogen production in the rural regions of Kazakhstan. A brief introduction to clean hydrogen technology and its connection with renewable energy sources is presented in the article. As an example, the case study on renewable energy sources availability was done for the Akmola region of Kazakhstan. We elaborated the model of clean hydrogen production with numerical results including studying the potential of renewable energy sources and utilizing produced clean energy for hydrogen production using the modern available technologies. Also, a part of using clean hydrogen in the region for the wheat-producing purpose based on the current fuel needs was covered. We believe that our research will stimulate the development of clean hydrogen production in the region. Kazakhstan has great renewable energy potential and could be a promising place for clean hydrogen production in the region as well.

Keywords: clean energy, hydrogen, renewables, rural regions, diesel fuel demand, water electrolysis, agriculture.

Introduction

Nowadays we can observe rapid development and changes in the provision of energy resources. Due to the current situation in the world, unpredictable prices and availability of conventional energy sources, clean hydrogen, and renewable sources could be the priority in some regions.

The fast changing world creates new challenges for energy demand covering. Oil and gas price fluctuations make them less stable and reliable power supply sources (Figure 1, 2) [1].

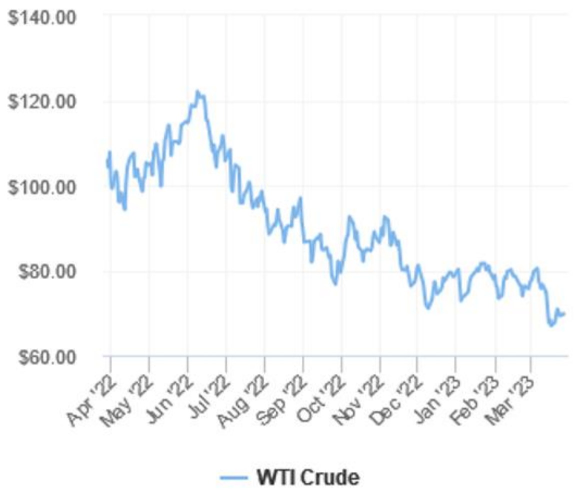

Fig. 1. **WTI Crude Oil price diagram, 2022-2023 [1]**

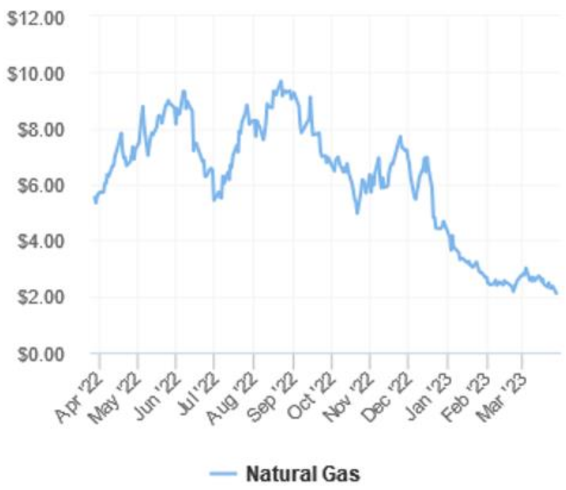

Fig. 2. **Natural gas price diagram, 2022-2023 [1]**

Environmental threats and climate risks cannot be avoided [2]. In such a reality, there is no way to find a new basement, new perspective energy supply sources. One of the options could be hydrogen fuel, especially “green” hydrogen. Hydrogen can be extracted from hydrocarbon fuels through the thermal process and today it is the most used technology, producing about 95% of hydrogen [3]. But to make it “clean” and “green” a traditional fuel component should be excluded. This goal could be met by the production of hydrogen by water electrolysis where water is split into hydrogen and oxygen through the application of electrical energy by using different technologies: alkaline electrolysis, PEM (proton exchange membrane), etc. [4].

Alkaline water electrolysis involves the usage of the diaphragm which separates anode and cathode electrodes, and the solution conductivity is enhanced by using strong electrolytes like potassium hydroxide. Hydrogen could be collected on the cathode during the electrolysis process (Figure 3) [4].

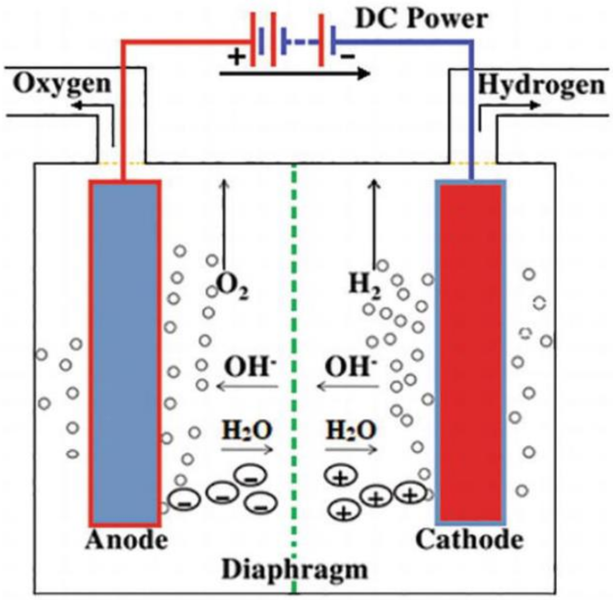

Fig. 3. **Alkaline water electrolysis concept [4]**

PEM type of electrolysis is a type of electro-osmotic flow where protons migrate to the cathode from the anode under the effect of the electric field and are reduced to molecular hydrogen. Oxygen is removed by the water circulation [3; 4].

The water electrolysis process seems the most perspective due to the hydrogen source availability (water) but at the same time, it is still the most expensive in the near term [5]. Green hydrogen involves the use of renewable energy sources for its production. But there are also certain costs here, such as large losses of electricity, reaching up to 35% [6]. However, according to forecasts, the cost of green hydrogen is expected to fall by almost 2 times by 2030, which makes it a very attractive source of energy [7].

In this case study based on literature analysis and our own calculations, the goal is to consider if green hydrogen could be a source of fuel for the agricultural Akmola region in Kazakhstan. The region has great agricultural potential and acts as the main wheat supplier in Kazakhstan. The issue of providing fuel for grain harvesters is important here. At the same time, the region has great wind potential and could be interesting for clean hydrogen production.

We believe that our research will stimulate the development of clean hydrogen production in the region.

1. Materials and methods

1.1. Prospects for use of hydrogen in agriculture

According to our model, we assume the replacement of the use of diesel fuel by green hydrogen. In addition, in order to speed up this process and reduce its cost, studies were carried out on possible technologies for the conversion of the existing diesel engines and the use of the existing fleet of vehicles. Having a need for diesel fuel, we will make a calculation to use an equivalent amount of green hydrogen. In turn, the calculation of the potential for the production of green hydrogen using renewable energy sources will also be performed.

Currently, the main source of fuel for agricultural machinery is diesel fuel. In 2022, more than 423 thousand tons of diesel fuel were provided for the autumn harvesting campaign in Kazakhstan, of which 83 thousand tons were fuel for the Akmola region, which is one-fifth of the volume for the republic [8]. It should also be noted that the main crop of this region is wheat.

Since diesel fuel and, accordingly, diesel engines are most often used in agriculture, the task of converting them to hydrogen arises. And such active work is underway to find solutions for the conversion of diesel engines to hydrogen.

According to our investigations, the most significant achievements were made by the University of New South Wales (UNSW) research team which modified a conventional diesel engine in which up to 90% of diesel could be replaced by hydrogen. It is still an experimental type, but they are going to convert it into a commercial product in two years [9; 10]. This innovation not only reduces emissions but also improves engine efficiency by 26% [11].

This innovation is an indicator that active developments are being carried out in this direction, to already known hydrogen cells, but its main advantage is precisely the modernization of the existing engines and the possibility of using the existing fleet of vehicles.

Another indisputable advantage of hydrogen is its energy intensity, which is almost three times higher than that of diesel. The energy intensity of diesel is about 12-14 kWh per kg but hydrogen has equal to 33.6 kWh of usable energy per kg [12].

To calculate the required equivalent of hydrogen fuel, we use the following formula:

$$H_2 = D \cdot K_1 \cdot K_2, \tag{1}$$

where H_2 – required hydrogen, tons;
D – diesel fuel consumption, tons;
K_1 – hydrogen replacement ratio;
K_2 – engine efficiency increase factor.

Thus, it can be assumed that to cover the annual demand of the Akmola region for hydrogen for sowing and harvesting campaigns, instead of diesel fuel, the agricultural industry may need 55 278 tons of hydrogen, given that $K_1 = 0.9$ and $K_2 = 0.74$.

1.2. Possibilities of hydrogen production

Nowadays, there are more and more manufacturers of industrial electrolysis plants for hydrogen. The most convenient for agricultural purposes are modular cells that can be quickly installed and scaled according to the needs (Figure 4) [13].

There is a trend that manufacturers are focusing specifically on the production of green hydrogen using renewable energy sources. On November 29, 2021, the largest PEM electrolysis plant was launched in the European Union. It has a production capacity of about 1, 300 tonnes of green hydrogen a year and uses renewable energy sources [14].

Speaking about the efficiency of using electricity for hydrogen production, at the moment, many manufacturers claim certain achievements in this area and indicate values of 1.55 kWh for 1 kg of hydrogen [15].

Ready-made modular stations are quite easy to use and can be used in close proximity to consumers. To produce large volumes of hydrogen, it is necessary to build fairly large facilities.

Fig. 4. **Containerized PEM electrolyser [13]**

2. Results and discussion

According to the literature analysis and calculations, it turns out that in order to meet the need for replacing diesel fuel with hydrogen for the Akmola region, it is necessary to produce it in the amount of 55.278 thousand tons annually.

To calculate the required amount of electricity, we use the following formula:

$$E = H_2 \cdot E_1, \tag{2}$$

where E – required electricity, GWh;
H_2 – required hydrogen, thousand tons;
E_1 – electricity consumption for production of 1 kg of hydrogen, kWh.

The amount of electricity required for this can be estimated at 85.681 GWh. Speaking about the potential and type of renewable energy sources in the Akmola region, the most promising is the use of wind energy [16].

The wind energy potential in the region of our interest can be evaluated using the Global Wind Atlas [17]. We are considering 50 m heights mean wind power density map (Figure 5) [17].

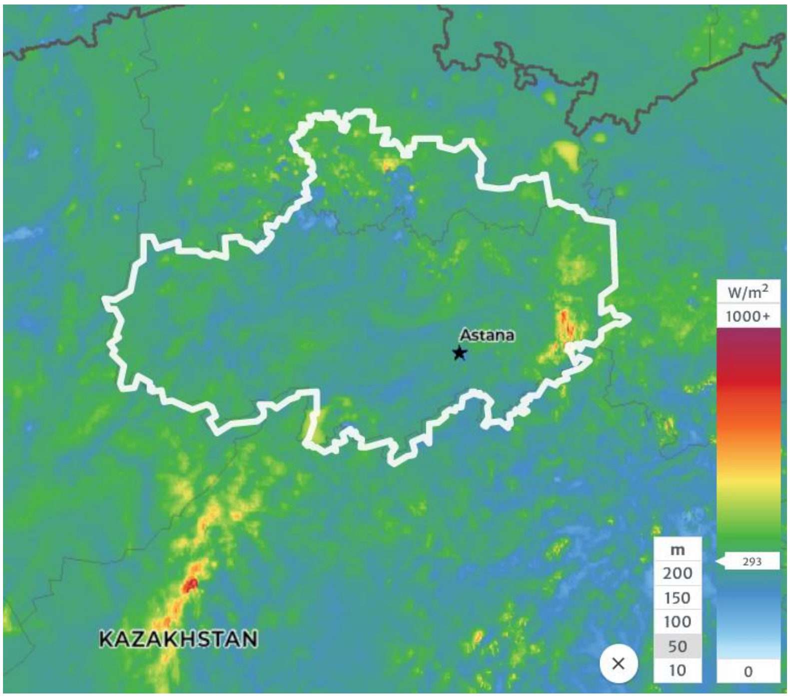

Fig. 5. **Mean wind power density map for 50 m heights [17]**

The average wind potential value in the Akmola region is 402 W/m^2 (Figure 6) [17]

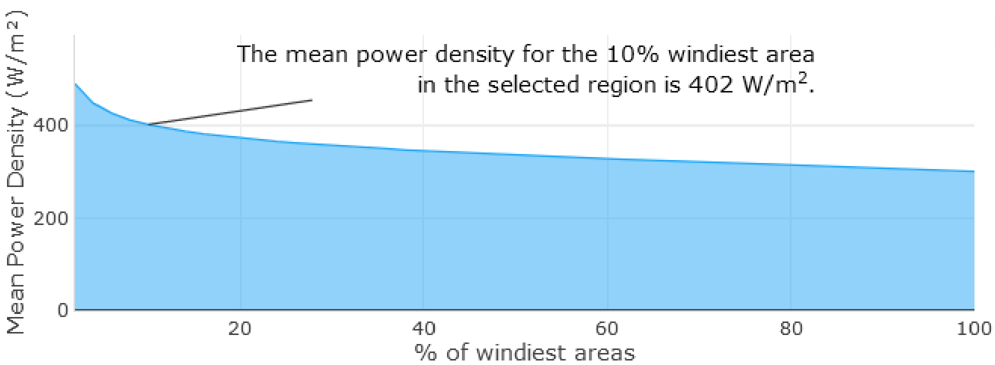

Fig. 6. **Mean wind power density at 50 m heights [17]**

The theoretical area required for a wind farm, based on the obtained potential per square meter, is calculated using the following formula:

$$S = E / P_w, \quad (3)$$

where S – required area, sq. meters;
E – required electricity, W;
P_w – average wind potential, W·m^{-2}.

With such output theoretically, 213 square kilometers will be required for wind generation. Such values are the possible highest theoretical potential according to the used sources.

The area of the entire Akmola region is 146.2 thousand kilometers [18], which makes it possible to place a wind farm of the required capacity. In addition, if we consider a height of 100 meters, then the wind potential is even higher there (Figure 7, 8) [17].

In such cases, the area required for wind farms is even smaller and could theoretically be about 151 square kilometers.

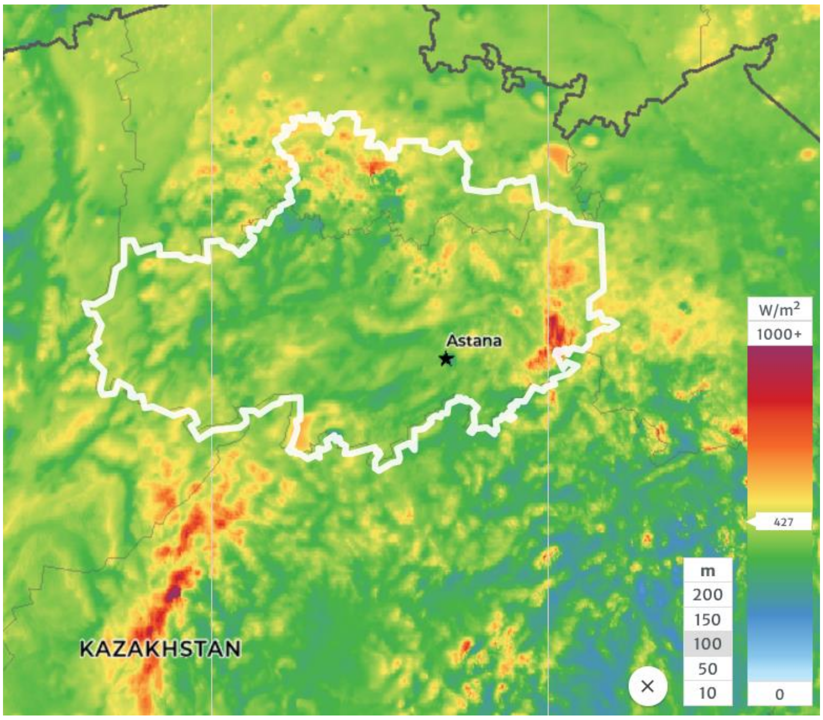

Fig. 7. **Mean wind power density map for 100 m heights [17]**

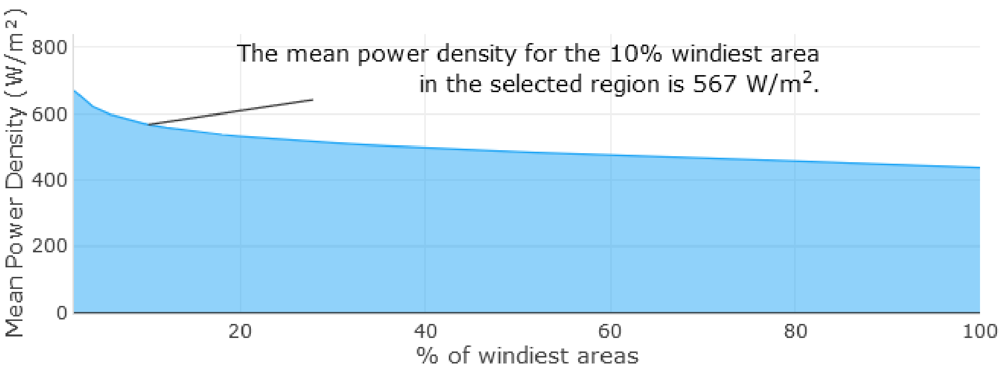

Fig. 8. **Mean wind power density at 100 m heights [17]**

Based on our calculations, it turns out that it is theoretically possible to cover the need for electricity for the production of green hydrogen for the agricultural sector of the Akmola region.

Conclusions

Currently, there is an active search for a replacement for traditional energy sources, primarily such as oil and gas. Hydrogen seems to be one of the most promising for today. In this case study, based on literature studies and our calculations, the perspectives of clean hydrogen production in the rural regions of Kazakhstan on the example of the Akmola region were examined.

Speaking of agriculture, where diesel is primarily used as a fuel, the potential for using hydrogen is also very high. Recent developments in the use of hydrogen in internal combustion engines show that it is 26% more efficient than diesel and up to 90% of diesel fuel in existing engines could be replaced with hydrogen.

The Akmola region of Kazakhstan is a large agricultural region, where wheat is predominantly grown and where there is a large demand for diesel fuel. At the same time, it has great potential in the production of wind energy. Thus, it is theoretically possible for the region to meet the demand for green hydrogen and replace diesel fuel with it. To cover hydrogen demand instead of diesel theoretically 151 square kilometers of wind farms could be used, while the whole Akmola region area is 146.2 thousand kilometers.

However, there are quite a few tasks to be solved: to bring to industrial operation and mass production internal combustion engines running on hydrogen, to build a network of filling stations, wind generating capacities, and hydrogen production stations, to increase their efficiency.

Among other things, projects for the introduction of green hydrogen in the agricultural industry should be subjected to a comprehensive analysis for economic efficiency and investment attractiveness.

In general, the prospects for the use of green hydrogen in Kazakhstan seem to be very promising.

Author contributions

Conceptualization, review, and editing G.R.; methodology, analysis and calculations Vl.Z.

References

[1] Oilprice.com, Energy news site. [online] [23.03.2023] Available at: https://oilprice.com/oil-price-charts/

[2] Zavadskiy V., Revalde G., Climate risks and their impact on development of RES in rural regions of Kazakhstan. Proceedings or Engineering for rural development, Jelgava, 25-27.05.2022, pp. 832-839, DOI: 10.22616/ERDev.2022.21.TF257.

[3] Hydrogen and fuel cell technologies office, Office of energy efficiency and renewable energy, U.S. Department of Energy. [online] [23.03.2023] Available at: https://www.energy.gov/eere/fuelcells/hydrogen-fuel-basics

[4] Youssef N., Amal A. Advances In Hydrogen Generation Technologies, chapter Hydrogen Generation by Water Electrolysis, 22.08.2018, DOI: 10.5772/intechopen.76814, [online] [20.03.2023] Available at: https://www.intechopen.com/chapters/60944

[5] The future of hydrogen, Report prepared by the IEA for the G20, Japan, 2019. [online] [15.03.2023] Available at: https://iea.blob.core.windows.net/assets/9e3a3493-b9a6-4b7d-b499-7ca48e357561/The_Future_of_Hydrogen.pdf

[6] 4 technologies that are accelerating the green hydrogen revolution, World Economic Forum, 29.06.2021. [online] [15.03.2023] Available at: https://www.weforum.org/agenda/2021/06/4-technologies-accelerating-green-hydrogen-revolution

[7] The green hydrogen economy, Predicting the decarbonisation agenda of tomorrow, PWC. [online] [15.03.2023] Available at: https://www.pwc.com/gx/en/industries/energy-utilities-resources/future-energy/green-hydrogen-cost.html

[8] Achkulakov B., More than 423 thousand tons of diesel fuel were allocated for autumn harvesting work, Kursiv, 27.08.2022. [16.03.2023]. Available at: https://kz.kursiv.media/2022-08-26/na-osenne-polevye-raboty-vydeleno-bolee-423-tys-tonn-dizelnogo-topliva/

[9] The race to make diesel engines run on hydrogen, BBC, 20.01.2023. [online] [15.03.2023] Available at:https://www.bbc.com/news/business-64248564

[10] Liu X., et al., Direct injection of hydrogen main fuel and diesel pilot fuel in a retrofitted single-cylinder compression ignition engine, International Journal of Hydrogen Energy, vol. 47, Issue 84, 2022, pp 35864-35876, ISSN 0360-3199, DOI: 10.1016/j.ijhydene.2022.08.149.

[11] Paleja A., Scientists retrofit diesel engines to use hydrogen as fuel, increasing efficiency 26%, Interesting Engineering, 10.10.2022. [online] [16.03.2023]. Available at: https://interestingengineering.com/innovation/retrofit-diesel-engines-hydrogen-fuel
[12] Molloy P., Run on Less with Hydrogen Fuel Cells, Interesting Engineering, 02.10.2019. [online] [16.03.2023]. Available at: https://rmi.org/run-on-less-with-hydrogen-fuel-cells
[13] Nel electrolysers. [online] [17.03.2023]. Available at: https://nelhydrogen.com/water-electrolysers-hydrogen-generators/?ppc_keyword = hydrogen%20generator&gclid = EAIaIQobChMIjdyMkZiL_gIVzyMrCh3PnwrXEAAYAiAAEgJ2ZfD_BwE
[14] Inauguration of Europe’s largest PEM electrolysis plant in REFHYNE project, Fuel cells and hydrogen. [online] [17.03.2023]. Available at: https://wayback.archive-it.org/12090/20220602205511/https://www.fch.europa.eu/news/inauguration-europe%E2%80%99s-largest-pem-electrolysis-plant-refhyne-project
[15] Hydrogen electrolysis, AHBD. [online] [17.03.2023]. Available at: https://ahdb.org.uk/knowledge-library/hydrogen-electrolysis
[16] Zavadskiy Vl., Unit Commitment in a dispersed power system involving renewable energy, LAP LAMBERT Academic Publishing, ISBN-13:978-3-659-82615-3; ISBN-10:3659826154; EAN:9783659826153, 2018.
[17] DTU Wind Energy, Department of Wind Energy, Global Wind Atlas. [online] [27.03.2023]. Available at: https://globalwindatlas.info/en/area/Kazakhstan/Aqmola
[18] Visit Kazakhstan. [online] [17.03.2023]. Available at: https://visitkazakhstan.kz/ru/guide/information/1/0/