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EVALUATION NOTE

ENERGY TRANSITION JOURNEY TO 2050 AND HYDROGEN ENERGY

In this article, we will provide a high level assessment of the Energy Transition towards 2050 in the context of the primary energy sources, and Green Hydrogen as an alternative form of clean energy.

Summary

The increasing global demand for energy and the uneven distribution of natural resources, especially oil, natural gas, and coal, pose a significant threat to energy security for many countries and poses risks in terms of climate change and environmental and energy sustainability. When combined with unfavorable geopolitical developments, declining or limited access to energy resources, along with rising energy prices, can create pressures on societies in terms of reliable and affordable access to sufficient energy[1]. This situation drives countries and global communities to search for clean, sustainable, and accessible energy alternatives to meet their energy needs.

The initiatives of international organizations such as the United Nations and global gatherings like the 2015 Paris Conference have raised awareness about environmental and climate change issues, emphasizing the necessity of increasing the share of renewable energy sources.

[1] The balance between "Energy Security," "Energy Sustainability," and "Reliable and Affordable Energy Access and Affordability" and the choices that countries need to make in these areas are referred to as the "Energy Trilemma" by the World Energy Council. These factors are interrelated and can be competing, requiring careful consideration and decision-making by nations.
https://www.worldenergy.org/assets/downloads/World_Energy_Trilemma_Index_2022.pdf?v=1669839605

Energy generation based on renewable sources such as wind and solar power has made advancements in terms of efficiency due to technological developments.

Green-clean hydrogen energy has the potential to compensate for some disadvantages of energy production from renewable sources, such as long-term storage and transportation infrastructure challenges.

Green-clean hydrogen energy has the potential to meet a significant portion, ranging from 12% to 14%, of the total global final energy consumption in the scenarios aiming for a temperature increase of no more than 1.5 degrees Celsius compared to pre-industrial levels by 2050. However, this potential can only be realized if there is significant acceleration in investments in electrolyzer and transportation infrastructure within this field.

Global energy consumption and the energy transition

The production and consumption of energy, which we have become dependent on in the 20th century with industrialization, are central to the lives of modern societies, from industries to cities, workplaces, and homes. Globally, the increase in final energy consumption[2], including electricity, heat, and fuel, has been closely following economic growth for a long time, but this increase has gained significant momentum since the Second World War.

At the beginning of the 1900s, coal was the leading fuel worldwide, while oil started to gain prominence only in the 1920s. Although natural gas consumption began to increase along with crude oil in the 1900s, this increase was initially much slower and later expanded its share in electricity generation, as well as in heating and cooking.

Technological advancements have led to significant progress in energy efficiency. Since the 1970s, nuclear energy has emerged as a significant electricity source, while starting from the 2000s, cleaner and more sustainable renewable energy sources such as wind, solar, geothermal, and hydro have increased their share to approximately 14% of the total primary energy consumption.

In the year 2000, global primary energy consumption was approximately at the level of 400 Exajoules[3], with approximately 88% of it derived from fossil fuels such as oil, coal, and natural gas, while the remaining 12% was equally distributed between renewable and nuclear energy sources. By the year 2021, total primary energy consumption had reached approximately 600 Exajoules with an average annual increase of 2%, and the share of renewable energy within this consumption had risen to 14%, while nuclear energy accounted for 4%, and fossil fuels had decreased to 82%[4].

International Energy Agency, based on the successful implementation of energy policies set by countries around the world, projects that global primary energy consumption will range between 629 and 740 Exajoules by 2050[5]. However, if carbon-neutral[6] targets are achieved successfully, global primary energy consumption is estimated to decrease to 532 Exajoules.

[2] Final Energy Consumption is the total energy consumed by end users, such as households, industry and agriculture. https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Glossary:Final_energy_consumption

[3] Joule is a unit of energy in the International System of Units and can be used to state the amount of energy produced by various energy sources under a common unit. Exajoule (EJ) equals to 10^18 joules. https://en.wikipedia.org/wiki/Joule

[4] The Statistical Review of World Energy, published in 2022, BP, https://www.bp.com/en/global/corporate/energy-economics/statistical-review-of-world-energy/downloads.html

[5] "World Energy Outlook 2022" report, International Energy Agency, November 2022

[6] Carbon Net-zero: Instead of zero carbon, the aim is to minimise as much as possible and to balance the residual carbon with equal carbon lowering alternatives (such as foresting as an example)

The main reasons for this decrease include a significant increase in the share of energy derived from renewable sources (with renewables accounting for 70% and nuclear energy for 12% of total primary energy production), advancements in energy efficiency and technologies, and behavioral changes in energy consumption by societies.

The transition to renewable energy, also known as the 'energy transition[7],' has significant implications for the future and way of life of humanity. Recent geopolitical crises, such as the Russia-Ukraine conflict, have prompted countries to reassess their energy security, sustainability, accessibility, and price stability policies, leading to increased actions to accelerate and expand the scope of energy transition.

IRENA, the International Renewable Energy Agency, identifies the main elements of the energy transition movement towards 2050 as follows: (a) renewable energy sources, (b) clean hydrogen and hydrogen fuels, (c) sustainable bioenergy-based electricity generation, (d) improvements in energy efficiency, (e) advancements in carbon capture and storage technologies, and (f) changes in consumer preferences towards electric-powered transportation[8].

Climate change, sustainability, energy security, and the search for alternatives to fossil fuels

Since the early 1990s, international organizations and initiatives, particularly the Intergovernmental Panel on Climate Change (IPCC) with the participation of 191 member countries, have emphasized the need to combat climate change and reduce carbon emissions in order to prevent global temperatures from rising more than 1.5°C above pre-industrial levels and to avoid exceeding 2°C. International meetings such as the 2015 Paris conference have led to significant steps towards this goal. These efforts have highlighted the importance of shifting the distribution of energy sources, specifically by reducing the share of fossil fuels and increasing the share of renewable energy sources. Many countries have also recognized energy independence as a national security issue and have embarked on different paths to meet the global energy demand through alternative sources, either due to their disadvantageous position in terms of energy resources or to diversify their energy mix.

Although an increasing number of countries have taken measures since the 2015 Paris Conference to reduce carbon emissions and combat climate change, it is still premature to declare a victory specifically in terms of renewable energy sources. There remains a long and challenging path ahead to achieve a genuine triumph.

In the year 2000, 32% of carbon emissions were attributed to Asia-Pacific countries, primarily China and India. However, by 2021, this figure had risen to 52%. In contrast, the contribution of the United States and European countries decreased from 44% to 25%.

The significant increase in carbon emissions observed in Asia-Pacific countries is due to rapid economic growth, increased energy consumption, inadequate investments in renewable energy sources, and the continued reliance on fossil fuels as a significant energy source. On the other hand, in the United States and European countries, efforts to improve energy efficiency, investments in renewable energy sources, the increased use of natural gas within

[7] "Energy Transition" can be defined as the shift from fossil fuel-based energy production and consumption to renewable energy sources in the global energy system. https://www.spglobal.com/en/research-insights/articles/what-is-energy-transition

[8] World Energy Transitions Outlook 2022: 1.5°C Pathway, IRENA, 2022

fossil fuels, and the reduction in coal consumption have led to a decrease in their share of carbon emissions.

According to the International Renewable Energy Agency's (IRENA) report dated 2022[9], achieving carbon neutrality by 2050 means reaching a neutral level for approximately 37 gigatons of global annual carbon emissions. Additionally, it entails reducing the world's total annual energy consumption to 2019 levels, accomplished through ambitious energy efficiency improvement efforts and increasing the share of renewable and sustainable energy in the overall energy mix to approximately 80%.

Energy production from renewable sources such as wind and solar can vary due to weather conditions, seasonal changes, and differences between day and night. Additionally, electricity generated from these energy sources is unfortunately not suitable for long-term storage and can experience significant transmission losses.

Hydrogen energy offers the possibility to compensate for concerns regarding the sustainable production from the renewable energy sources, the need for new technologies, the challenge of long-term storage of electricity, and the low efficiency. **Hydrogen energy, which has gained significant interest in recent years, can be converted into a fuel and energy source as low-emission or green-clean hydrogen. With significant investment in electrolyzer technology, whether currently active, planned, or announced, expected to gain momentum in the coming years, it is predicted that hydrogen energy could potentially meet a significant portion, around 12%, of the total global final energy consumption as projected in the 2050 1.5°C scenarios[10].**

Hydrogen Energy

Hydrogen is the oldest, lightest, and most abundant element in the universe, naturally occurring in various compounds including water and fossil fuels. Hydrogen energy is a secondary energy source obtained from fossil fuels or renewable energy sources through processes such as electrolysis, thermolysis, chemical reactions, and other methods, for final consumption. The energy content per unit of hydrogen is higher in terms of lower and upper heating values compared to fossil fuels, making it a sustainable energy source for various applications.

Hydrogen energy can be stored in different forms such as gas or liquid. There are two main methods for transporting hydrogen across international borders: pipelines and ships.

Hydrogen energy is classified into three categories based on the primary energy sources required for its production: green, blue, and gray hydrogen[11].

Green hydrogen is produced solely through the electrolysis[12] of water using electricity generated from 100% renewable energy sources. It is considered carbon-free as it does not result in CO2 emissions.

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[9] World Energy Transitions Outlook 2022: 1.5°C Pathway, IRENA, 2022

[10] Geopolitics of the Energy Transformation: The Hydrogen Factor, IRENA,2022,https://www.irena.org/Publications

[11] "Production of hydrogen - U.S. Energy Information Administration (EIA)". https://www.eia.gov/energyexplained/hydrogen/production-of-hydrogen.php.

[12] Electrolysis is the name of the chemical method of obtaining hydrogen from water using electricity. An electrolyser, on the other hand, is a device that produces hydrogen through a chemical process (electrolysis) that can separate the hydrogen and oxygen molecules formed by water using electricity.

Gray hydrogen is obtained through steam methane reforming or coal gasification, using natural gas or coal as feedstocks. This is the most commonly used method at present. The resulting CO2 is released into the atmosphere, contributing to pollution.

Blue hydrogen is similar to gray hydrogen, but with the addition of carbon capture and storage (CCS) technology. The CO2 generated during production is captured, stored underground, and prevented from entering the atmosphere.

According to the report by the International Energy Agency (IEA)[13], currently, hydrogen production worldwide is predominantly derived from fossil fuels. The IEA predicts that in a carbon-neutral scenario, by 2050, 95% of total hydrogen and hydrogen-based fuels will be consumed for transportation, power generation, and industrial purposes[14]. Currently, electrolyzers used to obtain clean hydrogen have a global capacity of 510 megawatts, which can only supply a small fraction, approximately 0.1%, of the total hydrogen demand.

According to the International Energy Agency (IEA), to achieve the carbon-neutral target aligned with the Paris Agreement by 2050, global electrolyzer capacity should meet 70% of the IEA's estimated global hydrogen demand of 475 million tons (Mt). This would require a global electrolyzer capacity of 3.7 terawatts (TW)[15]. In the International Renewable Energy Agency's (IRENA) 1.5°C scenario presented in the 2023 World Energy Outlook Preliminary Report[16], it is expected that by 2050, hydrogen energy will account for approximately 14% of the estimated global final energy consumption, which will be around 353 exajoules. Moreover, it is anticipated that 94% of the produced hydrogen will be sourced from renewable energy. In the same scenario, it is projected that by 2050, the global electrolyzer capacity will reach 5.7 TW, and the annual hydrogen production from renewable energy sources will amount to 518 Mt. The Hydrogen Council[17], based on the 1.5°C scenario[18], envisions the need for approximately 5.4 TW of electrolyzer capacity and an annual production of 400-550 Mt of hydrogen from renewable sources by 2050 to achieve the global "net-zero" target.

China, as the world's largest primary energy consumer, is expected to become the largest clean hydrogen market globally by 2050, with an estimated demand of 200 Mt. It is projected that Europe and North America will follow with each region having a demand of 100 Mt, and India with a demand of 55 Mt[19].

As of 2022, the largest 10 hydrogen energy projects in the world, based on electrolyzer capacity (totaling approximately 200 GW), are as follows: HyDeal Ambition (Western Europe, 67 GW), AquaVentus (10 GW), NorthH2 (Netherlands, 10 GW), Kazakhstan Hydrogen Project (30 GW), Western Green Energy Hub (Australia, 28 GW), Asian Renewable Energy Hub (Australia, 14 GW), Oman Green Energy Hub (Oman, 14 GW), AMAN (Mauritania, 16 GW), H2 Magallanes (Chile, 8 GW), and Beijing Jingneng (China, 5 GW)[20]. It can be observed that these top ten projects, despite their substantial capacity, represent only a small fraction of the

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[13] World Energy Outlook 2022" report, International Energy Agency, November 2022
[14] World Energy Outlook 2022" report, International Energy Agency, November 2022
[15] World Energy Outlook 2022" report, International Energy Agency, November 2022
[16] World Energy Transitions Outlook 2023: 1.5^{0}C Pathway - Preview, IRENA, 2023 https://www.irena.org/Publications/2023/Mar/World-Energy-Transitions-Outlook-2023
[17] Hydrogen Council was established in 2017 during the World Economic Forum held in Davos in 2017.
[18] Hydrogenfor Net-Zero: A criticalcost-competitiveenergyvector,HydrogenCouncil, November 2021
[19] Global Hydrogen Flows: Hydrogen trade as a key enabler for efficient decarbonization, Hydrogen Council, October 2022
[20] Geopolitics of the Energy Transformation: The Hydrogen Factor, IRENA, 2022, https://www.irena.org/Publications

5-6 TW electrolyzer capacity required by 2050. This highlights the significant investment needed globally to achieve the clean hydrogen production levels outlined in the 2050 carbon-neutral targets.

The highlighted project, HyDeal Ambition, is a collaborative initiative launched in 2020 that brings together 30 companies to encompass the entire green hydrogen supply chain. It aims to achieve a production capacity of 95 GW of solar power and 67 GW of electrolyzer capacity, with a target of producing 3.6 Mt of green hydrogen. As of January 2022, it has been recognized by IRENA as the world's largest green hydrogen project[21].

One of the prominent renewable energy projects in Australia, a leading hydrogen exporter, is "The Asian Renewable Energy Hub (AREH)". It encompasses an estimated $36 billion investment in a 26 GW capacity of wind and solar energy generation, aiming to produce an annual 1.6 Mt of green hydrogen from these sources[22].

In 2020, the United States produced approximately 11 Mt of hydrogen through fossil fuel reforming and is the second-largest hydrogen consumer in the world after China. The U.S. has set a net-zero carbon target by 2050 (UNFCCC, 2021), and according to this scenario, the domestic hydrogen demand is projected to range from 36 Mt to 56 Mt annually by 2050.

Europe is currently the most active region in terms of announced hydrogen projects, accounting for 50% of the global announced projects and 35% of the announced investment volume[23]. Presently, 87% of hydrogen production in the European Union (EU) comes from fossil fuel reforming, with the remaining amount predominantly derived from industrial by-products[24]. However, with the European Green Deal, the EU aims to achieve carbon neutrality by 2050, and hydrogen (green and clean hydrogen) holds a significant position within this framework. The focus of current efforts is to scale up the production of hydrogen from renewable energy sources, considering the trade-off between efficiency and cost, and to establish the necessary infrastructure for storage and transport. In July 2020, the European Clean Hydrogen Alliance (ECH2A) was established by the EU to set strategies and policies for hydrogen, as well as to achieve hydrogen technology targets by 2030. The alliance includes over a thousand stakeholders, including sector representatives, regional public authorities, civil society organizations, and other actors, all contributing to clean hydrogen projects and strengthening investments in the field. In May 2022, during the electrolyzer summit organized by ECH2A, the European Union made a commitment to increase electrolyzer capacity tenfold by 2025, enabling the achievement of hydrogen technology and infrastructure goals outlined in the "REPowerEU Communication[25]" published by the European Commission in March 2022[26]. Among other strategic action plans, the communication includes ensuring hydrogen-ready storage infrastructure, diversifying gas import supply chains by sourcing from countries other than Russia[27], increasing biogas and hydrogen production and procurement, aiming for 10 Mt of green hydrogen production (requiring 80 GW of electrolyzer capacity) and 10 Mt of

[21] https://www.hydeal.com/hydeal-ambition
[22] https://energydigital.com/renewable-energy/bp-buys-stake-in-Asian-Renewable-Energy-Hub
[23] Hydrogen for Net-Zero: A critical cost-competitive energy vector, Hydrogen Council, November 2021
[24] Accelerating Hydrogen Deployment in the G7: Recommendations for the Hydrogen Action Pact, IRENA, 2022, https://www.irena.org/Publications
[25] "REPowerEU Communication" is the European Commission's plan for reducing dependence on Russian fossil fuels and fast forward the green transition.
[26] https://single-market-economy.ec.europa.eu/industry/strategy/industrial-alliances/european-clean-hydrogen-alliance_en
[27] In order to replace 10cm per year of Europe's gas import demand prior to Russia's invasion of Ukraine, it is considered to purchase LNG from Azerbaijan, Algeria, Norway Qatar, the US, Egypt and West Africa.

green hydrogen imports by 2030[28]. In the UK, after the EU's targets, the country has set its own goal of reaching 10 GW of low-carbon hydrogen production by 2030, with half of it generated through electrolysis[29].

Germany, which has started making significant investments in the field of hydrogen in Europe, produced approximately 1-2 Mt of hydrogen in 2020, with 80% of it derived from fossil fuel reforming. In May 2021, Germany set a target to achieve carbon net-zero by 2045[30]. In June 2020, the German government emphasized the role of hydrogen by pledging a budget of 9 billion euros as part of the National Hydrogen Strategy to develop the country's hydrogen economy and establish international partnerships in this regard[31]. The German renewable energy company RWE aims to invest in a 10 GW electrolyzer capacity powered by North Sea wind energy through the AquaVentus project, targeting the production of 1 Mt of green hydrogen annually by 2035[32]. In addition to domestic hydrogen production investments, Germany has also entered into procurement agreements with potential hydrogen-importing countries such as Australia, Chile, Algeria, Namibia, Tunisia, and Ukraine[33].

In conclusion, while striving to provide clean and sustainable energy for various applications including transportation, heating, fuel, industrial power, and electricity generation, efforts are being made globally to create alternatives and reduce dependence on fossil fuels in the long term. Hydrogen energy currently represents a small fraction of global energy production, but it is increasingly becoming a focus of attention and seems it has the potential to play a significant role in decarbonization goals.

Currently, electrolyzers used to produce clean hydrogen have a global capacity of 510 megawatts, which can only supply about 0.1% of the total hydrogen demand. Organizations like IRENA and the Hydrogen Council project that achieving "net zero" goals by 2050 would require electrolyzer capacities of 5.4-5.7 terawatts (TW), enabling the production of 400-550 million tons (Mt) of renewable-sourced clean hydrogen. This amount is estimated to meet approximately 12-14% of the projected global final energy consumption by 2050. China, North America, Europe, and India are expected to become the largest markets for clean hydrogen, driving significant demand in 2050.

As of 2022, a significant portion of the world's largest 10 hydrogen energy projects, with a total electrolyzer capacity of approximately 200 gigawatts (GW), are being carried out under the leadership of Europe. When compared to the target of 5.4-5.7 terawatts (TW) mentioned earlier, it is evident that the path ahead is challenging and requires substantial progress in the coming years. However, green-clean hydrogen energy has the potential to compensate for some disadvantages of renewable energy production, such as long-term storage and transportation infrastructure limitations. It offers an important alternative for many countries in the energy transition process, contributing to sustainability and energy security.

[28] It is expected that the total hydrogen supply of 20 million tonnes to replace until 2030, a 20-50 bcm natural gas imports from Russia (as of figures prior to Russia's invasion of Ukraine).

[29] https://www.spglobal.com/commodityinsights/en/market-insights/podcasts/energy-evolution/032423-net-zero-oil-renewable-cement-steel-8rivers-ceraweek-beauchamp

[30] Accelerating Hydrogen Deployment in the G7: Recommendations for the Hydrogen Action Pact, IRENA, 2022, https://www.irena.org/Publications

[31] The National Hydrogen Strategy, Germany, June 2020

[32] https://www.rwe.com/en/research-and-development/hydrogen-projects/aquaventus/

[33] Geopolitics of the Energy Transformation: The Hydrogen Factor, IRENA, 2022, https://www.irena.org/Publications