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The Geopolitical Dependence of Hydrogen

Maciej Mrozowski, Kacper Bednarz

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Abstract: Climate change is increasingly causing drastic consequences for humanity both economically and environmentally. Facing these challenges, the world is looking for many alternative solutions in the field of energy, among others. One such solution is hydrogen. The article analyses the geopolitical aspects of hydrogen trade in the context of the global energy transition. Water, an essential component of hydrogen, has become a key element in the drive to reduce greenhouse gas emissions and the search for alternative, sustainable energy sources. The dynamic growth of the hydrogen sector is leading to new centers of geopolitical influence and changing traditional commodity supply chains. Forecasts for future hydrogen trade suggest an increase in the importance of renewable energy sources at the expense of traditional raw materials, which could shape new national and international strategies. The development of energy infrastructure related to the production and distribution of green hydrogen plays a key role. Analysing the map of global hydrogen trade, which indicates an increasing interest in this element as a clean energy source, we can see the growing role of this raw material in the global economy and its potential to revolutionize national and international energy strategies. In conclusion, the article shows that the geopolitical aspects of the hydrogen trade have the potential to significantly affect global politics, economics and energy distribution in the coming years, highlighting the need for appropriate action at the national and international levels.

Key words: hydrogen, energy transformation, supply chain, hydrogen production

1. Introduction

In the context of the global challenges of climate change and the need to reduce greenhouse gas emissions, the search for alternative, sustainable energy sources is becoming a key priority for countries and communities around the world. In the context of the global challenges of climate change and the need to reduce greenhouse gas emissions, hydrogen as a potential clean energy source is becoming of increasing interest in the context of the global energy transition. Hydrogen's properties as an energy carrier, in particular its ability to burn emission-free, make it attractive in the context of efforts to reduce greenhouse gas emissions and curb climate change. Hydrogen also has a wide range of applications in different sectors of the economy, including transport and the production of electricity and heat, highlighting its versatility as a potential energy carrier in the context of the energy transition. Furthermore, it should be noted that hydrogen has long been utilized in industries such as the production of ammonia in the Haber process and during petroleum refining, confirming its significance as a key component in many production processes (Graff, 2020: 1).

In terms of future energy prospects, the potential of hydrogen as a clean energy source has significant implications for the evolution of global energy supply chains and the geopolitical balance of power. Anticipated advances in hydrogen technologies suggest the possibility of shaping new energy distribution routes over the coming two decades. These possible developments open up new prospects for countries developing hydrogen technologies, enabling them to enter the global energy arena. It follows that such countries may seek to increase their own energy sovereignty and strengthen their geopolitical position by using hydrogen as a key element of their energy strategies. As a result, the development of hydrogen technologies may trigger shifts in the global political and economic order, which in turn may lead to the rise of new players on the international stage. In terms of future energy prospects, the potential of hydrogen as a clean energy source has significant implications for the evolution of global energy supply chains and the geopolitical balance of power. Anticipated advances in hydrogen technologies suggest the possibility of new energy distribution routes being shaped over the coming two decades. These possible developments open up new prospects for countries developing hydrogen technologies, enabling them to enter the global energy arena. It follows that such countries may seek to increase their own energy sovereignty and strengthen their geopolitical position by using hydrogen as a key element of their energy strategies. As a result, the development of hydrogen technologies may trigger shifts in the global political and economic order, which in turn may lead to the rise of new states in the international arena.

2. Global energy transition policy

Climate change currently poses the greatest threat to humanity, both in humanitarian, economic and environmental terms. A drastic increase of 0.7 °C in global temperature relative to the pre-industrial era leads to the deaths of approximately 150 000 people (Dobrowolski, 2020: 1). Millions of people around the world suffer the consequences of climate change in the form of various natural disasters. Violent weather events damage agricultural crops and seriously threaten global food security. Experts warn that in the absence of action to combat climate change, significant areas of Africa and Asia could become uninhabitable, which could result in massive population migration. It is estimated that by 2050 the number of potential climate refugees could reach 250 million people (Dobrowolski, 2020: 1). Forecasts clearly alarm that time for action is slowly running out. So-called Representative Concentration Change Pathways, or anthropogenic forcing scenarios, are now being used. Four basic scenarios, which are called RCP2.6, RCP4.5, RCP6 and RCP8.5, have been developed to estimate the evolution of atmospheric composition in the future, taking into account different levels of radiative forcing at the end of the 21st century (year 2100), expressed in units of W/m^2 (Wibig, 2020: 39). The scenarios predict climatic changes, for example rising temperatures and decreasing glacier volumes, which are not desirable from the point of view of ecosystem stability and human safety. These changes can lead to negative consequences such as extreme weather events and water shortages. It is therefore important to take action to reduce greenhouse gas emissions and adapt to a changing climate in order to limit the effects of these changes. Faced with a changing climatic reality and increasing challenges of greenhouse gas emissions, global energy policy has undergone a significant transformation in recent years. The previous model based mainly on the use of fossil fuels, primarily coal, is gradually giving way to strategies based on renewable energy, such as solar, wind and hydropower. Many countries are introducing policies to support investment in renewable energy sources and promoting technological innovation to increase the share of green energy in total energy production. In addition, countries are taking steps to increase energy efficiency and reduce environmental impacts through emissions regulations, carbon taxation and the introduction of emissions trading schemes. Joint international initiatives, such as the Paris Agreement, provide a platform for countries to act together to reduce greenhouse gas emissions and adapt to climate change. Under these initiatives, countries have committed to set and meet ambitious climate targets and to support adaptation measures in response to climate change.

2.1. International climate regulations

According to the so-called Stern Report, which was published in 2006, we can learn that approximately 1 % of the world's Gross Domestic Product (GDP) needs to be spent annually in order to effectively combat global warming by reducing greenhouse gas emissions. The report warns that failure to take appropriate action could lead to serious consequences in the long term. It is estimated that failure to act against climate change could lead to adverse weather patterns, which in turn could result in a decrease in global GDP of up to 20% (Olkuski et al., 2017: 96). Thus, international climate regulations play a key role in global efforts to address climate change and reduce its impacts. As awareness of the urgency of climate change grows, the international community is taking increasingly decisive action to achieve greenhouse gas emission reduction and climate change adaptation targets.Within this context, there are a number of international agreements and protocols that set out the environmental and climate commitments of states.

2.1.1. Paris Agreement

One of the key international agreements in the context of climate change. The Agreement was signed at UN Headquarters on 22.04.2016 in New York by the Commission and the Council on behalf of the European Union, with all Member States signing on their behalf. The European Parliament gave its consent to the EU ratification of the Agreement on 4.10.2016, and the following day the EU Council ratified it on behalf of the EU.

The ratification by the EU, which is responsible for around 12% of global greenhouse gas emissions, fulfilled the requirement for approval by at least 55 Parties to the Climate Convention, representing at least 55% of global emissions. The agreement entered into force on 4 November 2016, less than a year after it was signed.

It is a clear signal of an intensification of the global response to climate change, assuming that the increase in average temperatures is kept below 2°C above pre-industrial levels and even aiming to limit the temperature increase to 1.5°C. The agreement sets differentiated targets for different countries, taking into account their specificities and capacities, and provides mechanisms for monitoring, reporting and verifying actions.

The European Union's primary contribution to the achievement of the Covenant's objectives is to reduce its own greenhouse gas emissions by at least 40% across the economy by 2030 compared to 1990. An intermediate target has also been adopted, i.e. to achieve a share of RES in the energy consumed in the EU of at least 27% and to increase energy efficiency by at least 27% (Sobieraj, 2017: 181).

2.1.2. Kyoto Protocol

The Kyoto Protocol is an international agreement that was adopted in 1997 in the Japanese city of Kyoto as part of the United Nations Framework Convention on Climate Change

(UNFCCC). Its aim was to reduce greenhouse gas emissions by well-developed countries otherwise known as 'commitment countries'.

Under the Kyoto Protocol, countries undertook to reduce their greenhouse gas emissions by certain percentages compared to base year levels, which usually included the 1990s. These targets were set individually for each country, taking into account its economic situation and level of emissions.

Poland ratified the Framework Convention in 1996 and then signed the Kyoto Protocol in 1998 as an expression of its willingness to join the international process of action to delay climate change. Our country made a commitment to reduce greenhouse gas emissions by 6% between 2008 and 2012 compared to 1988 (base year) (Baran et al., 2010: 37). In order to enable countries to achieve these emission reduction targets in an efficient and economically viable manner, the Protocol has introduced a variety of policy instruments. These include:

- Emissions trading - which is a mechanism that allows countries to trade greenhouse gas emission credits, which allows for a flexible approach to emissions reductions by allowing countries that exceed limits to purchase credits from those that emit less.
- Clean Development Mechanisms (CDMs) - which allowed developed countries to invest in emission reduction projects in developing countries, which contributes to sustainable development and the reduction of global emissions, while bringing socio-economic and technological benefits to partner countries.
- Joint Implementation (JI) - which allows developed countries to invest in emission reduction projects in other developed countries, which promotes international environmental cooperation and helps achieve global emission reduction targets through efficient use of resources and technology.

Ratification of the Protocol was crucial to its binding legal force. However, some key countries, such as the United States, chose not to ratify it. After the commitment period expired, many countries also decided to withdraw from the Protocol, challenging global efforts to curb climate change. Despite some controversy, the Kyoto Protocol played a key role in establishing a framework for international action to reduce climate change and contributed to the development of many of the tools and strategies that are still used in global climate protection efforts. Its legacy also includes awareness of the problem of climate change and the need to continue international efforts to combat climate change.

2.1.3. Copenhagen agreement

The Copenhagen Accord was negotiated at the United Nations Climate Change Conference (COP15) in Copenhagen in 2009. Although not formally adopted by the entire international community, it marked a key point in the history of international efforts to combat climate change.

One of the key points of the Copenhagen Accord was a commitment by countries to provide financial assistance to developing countries to adapt to climate change and reduce greenhouse gas emissions. As part of this agreement, developed countries were to provide financial support and technology transfer to countries most vulnerable to the effects of climate change. Although the Copenhagen Accord was not legally binding, its provisions had a significant impact on further climate negotiations and environmental action.

2.1.4. Cancun agreement

At the 2010 United Nations Climate Change Conference (COP16) in Cancún, Mexico, the Cancún Agreement was negotiated, which proved to be a significant step forward in global efforts to reduce climate change. The agreement commits countries to take further action to reduce greenhouse gas emissions and to increase the availability of finance for climate action in developing countries. One of the main points of the agreement is to step up action on climate change adaptation to help countries cope with the increasingly visible impacts of climate change, such as extreme weather events and rising sea levels.

2.1.5. Durban agreement

Negotiated at the 2011 United Nations Climate Change Conference (COP17) in Durban, South Africa, the Durban Agreement established an important framework for further climate action. One of the key achievements of the agreement was the agreement on a timeframe for the negotiation of a new international climate agreement that would apply to all countries, including China and India, which have so far not been subject to emission commitments under the Kyoto Protocol. This agreement emphasised the need for all countries, both developed and developing, to be involved in the global effort to combat climate change and highlighted the role of international negotiations in achieving climate goals at the global level.

2.2. European climate regulations

The European Union plays a key role in global efforts to combat climate change. In response to the increasingly visible effects of climate change and its commitments under the Paris Agreement, the European Union continues to pursue sustainable and low-carbon development through ambitious legislation.

2.2.1. Fit for 55

The 'Fit for 55' package is an ambitious set of legislative and strategic measures, introduced by the European Commission on 14 July 2021, to meet the European Union's climate targets. Its main point is to raise the target for reducing greenhouse gas emissions by 2030 from the previous 40% to 55% compared to 1990 levels.

The package proposes a number of important measures, including the strengthening of the existing Emissions Trading Scheme (EU ETS) and the introduction of a new supplementary trading scheme at EU level. In addition, the 'Fit for 55' package includes a proposal to introduce a Carbon Boundary Adjustment Mechanism (CBAM) to ensure a level playing field in global markets.

In terms of updating existing climate and energy legislation, the package proposes amendments to the Effort Sharing Regulation (ESR), the Renewable Energy Directive (RED II) and the Energy Efficiency Directive (EED). In addition, climate change adaptation is also addressed by introducing targets for improving society's capacity to cope with extreme weather and other impacts of climate change.

In order to support regions and communities vulnerable to the negative impacts of the energy transition and to achieve the social climate goals, a Fair Transition Fund and a Social Climate Fund are proposed.

The 'Fit for 55' package thus constitutes a comprehensive European Union action plan to accelerate the fight against climate change and the achievement of ambitious climate targets. Its implementation will require international cooperation and the involvement of all social and economic sectors.

2.2.2. RED II and RED III Directives

The RED II Directive, established by the European Union, provides a framework for the promotion of energy from renewable sources (RES) and sets a binding EU target for the share of renewable energy in gross final energy consumption in the Union by 2030.

The main points of the directive include rules for financial support for electricity from renewable energy sources and regulation of the use of renewable energy in the heating, cooling and transport sectors. The directive also introduces sustainability criteria and greenhouse gas savings for biofuels, bioliquids and biomass fuels.

In the context of the RED II directive, biofuels include:

- advanced biofuels,
- biofuels from food crops,
- recycled carbon-based fuels.

The directive also imposes greenhouse gas emission reduction requirements for different types of biofuels and biomass fuels, depending on their intended use and the date of commissioning of the installation.

One of the key points of the RED II directive is the definition of GHG emission reduction targets for different types of biofuels and biomass fuels, with their respective deadlines. The GHG emission reduction requirements depend on the type and use of the biofuel or biomass fuel in question and the date the installation was commissioned.

In addition, the RED II directive introduces a sustainability certification system that includes audits of biomass sites, land use and GHG emission reductions. This system is intended to ensure that the production of biofuels and fuels from biomass meets certain sustainability criteria.

As part of the 'Fit for 55' package, the 2030 RES target has been increased from 32 per cent to 40 per cent as a result of the revision of the RED II directive. Together with the other proposals in the package, this is expected to enable a reduction in greenhouse gas emissions of at least 55 per cent (GHG-55 per cent) by 2030 (relative to 1990) and lead to climate neutrality by 2050 (Crow, 2021: 5).

On 9 October 2023, the RED III Directive was signed, which is a continuation and development of the RED II Directive, adopted by the European Union as a legal framework to promote energy from renewable sources (RES) and to set a binding EU target for the share of renewable energy in gross final energy consumption in the Union by 2030.

The differences between RED II and RED III bring significant changes that aim to intensify the European Union's efforts to promote renewable energy and combat climate change. RED III represents a further step in the drive to increase the share of renewable energy in total energy consumption within the Union. It also introduces new requirements for Member States, obliging them to support projects for the accelerated development of renewable energy through coordinated mapping of renewable energy deployment and the relevant infrastructure, in cooperation with local and regional authorities.

RED III emphasises the importance of retrofitting existing renewable energy plants as an important element in achieving renewable energy targets. Furthermore, it makes changes to the sustainability criteria for biofuels and biomass fuels, including a reduction in the minimum threshold for the application of these criteria from 20 MW to 7.5 MW.

In addition, RED III sets stricter national targets for individual Member States and introduces additional measures to promote renewable energy in various sectors such as bioenergy, heating, cooling, construction, transport and industry.

2.2.3. REPowerEU

RePowerEU is a European Union initiative that aims to reduce dependence on Russian fossil fuels through a transition towards renewable energy, diversification of supply and increased EU energy security. It was born in the context of Russia's aggression against Ukraine and has a two-phase objective:

- meeting climate targets,
- ensuring stability of energy supply.

Here are the main points of this plan:

- **Energy saving** - Energy efficiency is a key aspect of the transition towards clean energy, strengthening the resilience of the EU economy and shielding it from the high cost of fossil fuels. The plan envisages long-term investments in energy efficiency, including retrofitting buildings, and immediate energy savings by modifying consumer habits.
- **Diversification of energy imports** - The European Union is working hard to diversify energy sources and supplies in order to limit the effects of rising energy prices. This is being done through the creation of an EU energy platform, which has three main objectives:
  - balancing and organising demand,
  - optimisation of infrastructure,
  - international action.

In pursuit of this, diplomatic visits are being made to countries potentially replacing Russia as a major supplier of energy resources to seek alternative sources and partners for energy supply. This has resulted in significant success for the EU, as evidenced by 2022 data showing a 14 bcm increase in gas imports through non-Russian pipelines with connections to Europe (Ciechanowska, 2023: 2). This initiative aims to increase independence from a single energy supplier and reduce costs, which will contribute to the stability of energy supply in the EU.

- **Replacing fossil fuels and accelerating Europe's transition to clean energy** - In the context of the RePowerEU strategy, replacing fossil fuels and accelerating Europe's transition to clean energy is at the heart of a long-term effort to achieve an energy revolution in the region. This programme is based on the premise of reducing dependence on traditional energy sources, focusing on promoting renewable energy sources and energy efficiency. By investing in renewable technologies such as solar, wind, hydro and biomass, the European Union aims to replace existing fossil fuels, thereby reducing greenhouse gas emissions and environmental impact.

Accelerating the energy transition furthermore aims to increase the region's energy security through the use of more sustainable and environmentally friendly energy sources. In this way, RePowerEU becomes a key tool to support climate protection and sustainable energy development goals in Europe.

- Smart investments - The REPowerEU Plan implies significant changes in the energy system, both in terms of volumes and directions of energy flows. Accordingly, the European Commission is encouraging a number of long-awaited infrastructure projects, especially those concerning cross-border connections, which will allow for the creation of an integrated energy market that ensures security of supply in a spirit of solidarity (REPowerEU Plan, 2022).

- Strengthening preparedness - Europe is facing the challenge of potential gas supply disruptions, which requires active preparation and action by Member States. The European Commission is calling on them to take a number of measures to secure gas supplies. These measures include replenishing stocks, introducing energy savings, updating contingency plans, accelerating technical work on transmission systems, concluding solidarity agreements, identifying supply priorities, developing an energy demand reduction plan and reviewing standby plans in the electricity sector. These actions are essential to ensure stability and security of gas supply in the region.

International climate regulations provide a framework for action to reduce greenhouse gas emissions and limit climate change. By setting reduction targets and mechanisms to support their implementation, these international agreements create the conditions for a global energy transition. In the search for rational zero-carbon alternatives, hydrogen-related technologies are of particular interest. The element is a crucial gas for industry, as it is a key byproduct of various processes in many sectors of the economy (Król et al., 2022: 1). We are seeing a continuous increase in demand for hydrogen. Between 1975 and 2018, its consumption worldwide increased from roughly 29 million to 115 million t per year (Chmielniak, 2021: 74). It is being considered as a key ingredient in the energy transition, as its production and use can lead to the elimination of greenhouse gas emissions. The production of hydrogen from renewable energy sources and its use as a fuel in transport, industry and power generation can contribute to the goals of reducing CO2 emissions and decarbonising the economy.

In the context of hydrogen as a fuel, international climate regulations play an important role by promoting zero-carbon technologies. Hydrogen is being considered as a promising energy source that can contribute to the reduction of greenhouse gas emissions in the transport, industrial and energy sectors. The most advantageous use of hydrogen is its application in industry, which directly contributes to the decarbonization of the economy (Kostowski et al., 2022: 6). Through financial incentives, investment in research and development, and the creation of an appropriate regulatory framework, international climate regulations can support the development of hydrogen infrastructure and increase its competitiveness in the market.

Forecasts of the use of different energy sources in different sectors of the economy provide an indication of future energy demand and development directions, which can be used for energy policy planning, including the promotion of hydrogen technologies. By complying with international and European climate regulations, the hydrogen sector can be considered as an important component of strategies to combat climate change and reduce greenhouse gas emissions.

3. The state of current global energy supply chains

In the current energy transition, today's energy supply chains face a number of challenges to ensure sustainability, stability and global energy security. With the prospect of conflicting interests between states and a lack of stability, supply chain sustainability and cooperation with loyal economic partners is changing the economic model that has prevailed to date. A major factor in this change may be the energy crisis that Europe will experience as a consequence of its dependence on imports of energy resources from a single source (PIE Report, 2022: 5).

In July 2018, there was a conflict between the two superpowers China and the United States triggered by Donald Trump's introduction of a 30% commodity levy on imported photovoltaic panels. According to data the Commission collected, imports of photovoltaic cells increased by around 500% between 2012 and 2016. The tariffs did not officially target China, but the country accounted for 65% of global PV panel production. The US also introduced additional tariffs on steel and aluminium of 25% and 10% respectively. Canada, Australia, the European Union and several other countries except China were excluded from the duty. These developments resulted in Beijing imposing tariffs on approximately $3 billion worth of US exports in 2017. (Tomaszewska et al., 2019: 5). These events started a cycle of change in global chains, which have since gone through a turbulent period.

Also, the pandemic had a significant impact on traditional supply chains and global trade more than any other crisis in recent years. (Kauf, 2022: 1). It highlighted weaknesses in the commodity supply market and halted imports of key commodities to European countries and beyond. Cargoes with all kinds of medical equipment became a priority during the pandemic, but ports were crowded with other cargoes not necessarily with essential goods. Despite the extensive infrastructure, deliveries were not possible due to factory shutdowns or closures, as well as a lack of manpower to unpack goods - this was a consequence of governments' actions to reduce staffing at workplaces (Marela et al., 2020: 3).

The situation in the supply chain market has been destabilised again as a result of Russia's invasion of Ukraine. According to an analysis published on the Interos platform (2022):

- 1200 European companies and 2100 US companies have one or more tier one suppliers in Russia;
- 200 companies in Europe and 450 in the US have tier one suppliers in Ukraine. (Kauf, 2022: 2).

Sanctions have resulted in supply chain leaders being forced to give up and become completely independent of Ukrainian and Russian suppliers. Global trade problems have not disappeared, and have even worsened. As a result of these developments, notions of friendshoring, which involves locating production facilities to countries with shared values that cooperate politically and militarily, are becoming more common on the international stage. (Szwech, 2023: 1).

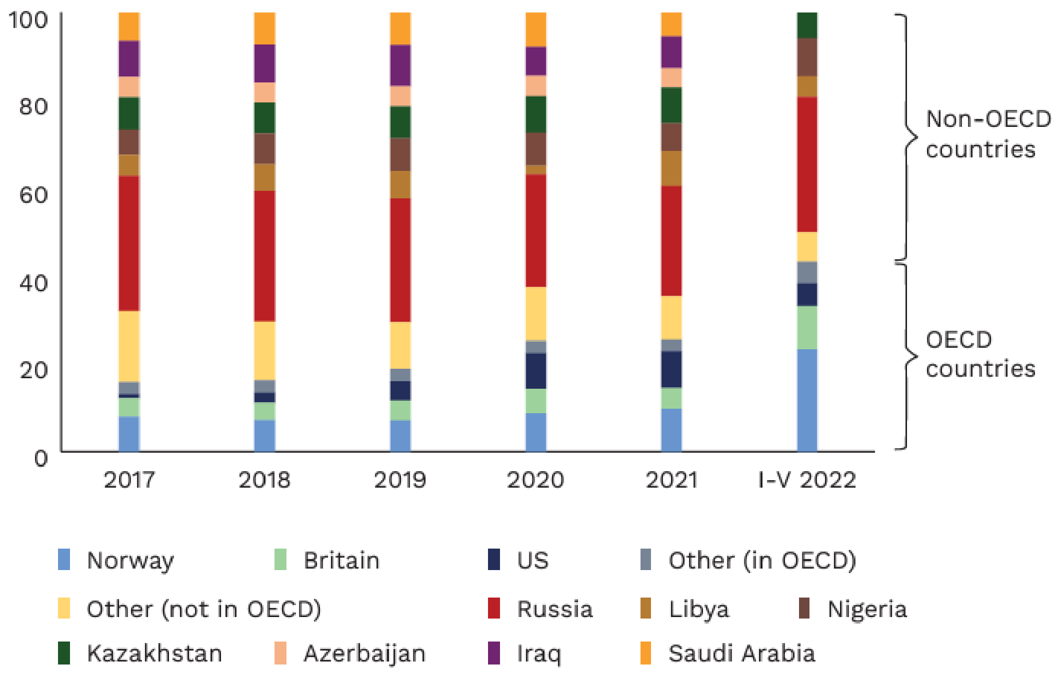
The criteria by which countries and companies will consider others friendly is very ambiguous, as purely theoretically they should be entities that share similar values and represent a non-authoritarian mode of governance (Washingtonpost, 2022).

The core of such a group can include NATO member states, which cooperate with each other within the North Atlantic Pact. Another aspect that determines membership in friendly states is membership in the OCED. OCED member states are characterized by a high level of economic development. The application of friendshoring in this group of countries is unquestionable, but it will significantly affect the cost of manufacturing numerous products, due to the higher production costs in countries with a high level of development. Consequently, it may also involve an increase in prices for consumers. However, it should be borne in mind that with the increase in production costs caused by the economic development of countries, higher production efficiency also stands.

The benefits that friendshoring can bring will depend largely on the category of goods. Priority in this aspect should be given to economic sectors from which EU countries obtain high import dependency. Over the period 2000 - 2020, the dependence of the energy sector of a typical EU country increased from 56.3% to 57.5%. This means that EU members over the course of two decades have become more dependent on energy imports mainly from Russian areas. (PIE Report, 2022: 31).

The main energy resources that EU countries import are oil and its products, natural gas and fossil fuels - mainly hard coal. The EU imports oil from various countries such as Russia, Norway, the US, Saudi Arabia and others. As much as 74% of imported oil in 2021 came from non-OECD countries (PIE Report, 2022: 32).

Fig. 1. Directions of crude oil imports to the European Union from 2017 to 2021 (in %)

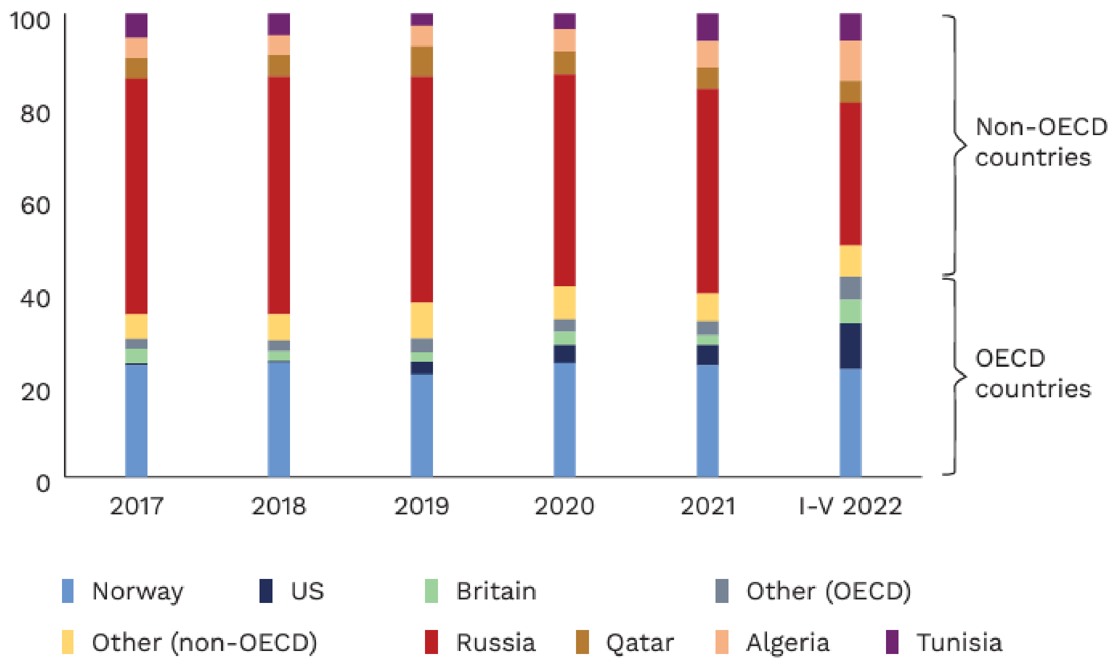


Source: Own elaboration of the State Economic Institute based on Eurostat data.

Natural gas plays a significant role in the countries of the European Union, both as an energy source and a raw material for production. It is the second most important commodity imported by the EU, following crude oil. The process of importing gas into the EU is diversified in terms of sources, with the largest share coming from Russia, which is the main supplier. However, the EU also imports gas from other countries, including Norway, Algeria, Tunisia, and Canada.

In 2021, the import of gas from non-OECD (Organization for Economic Cooperation and Development) countries constituted a significant portion of the total imports into the European Union, reaching as high as 66%. This indicates that the European Union has a substantial share in gas trade with countries outside this organizational group, which may influence its energy policy and the diversification of energy resource supplies.

Fig. 2. Directions of natural gas imports to the European Union from 2017 to 2021 (in %)



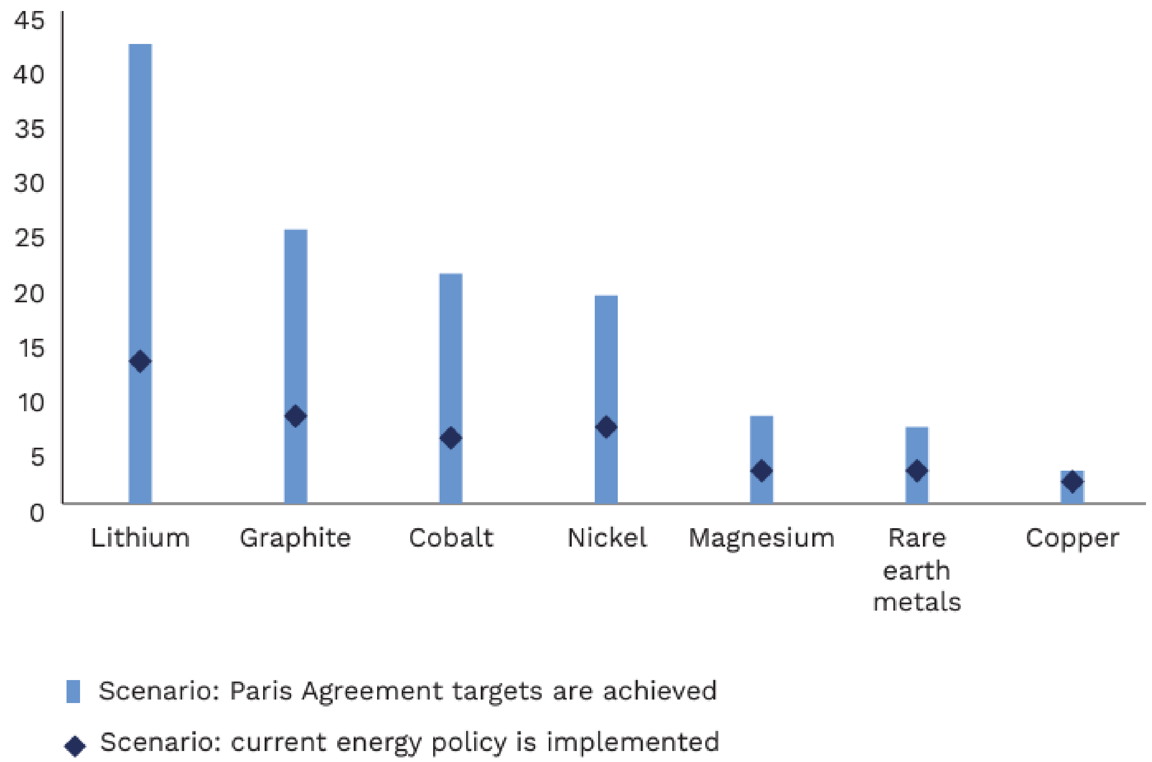
Source: Own elaboration of the State Economic Institute based on Eurostat data.

Based on the above data, it can be noted that as a result of the conflict in Ukraine, the role of one of the main importers of natural gas and oil after Russia was taken over by Norway, which has very large deposits of both these resources.

The European Union's export market for renewable energy-related equipment is the second largest in the world. Nevertheless, it is heavily dependent on the supply of materials, raw materials and components needed to manufacture these devices. In the case of photovoltaic panels, China is the main exporter, with about 63% of photovoltaic panel imports to the EU coming from China in 2019 (PIE Report, 2022: 35), while the European Union is the main importer. In this regard, increasing independence can be helped by recycling, which is estimated to be able to recycle about 90% of solar panels. By 2050, between 60 and 78 million tons of PV waste will be in circulation (IEA-PVPS, 2017).

Critical raw materials play a large role in the energy transition. They are needed in almost every field of renewable energy in quantities much greater than in conventional energy - for example, one 1 MW offshore wind power plant will consume 15 t of critical raw materials nearly 9 times more than a gas power plant and about 6 times more than a coal power plant (PIE Report, 2022: 37).

Fig. 3. Estimated growth of demand for selected critical raw materials used in low-emission technologies in 2040 compared to 2020



Source: Own elaboration of the State Economic Institute based on data from the IEA.

In the future, the demand for critical raw materials will increase. At this moment, 19 of the 30 raw materials that qualify for the European Commission's list of critical raw materials are used in the renewable energy sector. For, as many as 11 of them, the European Union's dependence on imports is 85% of which for 7 is 100%. For batteries needed for energy storage and electric vehicles, demand for lithium could increase 18-fold and for cobalt 5-fold in 2030, while the EU could need up to 60 times more lithium and up to 15 times more cobalt in 2050 compared to current supplies for the entire EU economy (EC, 2020).

When discussing the state of current global energy supply chains, it is impossible not to notice the complexity and dynamic changes that determine the current global energy situation. Today, the concept of stable energy supply chains is a key element for the proper functioning of the state. The development of new technologies and the expansion of energy supply pathways reduce the risks associated with possible disruptions in one of the supply chains and open the way for the creation of more sustainable and independent energy systems. This can lead to greater energy independence and reduce the negative impact on the environment. In the context of a rapidly changing political and economic environment, flexibility and adaptability are becoming key features for effective management of energy supply chains.

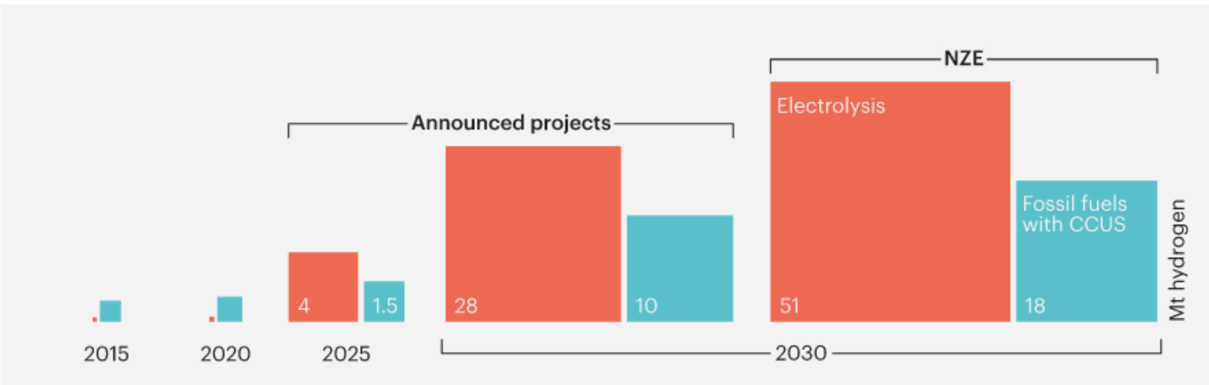
4. Hydrogen as a energy medium

When looking for a flexible energy carrier that could find applications in various energy sectors, we come across hydrogen. Along with electricity and advanced biofuels, hydrogen stands out as one of the few potential energy carriers with minimal emissions. Hydrogen can provide important support in solving a variety of critical energy challenges, enabling the decarbonization of a number of economic sectors, such as transportation, chemicals and metallurgy. In addition, its use can help improve air quality and enhance energy and economic security. Hydrogen in the era of newly available technologies can be used in a versatile way. Current technologies allow hydrogen to be stored, transported and produced using a range of alternative fuels as well as fossil fuels(Stachowiak, 2019: 3).

Interest in hydrogen as an energy carrier is widespread due to its high calorific value per unit mass, which is 120 MJ/kg. Traditional hydrocarbon fuels have almost three times lower heating value (Starosta, 2016: 3). It is also worth noting that hydrogen is one of the most commonly occurring elements in nature. This means that its availability is not limited and can be produced on a large scale, which is an important asset for ensuring energy security and reducing greenhouse gas emissions. In addition to its high calorific value and widespread occurrence, hydrogen is also distinguished by its ability to store energy. This is particularly important for renewable energy, which is characterized by instability and fluctuating conditions of access to energy sources. Hydrogen can be produced during periods of energy surplus, such as during wind or solar weather, and then stored and used during periods of deficit, helping to stabilize the power grid.

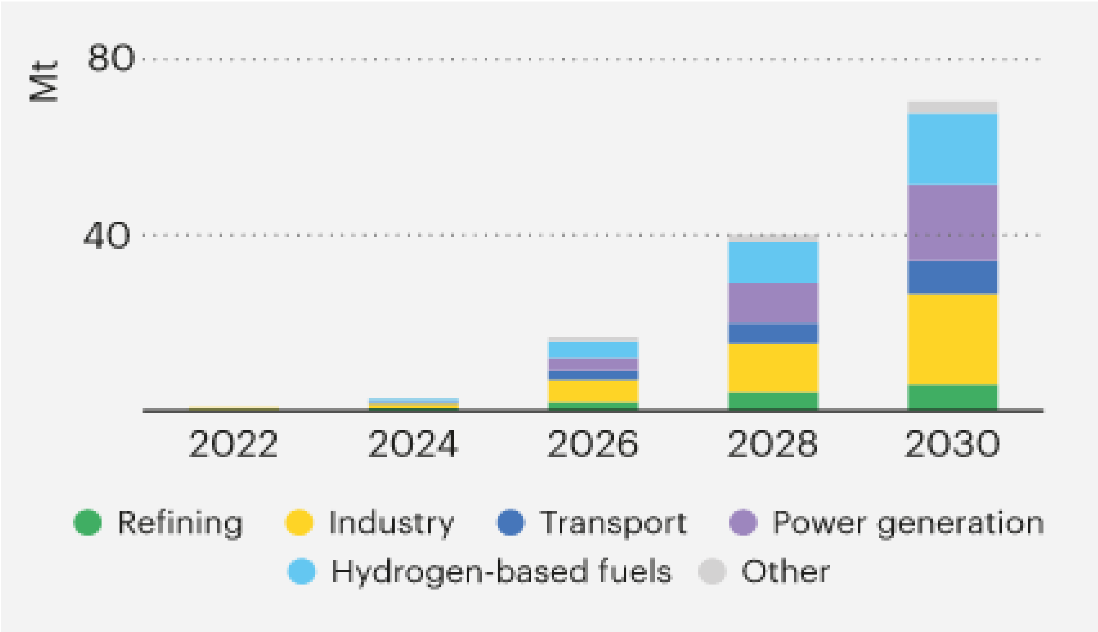
Hydrogen produced today is largely produced from fossil fuels through steam reforming of methane, coal gasification and the oxidation of heavy petroleum fractions. Hydrogen extracted in this way is not low-carbon. Therefore, it is mainly used for the production of ammonia or methanol, as well as in the petrochemical industry, for example, for fuel desulfurization. New methods of obtaining low-carbon hydrogen are increasingly being sought and tested, such as thermal decomposition of water, photocatalysis, biocatalysis or biomass fermentation. Demand for low-carbon hydrogen is growing, as shown in the figures and charts below.

Fig. 4. Low – emissions hydrogen production



Source: IEA Reports Hydrogen 2023

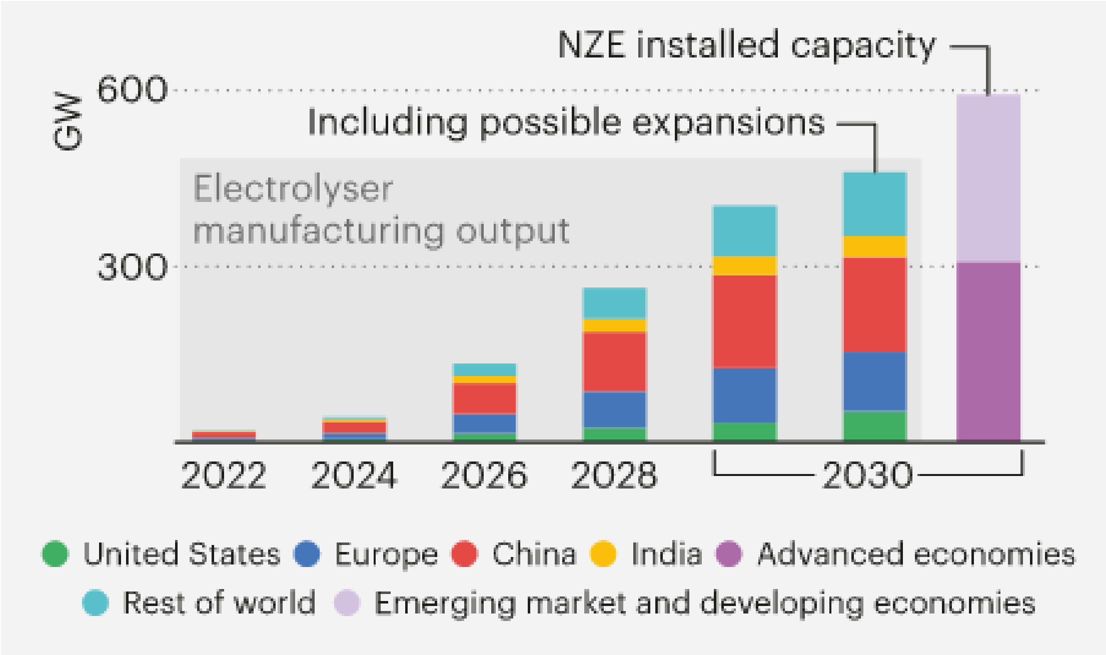
Fig. 5. Demand for low – emissions hydrogen grows quickly in the NZE, particularly in heavy industry, transport and the production of hydrogen – based fuels



Source: IEA Reports Hydrogen 2023.

Demand for low-carbon hydrogen is growing rapidly in the NZE, especially in heavy industry, transportation and hydrogen fuel production. Hydrogen production by electrolysis can have a very significant impact in the energy transition. As is well known, the value of energy derived from renewable energy sources is susceptible to changes in atmospheric conditions by which it is not constant. In the case of energy from wind turbines, the amount of energy we obtain depends on the wind speed. However, this one can change rapidly depending on the time of year and day. Insolation has a key effect on the extraction of energy with photovoltaic cells. By using hydrogen from electrolysis, we can ensure a continuous supply of energy when weather conditions are not favorable while providing completely emission-free energy. Another advantage of fuel cells used in electrolysis is their "scalability." They can be used to power a car engine as well as produce energy on a large scale (Sciążko et al., 2018: 1).

Fig. 6. Total electrolyzer production by 2030



Source: IEA Reports Hydrogen 2023

According to a report by the International Energy Agency (IEA), projections for electrolyser production show significant growth in the coming years. Electrolysers are a key component of hydrogen production using electricity to split water into hydrogen and oxygen. The cumulative production capacity of electrolysers is expected to increase significantly, according to the announcements.

The IEA report suggests that if these projections are fully realized, the cumulative production capacity of electrolysers could reach as much as 80% of the Neutral Zero Emission (NZE) level by 2030. This is a huge step toward accelerating the transition to sustainable energy sources and reducing greenhouse gas emissions.

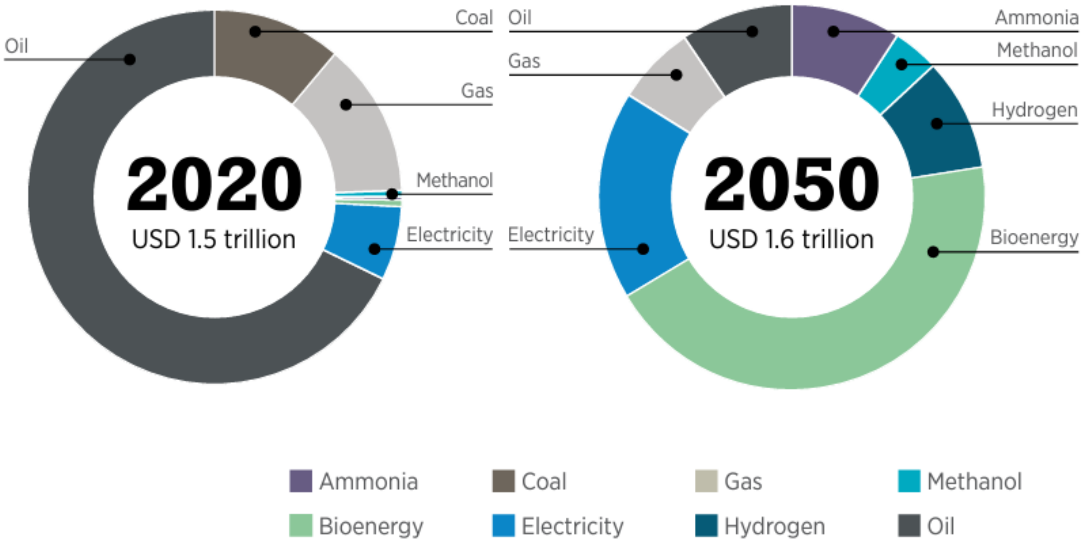
The growth in electrolyser production is particularly promising because it enables hydrogen production to be scaled up using renewable energy, reducing dependence on fossil fuels and accelerating the energy transition to greener solutions. If these assumptions come to fruition, electrolyser production could become one of the main drivers of hydrogen market growth and contribute to global emissions reduction and sustainable energy development goals.

5. Geopolitical aspects of the hydrogen trade

Water, the primary component of hydrogen, has been a source of life and economic development for centuries. The density of gaseous hydrogen (273 K, 1013 hPa) is 90 g/m3, while that of liquid hydrogen is 70.8 kg/m3, and crystalline hydrogen is 88 kg/m3. Therefore, it is the lightest element in each state of matter. Its thermal conductivity, at 0.1745 W/(m·K), as well as its specific heat of 14.195 kJ/(kg·K) (at 273 K), are the highest among all gases. The heating value of hydrogen is remarkably high, at 120 MJ/kg (for comparison, coal has 25 MJ/kg, and gasoline has 47 MJ/kg) (Wiącek, 2011: 447). In the 21st century, in light of the growing need to reduce greenhouse gas emissions, hydrogen has become a key component of the global energy transition. Contemporary initiatives, such as the preference for zero-carbon solutions, are helping to develop hydrogen technologies. Therefore, this element is gaining importance as a clean energy source, supporting the global energy transition. With the growing interest in alternative energy sources, hydrogen trade is becoming an important geopolitical factor, bringing with it both opportunities and challenges for global politics.

A published report by the International Renewable Energy Agency (IRENA) titled. "Geopolitics of the Energy Transformation. The Hydrogen Factor" shows the shaping of the future of hydrogen markets and an analysis of countries' strategies. From the report we can observe projections of shifts in the value of energy commodity trade over a 20-year horizon (Fig. 7.)

Fig. 7. Shifts in the value of trade in energy goods, from 2020 to 2050



Source: Report from the International Renewable Energy Agency (IRENA) titled 'Geopolitics of the Energy Transformation: The Hydrogen Factor'.

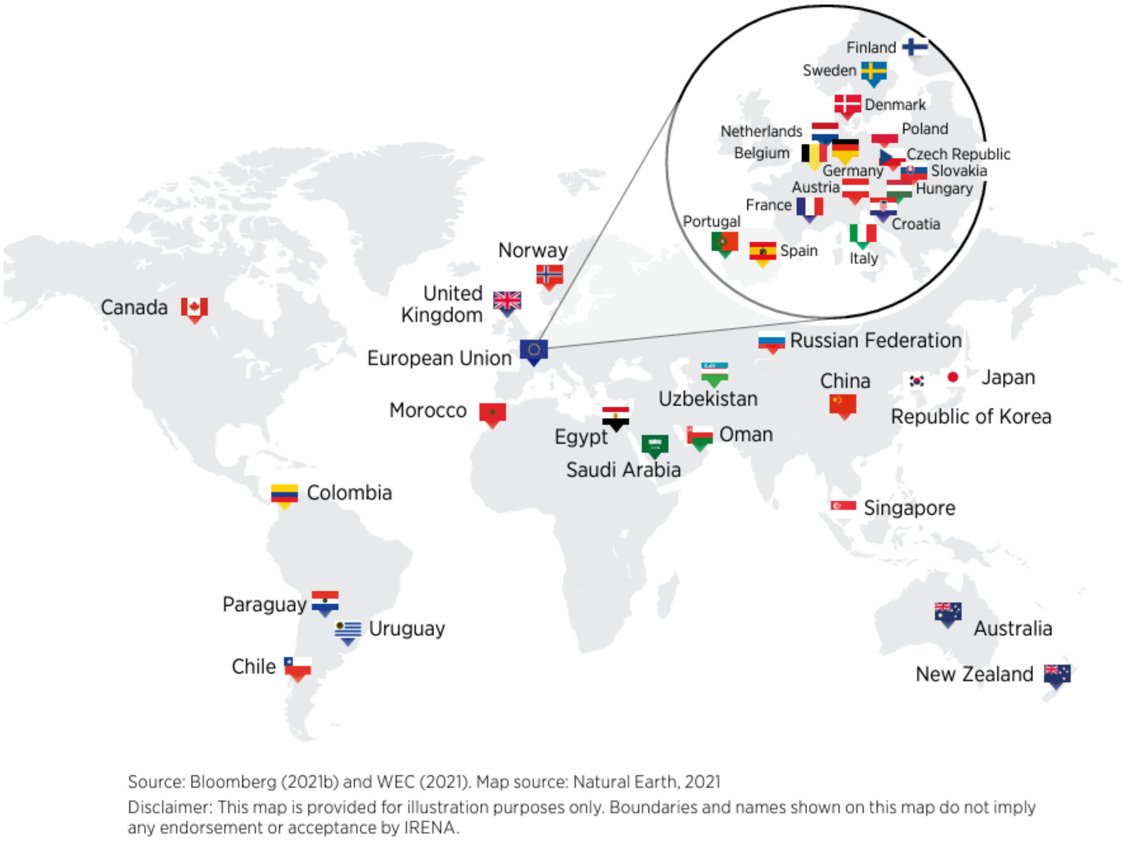
Analyzing Fig.7., we can see changes suggesting a diversified future for energy commodity trade, increasing the importance of renewable energy sources such as bioenergy and hydrogen, while traditional energy commodities such as oil and gas are declining. Such predictions could lead to a great deal of international turmoil, as changes in energy trade patterns could trigger political and economic responses in different regions of the world. Countries that are currently major exporters of traditional energy resources, such as oil and gas, may experience a decline in their economic and geopolitical influence, which in turn could lead to changes in their diplomatic and political strategies. In addition, countries dependent on imports of these raw materials may be forced to seek alternative energy sources, which could lead to competition for access to renewable energy sources, as well as increased investment in hydrogen technologies.

5.1. Geopolitical aspects of hydrogen sector development

The dynamic development of the hydrogen sector will lead to new interstate ties and contribute to the formation of new geopolitical centers of influence based on the production and use of hydrogen. We are privileged to observe a "great race for technological leadership" where hydrogen will play a special role. According to Francesco La Camera, director general of IRENA, hydrogen can play a key role as an enabler to achieve a climate-friendly energy transition of the future.

Recent years have seen dynamic changes in the global energy mix, with hydrogen strategies gaining increasing importance. Growing environmental awareness and the drive to reduce greenhouse gas emissions are driving countries to seek alternative, more sustainable energy sources. In response to these challenges, more than 30 countries have developed or are planning to develop national hydrogen strategies, indicating a growing trend toward active participation in hydrogen trade. It is worth noting that Japan was a pioneer in hydrogen strategies, having the only national strategy in 2017. However, things have changed dynamically in just seven years. The Japanese initiative was the catalyst for global interest in hydrogen as an environmentally friendly energy carrier. Now Japan, along with other countries such as Germany that are also betting on hydrogen, is becoming a key player in the global development of hydrogen strategies and the implementation of hydrogen-related technologies. This development underscores the growing global awareness and the need for international cooperation to accelerate the transition to sustainable and green energy models.

Fig. 8. Hydrogen strategies and those in preparatory phase, October 2021



Source: Report from the International Renewable Energy Agency (IRENA) titled 'Geopolitics of the Energy Transformation: The Hydrogen Factor'.

A report by the International Renewable Energy Agency (IRENA) entitled. "Geopolitics of the Energy Transformation. The Hydrogen Factor" indicates that countries with high renewable potential can become so-called "green industrialization" areas using their potential to attract energy-intensive industries, which can certainly increase economic competitiveness. The production of equipment such as electrolyzers and hydrogen cells can drive the economies of many countries and thus strengthen their roles on the international stage, which is why it is so important for countries to invest in new technologies and attract potential investors to commit their capitals to their hydrogen valleys. Currently, the most interesting strategies for developing the hydrogen industry are in Japan, China, India, the European Union, South Korea and the United States.

The dynamic development of the hydrogen sector is leading to new interstate ties and contributing to the formation of new geopolitical centers of influence based on hydrogen production and use. This "great race for technological leadership" is a key element, to achieve a climate-friendly energy transition.

5.2. Changes in supply chains

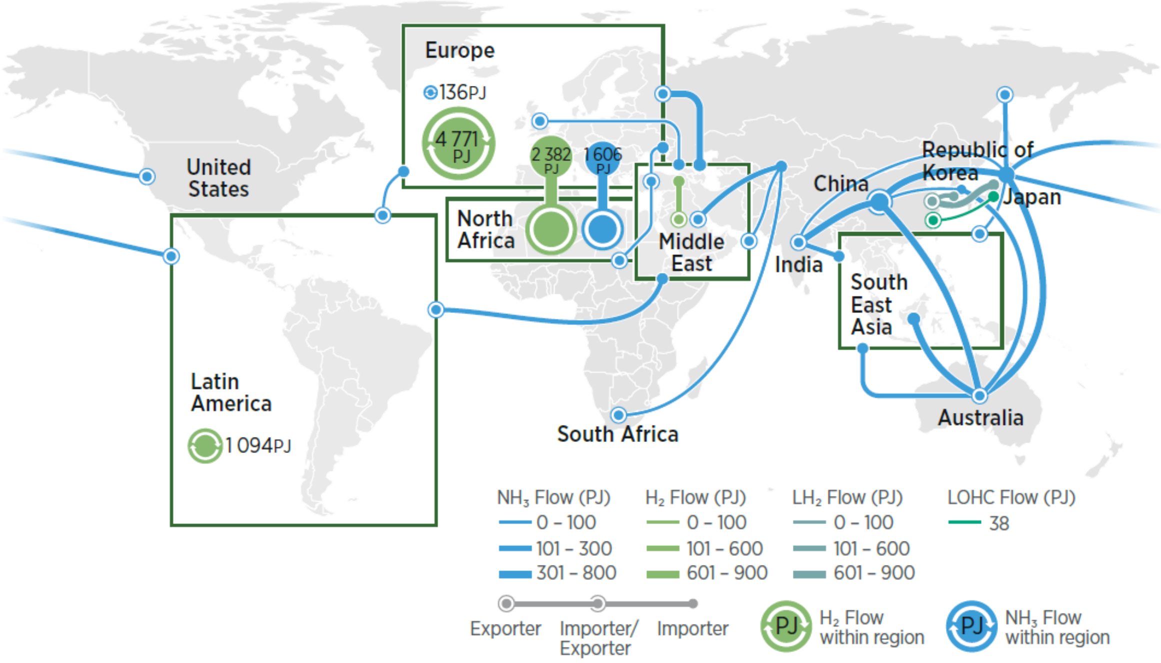
A leading hydrogen-related change in global trade is the transformation of traditional feedstock supply chains. Previously dominant supply chains based on oil, natural gas or other energy feedstock are beginning to give way to new, zero-carbon solutions. According to the latest data compiled by the International Renewable Energy Agency (IRENA), capital spending in the renewable energy sector is expected to increase significantly by 2050. Optimistic assumptions about capital spending on various green energy technologies indicate the potential for growth in the sector, which could significantly change the landscape of energy production and distribution around the world.

Green hydrogen production is projected to grow significantly by 2050. It is estimated that about 18.4 EJ/year of green hydrogen, which is about 36% of the total energy demand of 50 EJ/year, will be sold globally. This growing hydrogen trading market is creating new opportunities for energy supply chains, and changing the dynamics of global energy trade (IRENA Report, 2022: 56).

It is also worth noting that the development of hydrogen transportation infrastructure, including hydrogen pipelines and ammonia transport, is crucial to the successful large-scale movement of hydrogen. According to the report, about 55% of hydrogen trade will be through hydrogen pipelines, 40% through ammonia transportation, and 5% as liquid hydrogen. This is a huge change compared to current energy trade structures, which may influence the formation of new strategic alliances and change traditional trade directions (IRENA Report, 2022: 57).

Therefore, the development of energy infrastructure, especially in the context of green hydrogen production and distribution, will be crucial to the future formation of energy supply chains. Investment in modern technologies and infrastructure is essential to accelerate the energy transition and achieve global climate goals.

Fig. 9. Map of global hydrogen trade under optimistic technological assumptions in 2050



Source: Raport Global Hydrogen Trade To Meet the 1.5°C Climate Goal Part I

Analysis of a map of global hydrogen trade in 2050 (Fig. 9), taking into account optimistic technological assumptions, provides important clues about the formation of new trade routes. According to the data, the main hydrogen trade routes will be shaped by cost efficiency and the availability of green hydrogen.

The hydrogen trade map indicates that there is a tendency to concentrate hydrogen trade along designated routes that connect regions with high production potential with those interested in imports. New trade routes may also take shape based on existing or planned infrastructure, such as hydrogen pipelines or ammonia tankers. This could lead to the development of new hydrogen trade hubs, which would serve as distribution centers for a particular region or even interregionally.

6. Summary

The article focuses on analysing the geopolitical dependence of hydrogen, which are becoming an increasingly important factor in global politics and economics. In the context of the global energy transition, hydrogen is becoming a key element to support the goals of reducing greenhouse gas emissions and the search for alternative, sustainable energy sources. From reports based on data from international institutions such as the International Renewable Energy Agency (IRENA), future hydrogen trade forecasts and country strategies are analysed.

Leading developments include the evolution of the structure of energy trade, increasing the importance of renewable energy sources at the expense of traditional raw materials such as oil and gas. The dynamic development of the hydrogen sector is leading to the emergence of new centers of geopolitical influence and changing commodity supply chains. A key role is played by the development of energy infrastructure, especially related to the production and distribution of green hydrogen. Due to the use of hydrogen as a storage for renewable energy sources, it is possible to achieve supply stability while simultaneously reducing production costs (Kłaczyński et al., 2021: 2).

An analysis of the map of global hydrogen trade indicates a tendency to concentrate trade along cost-effective routes, which may lead to the emergence of new trade hubs and a shift in traditional trade directions. In the context of this dynamic development of the hydrogen sector, international cooperation and investment in modern technology and infrastructure become important.

In conclusion, the research article shows that the geopolitical aspects of hydrogen trade have the potential to significantly affect global politics, economics and energy distribution in the coming years. Therefore, it is important to monitor these developments and take appropriate action at the national and international levels to effectively respond to the challenges and seize the opportunities arising from the dynamic development of the hydrogen sector.

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Maciej Mrozowski – Student, Power Engineering, The Faculty of Civil and Environmental Engineering and Architecture at Rzeszów University of Technology. Volunteer at the Institute of Energy Policy, Energy Transition Ambassador (TE), H2 Academy member, Scientific interests: hydrogen technologies, renewable energy technologies, energy characteristics of buildings, and energy transformation.

Kacper Bednarz – Student, Power Engineering, The Faculty of Civil and Environmental Engineering and Architecture at Rzeszów University of Technology. Energy Transition Ambassador (TE), H2 Academy Scholarship holder , Scientific interests: nuclear energy, hydrogen technologies, energy transformation, heat recovery and renewable energy technologies.