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A Study on Green Hydrogen Production for Sustainable Future: Systematic Literature Review

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Abstract

Hydrogen is very much significant and cheaper one by storing in existing natural gas system as an alternative for all economic sectors that provide sustainable primary energy. Green hydrogen is one of the important and promising energy sources on the earth for decarbonizing the energy systems. Green hydrogen production safeguard the environment and results in positive economic impacts. Primary sources of energy embrace different renewal sources for sustainable energy conversion. Green hydrogen replacement produces zero greenhouse gases that influence pollutions in the atmosphere. Much synthesis of zero-emission liquid fuels is possible through the renewable hydrogen which is a best alternative for several chemicals and thermals. Researchers used PRISMA method of systematic and meta-analysis for revieing literature study. PRISMA is a technique which is much useful for serious reviews in reviewing literature study. Researchers assess biased data to ensure transparency and PRISMA enable to prepare literature review aesthetically with the help of synopsis of the selected topic. It is graphical representation simplifies the comprehensive selection methods and PRISMA also helps to perform the systematic review by complying the guidelines as prescribed technique to validate and reviews. Researchers have considered articles which are appropriate by following various stages of PRISMA methodology.

Key words: Hydrogen, Greenhouse, PRISMA, Literature Review, sustainability and reliability

Introduction

Sustainable energy conversion uses primary energy sources, such as renewable resources, that the planet naturally replenishes swiftly with zero emissions of greenhouse gases and other environmental pollutants. Although solar and wind power conversion technologies have lately been more affordable, managing the dynamics of the electrical grid and meeting end-user demand for energy-dense fuels and chemicals still present hurdles. The best option for a zero-emission fuel is renewable hydrogen, which also makes it the ideal feedstock for the synthesis of zero-emission liquid fuels and certain chemical and thermal end applications. Electrolysis systems that are dynamically managed to complement renewable wind and solar power dynamics can produce renewable hydrogen at very high efficiency. Sustainable primary energy can be produced in all economic sectors by storing hydrogen in the current natural gas system, which can offer huge storage capacity at a reasonable cost (Alireza et. al., 2018). An exceptional prospect to accomplish sustainable development and minimize the effects of climate change is presented by the United Nations Sustainable Development Goals (UN-SDGs). A crucial strategy for attaining the energy balance is decarbonizing the energy system. The most potential energy source for decarbonizing energy systems as of late is green hydrogen. Thus, it is imperative for all stakeholders to ascertain the various techniques employed in the generation of green hydrogen, as well as its financial and ecological implications. It is essential for policymakers and decision-makers to comprehend the significance of green hydrogen in accomplishing the various Sustainable Development Goals (A.G. Olabi et.al., 2023). Intact energy systems will need to use hydrogen solutions in order to bring the global temperature down below 2 °C. The technology is ready for widespread use, has undergone testing, and is safe. Consequently, there has been a growing demand for hydrogen (Ahmed SF et.al., 2021).

It is widely recognized that hydrogen is the most likely fuel to support a green environment. Globally, both developed and developing nations have set up policy frameworks, funding, and research on hydrogen. Quantitative and unbiased information about the hydrogen economy can be obtained by thoroughly examining journal articles published during the previous 50 years. Scholars and experts in the business sector predict that hydrogen will support other renewable energy (RE) sources in the energy revolution by 2030 (Gagan Deep Sharma et.al., 2023). PRISMA methodology has been used in this study to carry out the research on the proposed title to ensure transparency and quality. This technique would help the researchers and readers to understand the literature study easily with the systematic meta-analysis with the help of flow chart diagram. PRISMA methodology helps to identify the articles for review, screening process of articles, eligibility criteria and finalizing the list of literature reviews in a systematic manner. The study also found 127 records in the initial stage, 18 records were removed due to duplication of topic selected and total of 109 records have been considered for the study. 5 reports have been excluded in the research process and estimated 104 reports and 7 reports were not retrieved concluding total of 97 reports. At the end 3 reports were removed for repetition, 4 reports were removed for poor quality and 5 reports were removed for poor clarity and 85 reports were considered for review of literature study.

Statement of Problem

Global Warming is one of the major areas of discussion on climate change around the world. It is crucial to decarbonize and shift the environment to clean energy for the benefit of the existing community and for future generations. This throws light on the immense need to focus on the sustainable defensive mechanism to resolve the challenges on carbon emission. Innovators are employing electrochemical water electrolysis to produce hydrogen from two basic ingredients: electricity and water, in an effort to create a "green hydrogen economy" where emissions-free hydrogen is extensively used in daily life. However, the goal of the green hydrogen economy is to get all of its energy from renewable sources, ensuring that no fossil fuel or water-based cooling processes are used. Therefore, while analyzing the effect of hydrogen production on global water supplies, it is crucial to include only water that is directly needed for water electrolysis (Beswick R.R, 2021).

Literature Review - GCC Scenario

Domestic and industrial sectors generate billions of liters of wastewater every day. Although wastewater is frequently seen as a problem, it may also be seen as a rich source of energy and materials. Wastewater is a possible source of bio-hydrogen, a clean energy vector, feedstock chemical, and fuel that is widely acknowledged to play a part in the decarbonization of the future energy system. It also includes four to five times more energy than is needed to treat it (A K M Khabirul Islam et.al., 2021). The GCC countries consume a lot of "grey" hydrogen, or natural gas-based hydrogen, roughly 8.4 million tons annually, or about 7% of the world's total. Carbon capture, use, and storage (CCUS) retrofitting may be appropriate for some of this. The majority of hydrogen units are found in petrochemical plants, steel mills, and refineries. An estimated 39% of the region's H2 use comes from Gas-to-Liquids (GTL), which is followed by steel manufacturing (4%), ammonia production (21%), methanol production (9%) and oil refining (27%). At the moment, utilities, power plant developers, and industries in the area are more interested in producing hydrogen than oil and gas companies1 are. One cutting-edge, large-scale green hydrogen production project, the US$5 billion, 237 000 tonne/year Neom Helios project in NW Saudi Arabia, was created by Acwa Power and Air Products. It is the only one of its kind in the GCC.

The cost of producing hydrogen varies based on the region and technology, and this is expected to alter over time. As carbon pricing becomes more widely accepted and technology advances, "green" hydrogen may end up being less expensive than "blue" hydrogen. It is anticipated that the cost of green hydrogen will decrease from US$ 3.5-7.5/kg in 2020 to US$ 1.6-2.2/kg by 2030. The medium-term forecast calls for a sharp increase in global demand for green hydrogen, reaching 530 Mt, which would displace 10.4 billion barrels of oil equivalent by 2050, or 37% of the world's oil production in 2020. This ought to encourage Gulf nations to focus on exporting low-carbon goods. UAE has a lot of potential to manufacture green hydrogen, while being a key player in the oil market and holding roughly 10% of the world's crude oil supply. First, solar-powered electrolysis might be used to make green hydrogen; second, wind energy has also demonstrated significant promise, as seen by the construction of a 2-million-euro wind power facility in the United Arab Emirates. The use of green hydrogen could have a favorable impact on greenhouse gas emissions and climate change by being used in a variety of industries, including transportation and energy production (Farah Mneimneh et.al., 2023).

Oman Scenario

Oman's carbon emission accounts to 90 mt CO_2 emission, that include 28.4 mt, that occupies 32% from industry usage, 22.9 mt, accounts to 26% of emission from oil and gas activities, 17.1 mt, that occupies 19% from power activities and building construction finally 15.9 mt, that occupies 18% of transport facilities (Salim bin Nasser bin Said Al Aufi, 2022). The Oman Vision 2040 places emphasis on energy diversification through the use of renewables. The country desires to fulfil this vision by becoming a major green hydrogen producer in the GCC and MENA region by aiming to produce 1 million tons of green hydrogen by 2030 as well as increase the production to 3.75 million tons annually by 2040 and 8.5 million tons per year by the year 2050 accomplishing its energy diversification vision 2040 as well as setting the tune for achievement of net zero carbon emission by 2050. (Enrique Fernandez, 2022). With immense experience in the energy sector, strategic location and robust political relations, Oman is looking to set itself up as an important hub for production and export of green hydrogen (TNS, 2022). Water scarcity can be mitigated internationally with the aid of wastewater treatment. Oman, with its desert environment, is among the nations pursuing wastewater treatment with the goal of recycling cleaned water for other uses. A sustainable method of reusing treated water and generating green energy simultaneously is through the production of bio-hydrogen gas (Barghash H et.al, 2022-a).

Need for Hydrogen production

Green Hydrogen as a source of clean energy has received lot of attention in the literature in the last couple of years as it is a natural alternative to fuel-based energy which improves a nation's long-term energy security (chien et al., 2021). As per the UN's Intergovernmental Panel on Climate Change (IPCC), climate control and use of green energy go hand in hand and hence the use of green hydrogen as a clean energy carrier cannot be undermined. It is important to clarify and comprehend the significance of the water sector in the hydrogen economy. The water production has a crucial role to play in framing this transformation around water consumption as well as in facilitating the processes for a hydrogen industry that is sustainable, circular, socially responsible, and does not raise water stress and competition. The water sector generates wastewater streams that, instead of being used to produce potable or desalinated water, might be turned into a sustainable source of hydrogen. Revenues from wastewater are in the form of sales revenues from treated water sales and compost only. Hydrogen projects can add one more dimension by generating revenue from green hydrogen sales. In addition to the revenue from treated wastewater and compost, an additional 3.8 billion RO per year can be generated in Oman from green hydrogen sales at existing treatment capacity of 81,200 m3 /day treated wastewater effluent (Barghash H et al, 2022-b). Compared to petrochemical fuels, the main obstacle to the commercialization of hydrogen energy is cost. An innovative business strategy has to be created that turns the expenses associated with obtaining biomass into income by producing hydrogen. Generally, increasing scale and reducing costs through ongoing technological advancements can result in profitable hydrogen production. However, the flexibility of cost/benefit reduction is constrained by feedstock procurement expenses. Therefore, a well-developed model that expands the hydrogen production value chain to incorporate the income from processing bio waste, lowering the cost of fuel sources, and producing hydrogen from biomass is required (Pao-Long Chang et.al., 2011).

Benefits of wastewater utilization

Predictions indicates that the fully developed hydrogen economy would use about 34,500 GL of water yearly, or about 2.3 Gt of hydrogen annually. Given the increased number, one may wonder if using water as a feedstock for the "green hydrogen" economy is still viable (Beswick, 2021). Desalination may cost 5% of the total cost of producing hydrogen, but brine management and disposal problems persist, water extraction can be increased up to five times, and the extensive removal of microorganisms from seawater can negatively impact regional ocean diversity (Jones, 2019). If they are not adequately maintained, aquatic ecosystems are especially vulnerable. An ecosystem typically contains links to various human activities, industry, and agriculture in addition to metropolitan regions. In such a nexus, it is necessary to maintain a delicate balance between precipitation, evaporation, the amount of water extracted for human activities, and the quality of the water returned to the environment. The additional burden that a hydrogen economy on a larger scale would place on water systems, especially considering climate change and highly erratic rainfall. Since green hydrogen will link the energy-water nexus in previously unheard-of ways, water and energy will become directly dependent on one another for the first time (Hussey, 2010).

Manufacturing hydrogen from wastewater contaminated with mercury opens up possibilities for treating contaminated industrial wastewater while also generating energy that could meet the process's energy needs and more. For a self-sustaining wastewater treatment process that converts waste into wealth, a multifunctional strategy with a circular economy will be optimal (Abdul Malek et.al 2021). The sustainability of hydrogen production sources, systems, and storage options have all been thoroughly reviewed by Canan Acar and Ibrahim Dincer. The social, technological, financial, and environmental aspects of the sources and systems needed for sustainable hydrogen production have not received enough attention in research, according to their investigation. Future research on hydrogen end-use alternatives, such as various fuel cells and internal combustion engines, could incorporate this 3S methodology to improve the sustainability analysis of hydrogen energy systems even more for a sustainable future. The Philippines which has an abundance of renewable energy sources, including geothermal, hydropower, wind, solar, biomass, and ocean, aims to achieve a green hydrogen economy by 2050. The Philippines has laid out a roadmap for the technology and market development that is divided into three phases: I-green hydrogen as industrial feedstock, II-green hydrogen as fuel cell technology, and III-commercialization of green hydrogen. Even while the green hydrogen economy has the potential to speed up the energy transition, there are still social, economic, and technical obstacles to overcome (Hydrogen in the GCC, 2020).

Production and transportation systems based on renewable energy and green hydrogen have the potential to decouple harmful CO_2 emissions from the whole iron and steel supply chain. Supply chain architecture, energy vector, and time will all significantly affect the system's resource and financial burden; controlling these factors is essential to speeding up the decarbonization of the steel industry and maintaining the system's competitiveness with fossil fuel-based alternatives (Alexandra Devlin & Aidong Yang 2022). The cost modeling highlights the significance of energy pricing and indicates that the UK's low-carbon steelmaking methods are less competitive with respect to emissions-intensive incumbents because of disparate carbon costs and higher power prices than in many other nations. This drawback for low-carbon steelmaking alternatives puts pressure on an industry already experiencing heightened competition in international markets and conveys conflicting messages about the government's commitment to Net Zero. While addressing these cost issues need to be a top priority for policy, it might not be enough to create a decarbonized and competitive UK steel sector. Given the worldwide structure of the steel industry, coordinated international action on issues including the establishment of markets for green steel export levies on scrap will probably be required as well (Clare et.al, 2022)

The next development in technological advancement toward an emission-free and sustainable energy system is the energy turnaround and hydrogen economy. The policies necessary to implement them call for a daring shift in the direction of politics, the economy, and society. It is to be hoped that this path of energy transition is quickly recognized as the chance that it poses for the health and livable environment of future generations, given the growing dissatisfaction among scientists and especially young people with the hesitancy regarding the necessary transition steps in our economy (Alexander Trattner et. al., 2022). A study that intends to showcase Vietnam's policy and potential for transitioning to a green hydrogen economy has been conducted. It endorses that Vietnam should investigate and utilize every energy source that is accessible in order to address the energy problem as well as the sustainability of the current economy. Transporting electricity from offshore to inland might out to be far less profitable than producing electricity using renewable energy sources offshore and using it to electrolyze water to produce green hydrogen. Furthermore, in order to develop a green hydrogen economy, further advancements in the fields of H_2 generation, storage, transportation, and distribution are required. Expanding the scope and implementing sensible policies for the green hydrogen economy are key responsibilities of the government in this regard (Anh Tuan Hoang, et.al., 2023). An extensive analysis of Morocco's energy industry is provided in a document, with particular attention to the significant obstacles that must be overcome in order to create an economy based on green hydrogen that has the potential to create jobs and become carbon neutral. Establishing a green hydrogen industry in Morocco is hindered by a number of issues that call for collaboration with Europe and other foreign allies. Increasing the competitiveness of green hydrogen, increasing production, and developing the necessary skills are some of these problems (B.E. Lebrouhi, et.al., 2024).

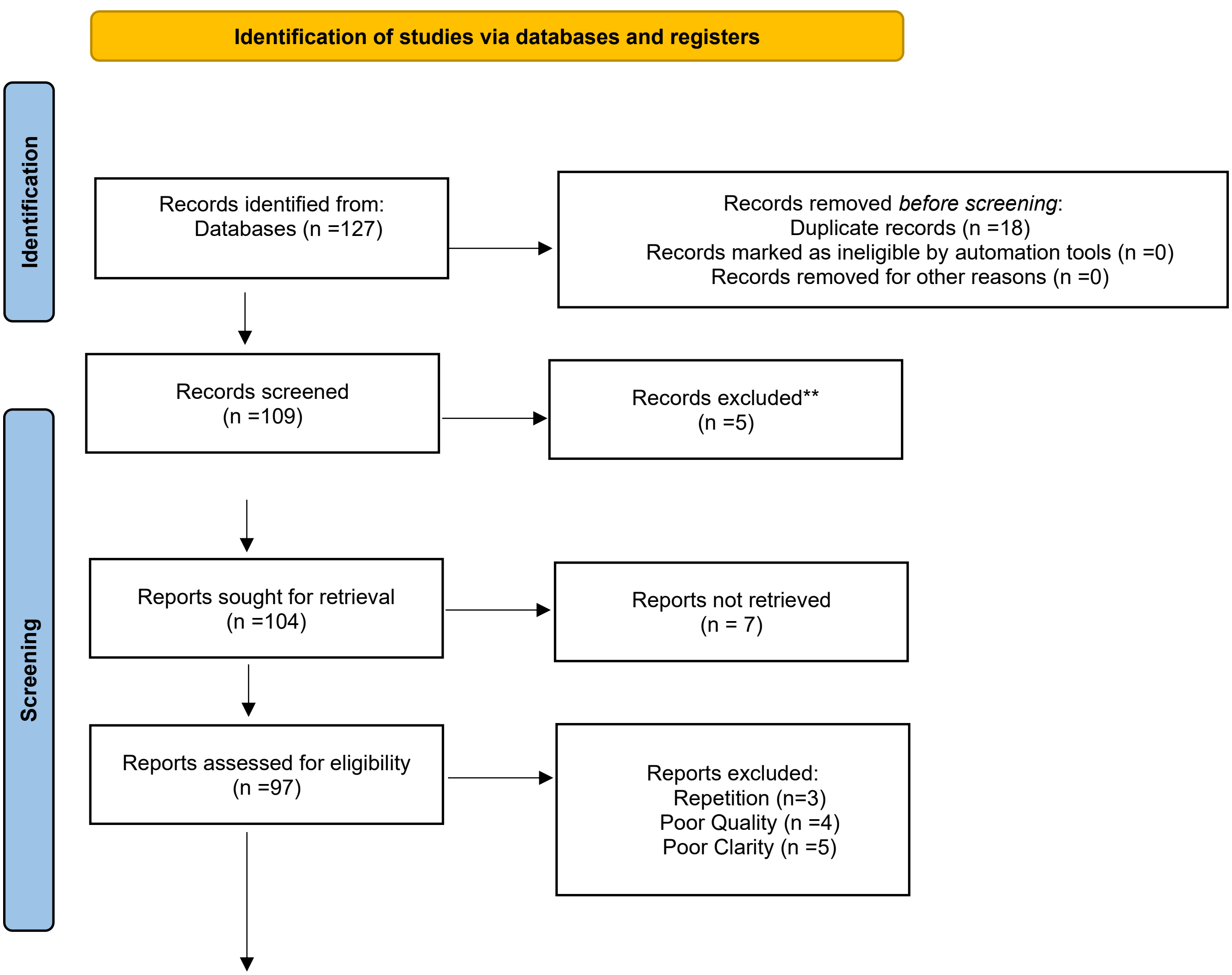
The literature and research on the evolution of hydrogen technologies have been reviewed by Jakub Dowejko (2023) and the prospects of hydrogen technology in Poland have been delineated. Reducing greenhouse gas emissions and air pollution can be achieved through the utilization of hydrogen energy. The impact on the nation's economy of the transformation of the energy system through the use of hydrogen energy is a significant factor. On the one hand, by lowering reliance on imports of fossil fuels and enhancing energy security, the development of hydrogen technologies may help the nation become more energy independent. However, there may be financial advantages to this change as well. Following the completion of a SWOT analysis, many advantages and difficulties associated with this technology's application were identified. Examples of Polish projects utilizing hydrogen energy were also provided, along with the goals of Poland's energy policy for the period of 2040 (Jakub Dowejko, 2023).

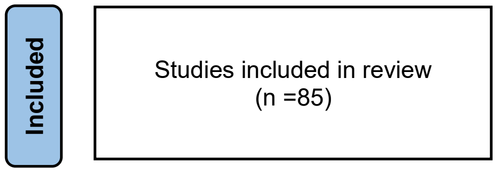
Bibliometrix R-tool and VOSviewer, two software that perform integrative reviews, are used in a study to examine the socioeconomic effects of hydrogen energy literature that is sourced from the Scopus database. It has been found that the majority of research addresses interdisciplinary issues such generation, storage, transportation, application, viability, and development of policies (Gagan Deep Sharma et.al., 2023). All Quintuple Helix Model stakeholders are directly impacted by resource use, particularly in light of the world's growing population. In order to address climate change, this model needs to use resources more efficiently, rethink existing business models or create new ones, and prioritize modifying consumer behavior, enhancing human well-being, and constructing climate change resilience. The research conducted by Gemma Duran-Romero et.al reveals, governments, corporations, and society a framework for action based on the contribution of Circular Economy towards sustainability. New information on eco-innovations that could help meet climate change mitigation targets has been made available by this study. Policymakers are urged by the literature to take climate change and Circular Economy goals into consideration at the same time, as their interdependence has been demonstrated (Gemma Duran-Romero et.al, 2020).

Research Methodology

PRISMA is a technical and systematic and meta-analysis revieing literature process with the help of visual diagram to carry out the research study in the anticipated topic with the aim of enhancing transparency, quality methodology and preparing reports in a specified area to understand and review easily for the researchers to examine the probable biases. PISMA flow charge enhance definite correspondence of the various techniques to identify the data, screening the information and inclusive and exclusive of the various studies by researchers to improve the transparency and repeatability of the research procedures. PRISMA flow chart also support to examine the reliability factors and validity factors of various literature reviews considered to ensure the accuracy in an organized manner of the assortment process. It also helps to determine the assessment of inclusive and exclusive data relating to the title designated with logical reasons. Researchers assess biased data to ensure transparency and PRISMA enable to prepare literature review aesthetically with the help of thorough depiction of synopsis of the selected topic. It is graphical representation simplifies the comprehensive selection methods and PRISMA also helps to perform the systematic review by complying the guidelines as prescribed technique to validate and reviews with the transparency and reliability through proper procedures.

Analysis, Interpretation and Conclusion





Source: Research Methodology Process

PRISMA is a technique which is much useful for serious reviews without compromised the quality in reviewing literature study. The flow diagram of the PRISMA comprise of twenty-seven substances and four stages. Statement is very efficiently illustrated for better quality in literature review study. Step one is basic one which is used to identify with the related diagram. During the first stage, the researchers have used very important information viz., key terms for each data while retrieving. The database shows the final result of 127 records in the left side of upper chart box. Unsuitable information and duplicate records are easily identifiable and could be removed easily namely the records which are very old in the publication and published in other languages could be removed. Before considering the screening process the list of records which are duplicate estimating 18 records were deleted. Records marked in the process as ineligible by automation tools are zero and the records removed for other reasons also estimated as zero. Researchers have considered the articles which are appropriate to search enquiries by screening and it is also significant to count the rejected articles and write the total number of records excluded. The flow diagram describes the number of research studies finalized in the first stage of screening and proceeding to the next stage by considering the likely relevant studies are 109 records have taken.

The second stage in the PRISMA technique is to add the number of records in the screening process. Researchers make sure to include records by screening them and it is mandatory to count the deleted articles and incorporate the total number of files. Second stage also refers to the reports acquired in advance that are to be retrieved are total 104 reports after reports exclusion of 5 reports. Researchers have used to determine the tools and resources which are not to be included are total 7 which are not having full text required for the study. The second stage also include the number of reports required to be retrieved and should subtract the number of reports that are not to be retrieved would be the total number of reports eligible after the evaluation. The researchers have included the total number of articles which are excluded after thorough review of each and every article at this stage. It is important to add article to make sure it has excluded the number of reports with repetition which are 3, poor quality articles which are 4 and poor quality of 5. At the final stage after the total number of the records examined, final records have been evaluated at 85 in total for the study.

Conclusion

About twenty countries are using public-private partnerships and customized incentives to initiate market scale-up efforts. These countries include Japan, South Korea, Germany, the United States, Australia, China, and India. However, experts agree that significant improvements are needed from all stakeholders involved in order to fulfill this ambitious aim (Han S-M, Kim J-H & Yoo S-H, 2021). The ensuing worldwide roadmaps, which extend until 2030 and beyond, aim to improve the production of clean and green hydrogen, establish distribution networks and manufacture components, at reduced costs. These forecasting scenarios take into account all stakeholders, including industry, investors, and regulators, since they need to collaborate in order to successfully realize this vision. Owing hydrogen has specialized applications in the energy, transportation, building, and industrial sectors, its usage is expected to grow steadily until 2030.

Possible outcomes that could lead to a hydrogen economy during the next three decades will be new coalitions formed to develop cross-sector collaborations for hydrogen initiatives. Costs associated with producing and transporting hydrogen will be cut in half by 2030 and will then gradually reduce until 2050. By 2050, the cost of producing renewable hydrogen will range from $1 to $1.5/kg in a number of Middle Eastern, African, Russian, Chinese, American, and Australian nations and Production costs in regions with few renewable resources, such most of Europe, Japan, or South Korea, will be roughly $2/kg throughout this time, suggesting that these markets will be net importers of green hydrogen from other regions. Possible outcomes also include geographic limitations, even places with plenty of renewable energy sources but high population densities will import hydrogen in order to facilitate the direct consumption of green power and hydrogen conversion. There are hydrogen production zones in several large countries, such as the US, Canada, Russia, China, India, and Australia. This could result in international hydrogen trade. Similar to current oil and gas hubs, export and import centers will spring up all over the world, with new players in areas abundant in renewable resources (Sanjay Kumar Kar, et.al., 2022). PRISMA refers to preferred reporting items for systematic review and meta-analysis. The viewpoint of the technique is to identify and incorporate the least set of data for disseminating in a systematic review with meta-analysis. The benefit of this procedure is to support the researchers to develop the quality of the reporting and meta-analysis with different styles and approaches predominantly estimating along with involvements. PRISMA technique has been used to ensure the transparency and quality of the articles considered for the review on the proposed title. This method of reviewing literatures made it easy for the readers with the help of flow chart diagram to enable systematic meta-analysis. The study also sued step by step process of PRISMA approach by identifying the review of articles, screening of those articles, determining the eligibility criterion and finalizing the list of reviews of literature. Total of 127 records were taken for the scrutiny at the initial phase, out of which 18 reports were removed due to duplication. At the end, 3 reports were excluded due to repeating the same content and article, 4 articles were deleted for poor quality and 5 reports were erased for poor quality resulting 85 reports for final review.

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