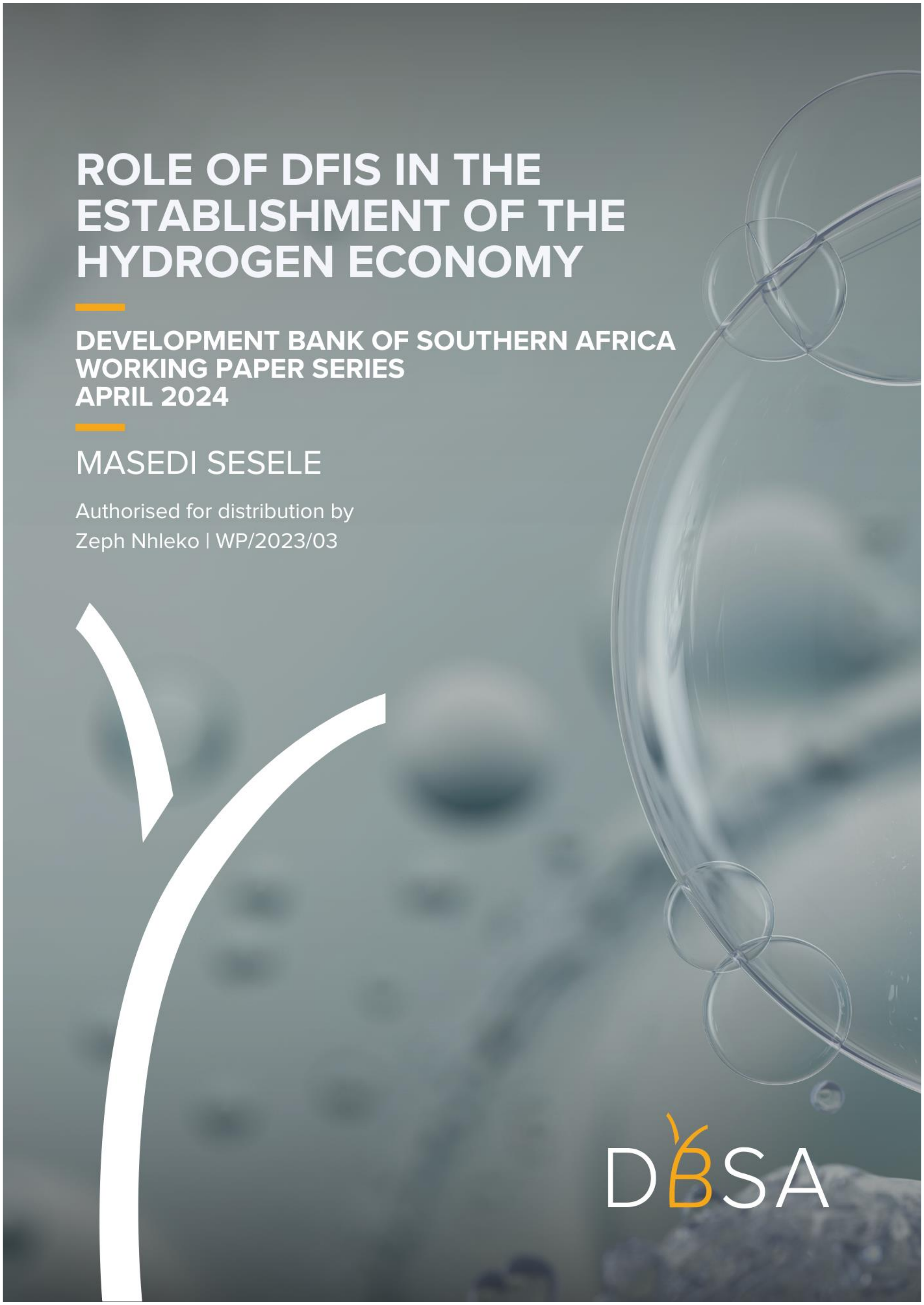

ROLE OF DFIS IN THE ESTABLISHMENT OF THE HYDROGEN ECONOMY

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List of acronyms

AC	Alternating Current
AFD	Agence Francaise de Developpement
CEOG	Centrale Electrique de l'Ouest Guyanais
COP26	2021 United Nations Climate Change Conference
DBSA	Development Bank of Southern Africa
DC	Direct Current
DFIs	Development Finance Institutions
Dirco	Department of International Relations and Cooperation
DSI	Department of Science and Innovation
EIB	European Investment Bank
EIU	Economist Intelligence Unit
GH2	Green Hydrogen Organisation
GIZ	Deutsche Gesellschaft für Internationale Zusammenarbeit
H2	Hydrogen
IATA	International Air Transport Association
IDB	Inter-American Development Bank
IEA	International Energy Agency
IFC	International Finance Corporation
IRENA	International Renewable Energy Agency
Kg	Kilogram
Km	Kilometer

Abstract

The objectives of this research are to define the properties of hydrogen, its production from different sources, its different uses, and challenges in establishing a hydrogen economy. Furthermore, the research identifies key opportunities and roles for development finance institutions (DFIs) in the establishment of the green hydrogen economy in South Africa with reference to the broader Southern Africa context. The study found that DFIs have significant roles to play in the green hydrogen economy such as scaling up renewable energy capacity to produce green hydrogen; creating an enabling environment for green hydrogen investments; hydrogen infrastructure development; green hydrogen project preparation facilities and scaling up innovative financing instruments to catalyse green hydrogen investment.

1. Introduction

The transition towards a global low carbon economy to protect the environment has become an important issue for development finance institutions, governments, and other stakeholders with an interest in sustainable development. However, the limited gas supplies due to the Russia invasion of Ukraine and extreme weather events have forced many countries to fall back on fossil fuels, which will delay the transition to green energy and net-zero emissions (EIU, 2023).

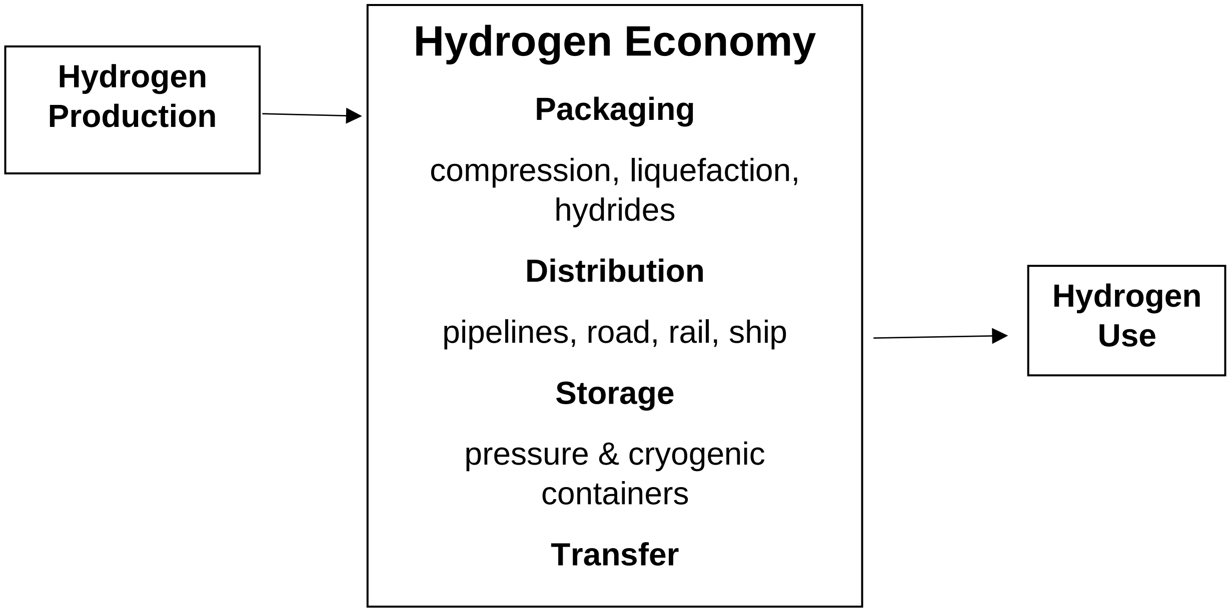
Hydrogen has since emerged as an alternative energy carrier that produces no emissions when utilised to meet energy needs and can be produced from many sources. Hydrogen is a synthetic energy carrier for energy generated by other processes. High grade electrical energy is transferred to hydrogen by electrolysis of water and is used not only to produce hydrogen, but also to compress, liquefy, transport, transfer and store the medium. The use of hydrogen has the potential to help decarbonise the industrial, transport and heating sectors as hard-to-abate sectors such as steel production will be nearly impossible to decarbonise through electrification alone (Woodward, 2021). The 26th session of the Conference of the Parties (COP 26) urged development banks to scale up investments for climate action and explore innovative approaches and instruments for mobilising climate finance.

The objective of this paper is to define the properties of hydrogen, its production from different sources, its different uses and challenges in establishing a hydrogen economy. The paper will further identify key opportunities and roles for DFIs in the establishment of the hydrogen economy in South Africa with reference to the broader Southern African context. This will also include an analysis of different hydrogen projects and plans led by development finance institutions, including the South African Hydrogen Valley feasibility and likely economic outcomes.

2. Background

Hydrogen is an important energy carrier which can be stored, transported and used for fuel or converted to electrical energy in devices like fuel cells. A hydrogen economy as shown in Figure 1 is projected as a possible contribution to solving the current energy crisis and environmental degradation as hydrogen's conversion to heat or power is simple and clean. When combusted with oxygen, hydrogen forms water and no pollutants are generated or emitted (Bossel & Eliasson, 2003). The water is then also returned to nature, its original source. As such, hydrogen is emerging as a logical and appropriate choice as a chemical fuel to replace today's fossil fuels, mainly because hydrogen is a complementary energy carrier to electricity. Both energy carriers are necessary as each can satisfy a range of energy service demands, some of which cannot be satisfied by the other (Rosen & Koohi-Fayegh, 2016).

Figure 1 Schematic Presentation of a pure Hydrogen Economy



Source: Bossel & Eliasson (2003)

Physically, hydrogen is the smallest of all atoms and as such is the lightest gas (about 8 times lighter than natural gas). Hydrogen also carries less energy per volume than natural gas at any pressure and has high lower heating values as compared with traditional fossil fuels. Hydrogen offers the highest burning velocity as compared to all other fuels (such as propane, methane, gasoline, diesel and methanol) whether liquids or gases. A high-performance indicator is offered by the hydrogen fuel cells in terms of efficiency, as fuel cells are not constrained by thermal efficiency limits of the thermal Carnot cycle (Ishaq, *et al.*, 2022).

Currently, hydrogen production is dominated by fossil fuels. Natural gas is currently the most commonly used primary source of producing hydrogen. The steam methane reforming method is the most widely used method of producing hydrogen from natural gas (Amin, *et al.*, 2022). Hydrogen has also been widely produced from the coal gasification process, which is a process of converting any hydrocarbon source into useful synthetic gas, using a source like oxygen into the process. Furthermore, nuclear energy can also be used as a primary energy source for hydrogen production. This is because nuclear power plants can produce both electricity and heat which can be used for conventional water electrolysis, thermochemical or electrochemical processes in extracting hydrogen gas (Amin, *et al.*, 2022).

The production of hydrogen from non-renewable energy sources has garnered criticism because that type of production will have a negative impact on the environment, which will contradict its status as a renewable energy source. This has resulted in the emergence of production methods of hydrogen using renewable energy sources, which has been termed green hydrogen and contributes to a small fraction of hydrogen production (Amin, *et al.*, 2022). Hydrogen can be produced from biomass through biological processes and gasification. Hydrogen can also be produced from solar and wind powered electricity by means of water electrolysis.

Current and potential industrial uses of hydrogen include the use of hydrogen in oil refining, the chemical sector, iron and steel production and in high temperature heatings. Hydrogen can also be used as a basis for clean transport fuels, fuel for heating in buildings and for power generation and electricity storage (IEA, 2019). In South Africa, the role a hydrogen economy can play in the reindustrialisation of the country has been recognised (South African Government, 2023). In 2007, the South African Cabinet approved South Africa's hydrogen strategy to initiate the development of hydrogen and fuel cell technologies through a 15 year programme. Currently, hydrogen cells have been used in the country as power sources in hospitals. Recently, the first ever hydrogen powered truck was unveiled (DIRCO, 2022).

3. Methodology

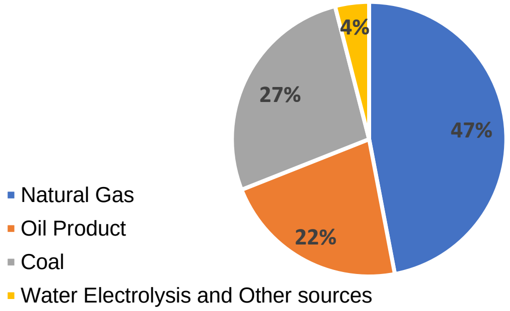
The methodology in this study followed two approaches. Firstly, a systematic review of existing literature with regard to the hydrogen economy and the roles DFIs can play in its establishment was undertaken. Secondly, hydrogen founding initiatives were documented such as the South African hydrogen valley feasibility, green hydrogen funds and hydrogen projects and plans led by development finance institutions. The selection of hydrogen projects, plans and funds was dependent on the availability of data. Interviews with key informants were also conducted to gather information on the hydrogen economy.

4. Literature Review

4.1 Hydrogen production

Globally, hydrogen is mainly produced by fossil fuels as the most widely used hydrogen production technology in recent years is natural gas steam reforming, oil reforming and coal gasification, with a small contribution coming from water electrolysis as shown in Figure 2. In 2021, electricity had a global average renewable energy share of around 33 percent, which means that only 1 percent of global hydrogen output was produced from renewable energy (IRENA, 2022).

Figure 2 Global hydrogen production by sources as at end of 2021



Source: IRENA (2022)

4.1.1 Hydrogen production from non-renewable energy

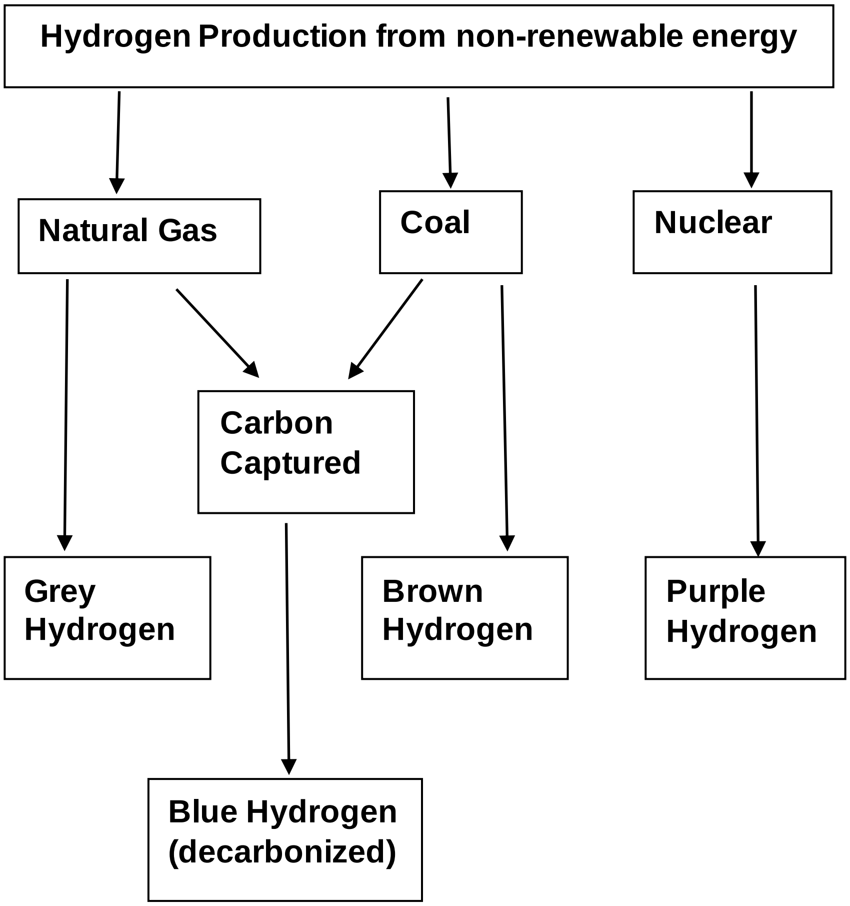
Grey hydrogen is a fossil-derived hydrogen derived from natural gas or methane through steam reforming processes. This method of hydrogen production results in significant carbon emissions without any mitigation technologies applied (Chew, et al., 2023).

Brown hydrogen is fossil-derived hydrogen derived from coal through the gasification process. Hydrogen production from the coal gasification process is a very well-established technological process already in use in countries with high coal endowment such as China and Australia. However, this process is coupled with high carbon emissions and poses environmental concerns (Amin, et al., 2022).

Since both brown and grey hydrogen generate carbon emissions, blue hydrogen is a process whereby the grey and brown hydrogen processes are retrofitted with carbon capture and storage technology such that the carbon dioxide generated from grey and brown hydrogen processes can be captured and stored underground (Ajanovic, *et al.*, 2022). This will result in low carbon hydrogen and relatively low emissions.

Purple hydrogen results from the use of nuclear energy, which produces electricity and heat that can be utilised for conventional water electrolysis, thermochemical, or electrochemical processes in extracting hydrogen gas (Amin, *et al.*, 2022). Excess energy from nuclear reactors can be utilised to produce electrolytic-grade hydrogen on a massive scale instead of reforming hydrocarbons (Grigoriev, *et al.*, 2020).

Figure 3 Hydrogen production from non-renewable energy sources

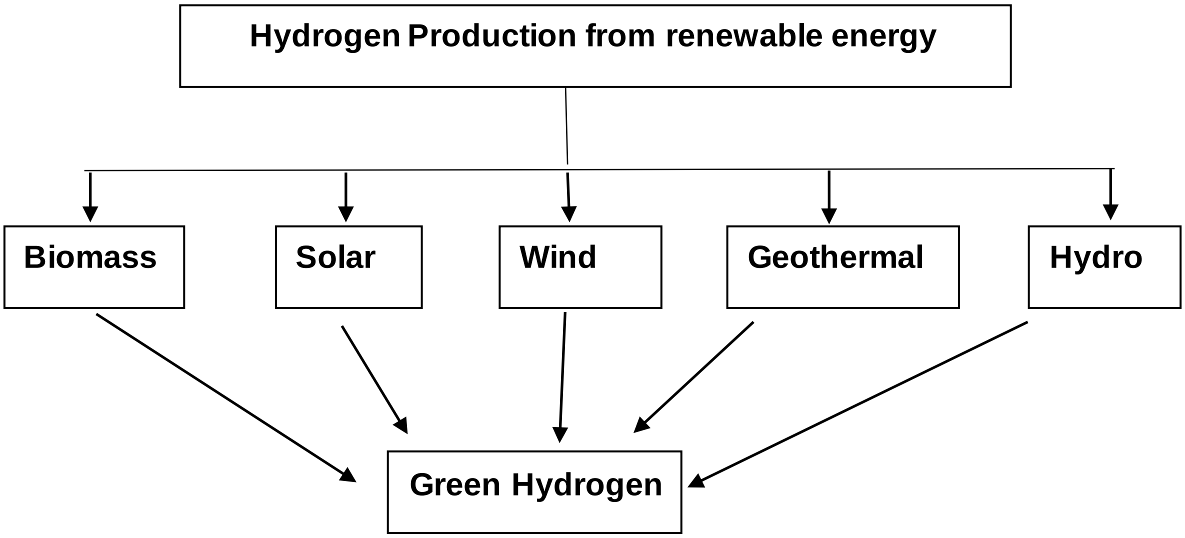


Source: Adaptation from Chew, et al. (2023); Amin, et al. (2022); Ajanovic, et al.(2022)

4.1.2 Hydrogen production from renewable energy

Green hydrogen is produced from renewable energy sources. Biomass fermentation, gasification, reforming, pyrolysis, and bio-photolysis processes can produce hydrogen. The process can result in minimal carbon emissions entering the atmosphere which have been deemed acceptable due to the life cycle assessments and audits showing the practice is near carbon neutral (Newborough & Cooley, 2020).

Figure 4 Hydrogen production from renewable energy sources



Sources: Adaptation from Chew, et al. (2023); Amin, et al. (2022); Ishaq, et al., (2022)

Solar thermolysis, solar thermochemical cycle, solar gasification, solar cracking and electrolysis can be used to produce green hydrogen. Solar photovoltaic sources generate electricity which is used in electrolysis and produces hydrogen. Thermal energy from concentrated solar thermal energy is also used to produce hydrogen through solar gasification and solar ammonia reforming (Ishaq, et al., 2022).

Wind energy-based hydrogen is produced from the electrical energy generated from wind as an energy source. The electricity is converted from AC to DC and employed to the electrolyser which splits water into oxygen and hydrogen (Harrison, 2023).

Geothermal energy is defined as the heat generated inside the earth’s sub-surface (Lund, 2023). The geothermal energy is harvested from the underground to the surface through a heat transfer carrier where heat is first transferred through conduction heat transfer between rocks then through convective heat transfer. The hot water is then delivered to the surface (Ghazvini, et al., 2019). The geothermal power can then be fed to water electrolysis for hydrogen production and the heat can also be used for thermochemical hydrogen production.

Hydropower is the conversion of water-flowing energy into electricity (Kaunda, et al., 2012). Hydropower is measured as a renewable energy source since the cycle of water is continually renewed. The electricity generated from hydropower can be employed to an electrolyser which splits water into oxygen and hydrogen.

4.2 Challenges in hydrogen production

The production of hydrogen face challenges, particularly regarding energy security, energy equity, and environmental sustainability. These challenges differ depending on the renewability or non-renewability of the production source and method.

4.2.1 Non-renewable production

Hydrogen production which is mainly dependent on fossil fuels faces issues of availability, as non-renewable energy sources have finite availability. The current global reserves-to-production ratio – the ratio that represents the length of time that those remaining reserves would last if production were to continue at the previous year's rate – for coal is 139 years (BP, 2021). While the global reserves-to-production ratio for natural gas is 48.8 years (BP, 2021).

The volatile market for energy prices places a challenge on the production of hydrogen using non-renewable energy sources. With the implementation of carbon emission taxes and the volatility in gas prices due to the recent Russia-Ukraine conflict, prices of non-renewable energy sources are likely to increase substantially, which poses a threat to energy equity (World Economic Forum, 2023). Issues related to sustainability are magnified by the use of non-renewable energy sources when producing hydrogen. Both grey and brown hydrogen account for high carbon intensity, which contributes to annual carbon emissions that pose a threat to the environment. Brown hydrogen is twice as carbon intensive as grey hydrogen, while grey hydrogen is nine times more carbon intensive than green hydrogen (Gupta, 2022).

The use of carbon capture and storage technology has tried to reduce the emissions associated with hydrogen production from non-renewable energy sources. The technology is however not 100 percent efficient in removing emissions, which then affects its reliability (Chew, *et al.*, 2023). The carbon capture and storage technology is also very energy-intensive, expensive and takes a long time to build (Stephenson, 2023). With increased gas prices, coupled with expensive carbon capture and storage technology, the production of blue hydrogen is very costly and not 100 percent sustainable.

4.2.2 Renewable production

Hydrogen produced from renewable energy does also presents issues with availability due to the reliability of the renewable energy source. The intermittent nature of renewable energy sources such as solar and wind create reliability issues (Dixon, 2023). Location and weather conditions play a huge role in the efficiency of both solar and wind energy. This creates a cause for concern as to their sustainability in hydrogen production.

Solar and wind technology prices have been gradually decreasing over time and now have a significant cost advantage over fossil fuels (Allen, 2023). This has led to increased construction of solar and wind farms. The life span of solar panels is between 25 to 30 years, while that of wind turbines is between 20 to 25 years (Bowman, 2021). It remains unclear what will happen to the technology once it has reached its useful life, and this may create environmental damage. As such the waste material will need to be treated before disposal or recycled.

The use of renewables in producing hydrogen heavily involves electrolysis, which has an energy efficiency of between 40 and 60 percent, which means it has a conversion loss of between 60 and 40 percent (Chew, *et al.*, 2023). The method itself is not highly efficient and coupled with solar panels (with efficiency of between 18 to 22 percent) and wind turbines (with 60 percent efficiency), the efficiency issue can be aggravated (Harrisons Solar, 2022).

Renewable energy sources are mainly deployed in the generation of electricity to increase electricity generation capacity and decrease energy poverty. Without heavily increasing the capacity of renewable energy sources, diverting some of their current capacity towards producing green hydrogen will likely cause a decrease in their capacity to produce electricity for other end uses (Graaf, 2022). This has the potential to cause unintended energy poverty related concerns.

4.3 Storage of hydrogen

Hydrogen is mostly stored physically as a gas or liquid in tanks for small-scale mobile and stationary applications. Storage of hydrogen as a gas requires high-pressure tanks (TWI Global, 2023). Compressed or liquefied hydrogen is also stored in tanks which have high discharge rates and efficiencies of close to 99 percent (IEA, 2019).

Hydrogen can also be stored in chemical bonds with other materials such as metal hydrides, which allow large quantities of gaseous hydrogen to be thermally adsorbed and desorbed in chemical bonds with the surface of certain metals (Rosen & Koohi-Fayegh, 2016). Hydrogen can also be stored in ammonia, which is a combination of hydrogen and nitrogen gas. The process to combine both gases is the Haber-Bosch process and the hydrogen can be extracted from ammonia when and where it is needed by heating the ammonia to high temperatures (Serpell, *et al.*, 2023).

There has also been research on the potential of salt caverns, depleted natural gas or oil reservoirs and aquifers as options for large-scale and long-term hydrogen storage. They are currently mainly used for storage of natural gas but they also have the advantage of providing significant economies of scale, high efficiency, low operational and land costs which is ideal for hydrogen storage (IEA, 2019).

4.4 Transmission and distribution of hydrogen

In recent times, around 85 percent of hydrogen is produced and consumed on-site while only around 15 percent of hydrogen is transported via trucks or pipelines (IEA, 2019). This is due to the low energy density of hydrogen which makes it very expensive to transport over long distances. To overcome the density challenges, hydrogen is usually either compressed, liquefied, or incorporated into larger molecules that can be transported as liquids.

In many countries, existing natural gas pipeline networks could be used to transport and distribute hydrogen as there are around 3 million km of natural gas transmission pipelines worldwide. New infrastructure with hydrogen dedicated pipelines and shipping networks can also be developed to allow for large-scale overseas hydrogen transportation (Ishaq, *et al.*, 2022). Approximately 5 000 km of hydrogen pipelines exist worldwide, largely in the United States of America, Belgium, and Germany (Burchard, 2023). These are operated by industrial hydrogen producers and are mainly used to deliver hydrogen to chemical and refinery facilities.

Currently, there are no ships that can transport hydrogen. If such ships existed, they would be like liquefied natural gas ships, which would require the hydrogen to be liquefied prior to transportation (IEA, 2019). The shipping supply chain would require new infrastructure which will include storage tanks, liquefaction plants, conversion, and reconversion plants to be built at the loading and receiving terminals as appropriate.

In terms of local distribution, hydrogen is mainly distributed through compressed gas trailer trucks for distances which are less than 300 km (Li, *et al.*, 2020). Hydrogen can also be transported by cryogenic tanker trucks, which can carry up to 4 000 kg of liquefied hydrogen (Brown, 2019). These types of tanker trucks are commonly used for long journeys of up to 4 000 km but are not suitable for distances beyond that, as the hydrogen will heat up and cause a rise in pressure.

4.5 Cost of hydrogen

The cost of hydrogen production, transportation and storage will play an important role in establishing the competitiveness of hydrogen within the global energy mix. If hydrogen was to be produced and consumed on-site, then its cost can be low, however, if the produced hydrogen must travel a long distance before it is used, then the cost of the transmission and distribution may be significant.

4.5.1 Production cost of hydrogen

Table 1 shows the costs of each of the listed methods of hydrogen production. The most economically advantageous methods are steam methane reforming and coal gasification. The costs of producing hydrogen from these non-renewable methods are lower than other methods in the table. This is due to the technology being widely used and highly well-established in the production of hydrogen (Ji & Wang, 2021). The use of nuclear for hydrogen production is also relatively inexpensive, as existing nuclear facilities can be used in producing hydrogen either through electrolysis or thermolysis (Amin, et al., 2022).

The use of biomass in producing hydrogen is also relatively inexpensive, as processes such as biomass gasification can use waste as feed stocks instead of already commercialised fossil fuels (Ji & Wang, 2021). The production of hydrogen from geothermal energy has also been documented to be relatively inexpensive and largely depends on the level of efficiency of the geothermal power plant. Highly efficient geothermal plants produce hydrogen at lower costs as compared to less efficient plants (Ghazvini, *et al.*, 2019).

The production of hydrogen from renewable energy sources is relatively expensive as the costs take into consideration the construction of renewable energy plants. These costs also vary depending on the type of renewable energy used. Solar PV has the highest costs depending on the energy conversion method and level of efficiency (Amin, *et al.*, 2022). Highly efficient solar plants produce hydrogen at a lower cost as compared to low efficient plants. The cost of hydrogen produced from wind turbines depends on the amount produced and the type of turbines used. Larger turbines tend to produce hydrogen at a lower cost as compared to smaller turbines (Amin, *et al.*, 2022).

Table 1 Cost of various hydrogen production technologies

Method		**Cost ($/KgH$_2$)**
Fossil fuels to hydrogen	Steam methane reforming	2.08
	Coal gasification	1.34
	Steam methane reforming (with carbon capture and storage)	2.27
	Coal gasification (with carbon capture and storage)	1.63
Biomass to Hydrogen	Biomass gasification	1.77-2.77
	Direct bio-photolysis	2.13
	Photo fermentation	2.83
Electrolysis	Solar PV electrolysis	5.78-23.27
	Wind electrolysis	5.27-9.37
	Nuclear electrolysis	3.56-7.00
	Geothermal electrolysis	1.08-2.05
Thermolysis & thermochemical cycles	Nuclear thermolysis	2.17-2.63
	Solar thermolysis	7.98-8.40

Source: Ji & Wang (2021); Amin, et al. (2022)

4.5.2 Storage, transmission, and distribution costs of hydrogen

The potential use of salt caverns for hydrogen storage presents a low-cost option for hydrogen, as they have low operational and land costs. Salt caverns have been used for hydrogen storage in the chemical sector in the United Kingdom and the United States and cost less than USD 0.6/kgH$_2$ with around 98 percent efficiency (IEA, 2019). The IEA has also estimated that the cost of converting and storing hydrogen in chemicals such as ammonia costs around USD 1/kgH$_2$.

The use of existing natural gas infrastructure would avoid significant costs associated with developing new transmission and distribution infrastructure for hydrogen. However, the development of new hydrogen transmission and distribution infrastructure will result in high capital costs. Pipelines have low operational costs and a lifespan of around 40 years, however, they require high capital cost (Molnar, 2022). The IEA has estimated that it would cost around USD 1/kgH_2 to transport hydrogen as a gas for around 1 500 km.

On the potential of shipping hydrogen, significant costs can be incurred as part of the necessary shipping supply chain infrastructure, the actual ships, liquefaction process and the conversion process (IEA, 2019). The IEA has estimated that transporting liquid hydrogen by ship for around 1 500 km can cost USD 2/kgH_2.

The costs for transporting hydrogen using trucks is relatively high. Taking into account costs associated with hydrogen extraction, conversion and reconversion, the overall cost of transporting hydrogen via trucks for a distance of 500 km can be up to USD 2.9/kgH_2 (IEA, 2019). Therefore overall the cost of transporting hydrogen depends on the mode and distance, plus any additional costs associated with conversions.

4.6 Present and potential uses of hydrogen in the context of a hydrogen economy

4.6.1 Present uses of hydrogen

The current usage of hydrogen is dominated by industrial application. Oil refining is the largest user of hydrogen, with about 33 percent of the global demand for hydrogen being consumed by refineries in order to turn crude oil into various end-user products such as transport fuels (IEA, 2019). Hydrogen is also used in smaller volumes for oil sands and biofuels.

The chemical industry is the second largest user of hydrogen as it consumes it in the production of methanol and ammonia (D’hont, 2021). Ammonia is mostly used in the manufacturing of fertilisers while methanol is used for a diverse range of industrial

applications. Hydrogen is also used in the production of iron and steel as steel is produced from a process called direct reduction iron, which requires hydrogen (IEA, 2019).
An emerging usage of hydrogen is through fuel cells which require hydrogen to cleanly and efficiently produce electricity, water and heat (EIA, 2023). In South Africa, hydrogen fuel cells have been used to power field hospitals set up for COVID-19 patients during the various waves of the COVID-19 pandemic (DSI, 2020). In the United States, hydrogen fuel cells are used to power the electrical systems on spacecrafts (EIA, 2023).

4.6.2 Potential uses of hydrogen

Hydrogen can be considered an alternative vehicle fuel, as it can power fuel cells in zero-emission vehicles. The fuel cell has the potential to be two to three times more efficient than an internal combustion engine running on gasoline (EIA, 2023). Hydrogen fuel cell electric vehicles would reduce local air pollution as they have zero tailpipe emissions. Hydrogen based-fuels can also be used in shipping and aviation, which have limited low-carbon fuel options available (IATA, 2019).

Hydrogen also has the potential to be used for high temperature heat. The heat can be used in industries for melting, gasifying, drying and mobilising a wide array of chemical reactions (IEA, 2019). Hydrogen has the potential to also be used in households for heating, though appliances such as boilers, cooking appliances and gas fires will need to be hydrogen ready. Hydrogen boiler technology is already being developed and used in the manufacturing industry and has the potential to be adapted to serve households, provided there is a government led transition (Nationalgrid, 2022).

Hydrogen can potentially be used for power generation and electricity storage. The carbon intensity of conventional coal power plants can be reduced by co-firing ammonia and hydrogen-fired gas turbines could be a source of flexibility in electricity systems. Hydrogen in the form of either compressed gas, ammonia or synthetic methane could be used for long-term storage options to balance seasonal variations in electricity generation from renewables (EIA, 2023).

4.7 Socio-economic impacts of the hydrogen economy

4.7.1 Food Security

The agriculture sector is key to food security and economic growth. However, the sector is highly carbon-intensive and relies on unsustainable fossil fuels for food production (Hamukoshi, et al., 2022). Green Hydrogen can provide a sustainable and clean alternative for food production in agriculture and strengthen food security. Hydrogen is already used in some agriculture activities such as grain drying and cooling. However, it has the potential to be used in more agriculture activities such as Hydrogen-powered harvesters irrigation systems, greenhouses, and autonomous farming machinery (Conklin & Beresnya, 2023).

4.7.2 Transport Sector

With the large potential for green hydrogen use in the transport sector via electric vehicles and fuel cells, countries which produce green hydrogen can export it to countries which require it to decarbonise their transport sector, as part of the Paris Agreement towards carbon-neutrality (United Nations Climate Change, 2015). This will be beneficial for the exporting countries as companies in such countries would benefit from the sale and value addition of material required in the green hydrogen economy, such as platinum for fuel cells and electrolysis.

4.7.3 Geopolitical Issues

The use of hydrogen to fuel vehicles poses a major threat to the petroleum sector, which generates large amounts of revenue and creates many employment opportunities across the world. As such, replacing crude oil with green hydrogen has the potential to cause major economic, social, and political instability (Fickling, 2020). Governments then have the responsibility to assess this transition to green hydrogen and ensure no one is negatively affected or left behind. The construction of new green hydrogen infrastructure will create new jobs and opportunities for training new skills which can stimulate the economy.

There have also been concerns that African countries may not have the market locally to consume green hydrogen (due to its costs), which will then mean that most of the hydrogen produced in countries like South Africa and Namibia will then mostly be exported overseas. This is a geopolitical concern, as it may be misperceived that African countries produce energy for the consumption of European or Western countries, while Africa remains an energy poor continent. However, the emergence of the electric vehicle market particularly presents an opportunity for consumption of hydrogen locally, and not necessarily only for export purposes.

The large-scale use of water for electrolysis during green hydrogen production can also pose a concern for water scarce countries. Communities in water scarce countries may believe that water should be intended for their own consumption or at least consumption of the agriculture sector, as such they may view hydrogen production as a waste of scarce water resources.

4.8 Opportunities for development finance institutions in the hydrogen economy

Development finance institutions (DFIs) are at the early stages of formulating and implementing their support for green hydrogen. There are some pioneering projects led by DFIs in the hydrogen space which are explored in the founding initiatives section of this paper. DFIs are uniquely placed to develop the green hydrogen economy for emerging and developing economies and this section highlights some key opportunities for DFIs within this space.

4.8.1 Climate finance commitments

DFIs have already made commitments to align their operations with climate change mitigation and adaptation goals, in support of achieving net-zero emissions targets set by the Paris Agreement (United Nations Climate Change, 2015). As such, an opportunity for DFIs to invest in the establishment of the green hydrogen economy is aligned with their existing climate financing commitments.

4.8.2 Risk reduction capacity

The development of the green hydrogen economy may have offtake risks associated with it particularly in developing and emerging economies. An offtake risk is the risk of not getting paid for the power output, which is a major barrier for energy investing in developing and emerging economies which are faced with poor economic growth and low income. These can lead to the potential for bad debts, tariff-underpricing and even theft which in turn increase financing costs and delay the much-needed investment in power infrastructure. DFIs are well placed to mitigate such risks by managing and sharing the risk, while also reducing the cost of investment capital to allow such economies the opportunity to benefit from green hydrogen projects (GH2, 2022).

4.8.3 Knowledge and expertise

DFIs have vast experience in successfully scaling up investment in the development of the renewable energy sector (Xu & Gallagher, 2022). This experience and expertise are highly required to ensure the appropriate development of the hydrogen economy, by employing effective climate financing strategies and infrastructure development.

5. Founding Initiatives

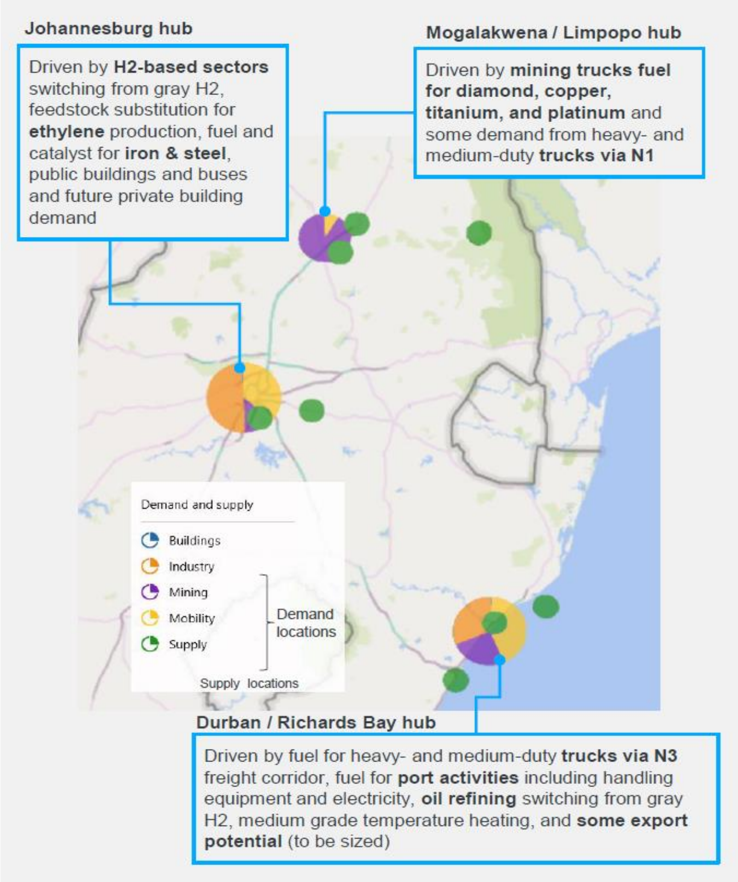
5.1 South African hydrogen valley feasibility

The South Africa Hydrogen Valley Final Report was commissioned by the Department of Science and Innovation (DSI) and its partners, Anglo American Platinum, Bambili Energy and Engie Energy Services SA. It identified nine hydrogen-related projects across the mobility (mining trucks, buses), industrial (ammonia/chemicals) and construction sectors (fuel cell power) that could be used to kickstart the establishment of a South African hydrogen valley (DSI, 2021).

A Hydrogen Valley aggregates multiple demand segments along key hydrogen production routes within a specific geographic region. The feasibility study identified three hubs along the valley: Johannesburg, Durban/Richards Bay, and Mogalakwena/Limpopo. These locations are based on their potential for high future hydrogen demand, access to sun/wind and water infrastructure for hydrogen production, and contribution to the just transition (DSI, 2021).

The feasibility report estimated that the levelised cost of green hydrogen across the hubs is expected to be ~$4 per kg H2[2] , which is more expensive than grey hydrogen. However, it is estimated that the hydrogen valley can potentially add USD 3.9 – 8,8 billion to the South African gross domestic product, while creating 14 000 – 30 000 jobs per year by 2050. The report also highlighted the need for regulatory and policy enablers to start the hydrogen economy, as there are current barriers in scaling up hydrogen in the valley. These barriers include limited hydrogen infrastructure particularly transport and storage, limited and unreliable green electricity on the grid, high costs of electrolyzers, and unclear hydrogen demand (DSI, 2021).

Figure 5 South African Hydrogen valley feasibility



Johannesburg hub

Driven by **H2-based sectors** switching from gray H2, feedstock substitution for **ethylene** production, fuel and catalyst for **iron & steel**, public buildings and buses and future private building demand

Mogalakwena / Limpopo hub

Driven by **mining trucks fuel for diamond, copper, titanium, and platinum** and some demand from heavy- and medium-duty **trucks via N1**

Durban / Richards Bay hub

Driven by fuel for heavy- and medium-duty **trucks via N3** freight corridor, fuel for **port activities** including handling equipment and electricity, **oil refining** switching from gray H2, medium grade temperature heating, and **some export potential** (to be sized)

Source: Department of Science and Innovation (2021)

5.2 Green hydrogen funds

The establishment of the innovative blended financing fund that facilitates and accelerates the development of a green hydrogen sector has gained prominence in recent times. One such fund is the SA-H2 Fund in South Africa, which is supported by Climate Fund Managers (CFM) and Invest International of the Netherlands, Sanlam Limited of South Africa, the Development Bank of Southern Africa (DBSA), and the Industrial Development Corporation of South Africa, in collaboration with other strategic partners (DBSA, 2023).

The SA-H2 fund aims to secure US $1 billion funding in South Africa or via other channels for the development and construction of large-scale green hydrogen infrastructure assets across South Africa. The fund is intended to create a market to attract and mobilise public and private capital, which will allow private sector developers access to capital for hydrogen projects in South Africa. The development of green hydrogen infrastructure will create jobs, train new skills, generate export revenues, and decarbonise the economy (DBSA, 2023).

Similarly, in Namibia, the establishment of SDG Namibia One sovereign wealth fund was also intended to develop the green hydrogen sector. The fund is supported by Namibia’s Environment Investment Fund, Climate Fund Managers and Invest International. About 100 percent of the initial funding of €40 million will be provided as grant funding by Invest International. This vehicle looks to raise money from local institutional investors and investors from around the world to develop Namibian green hydrogen projects and related hydrogen infrastructure (EIF, 2023).

5.3 Hydrogen projects and plans led by development finance institutions

Through the International Hydrogen Ramp-Up Programme, the Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) has provided technical assistance and capacity building to government officials in selected developing and emerging countries for early phase green hydrogen project development. The programme aims to identify, prepare and accompany the implementation of projects for the production and use of green hydrogen (GIZ, 2023).

In Barbados, the International Finance Corporation (IFC) and Inter-American Development Bank (IDB) have supported the development of a 50 MW solar generation facility with green hydrogen and lithium-ion battery storage that will provide firm and clean electricity to the Barbadian grid (IFC, 2022). The IFC is tasked with providing solar resource assessment, geotechnical and hydrological studies, and environmental life-cycle assessment, which strengthen the bankability of the project for international investors to finance its construction. The IDB is tasked with financing the environmental and social Impact assessment of the project.

The Centrale Electrique de l'Ouest Guyanais (CEOG) project under construction in French Guiana is intended to be the world's largest hydrogen-based renewable energy storage facility, upon completion. The project is financed through long-term senior debt, equity bridge loan, tax credit bridge loan, and debt service credit facility from the Agence Francaise de Developpement (AFD) and the European Investment Bank (EIB) amongst other agents. The facility is intended to house a hydrogen storage unit to store 128MWh of electricity in the form of hydrogen and make use of fuel cells to generate 3MW of electricity during the night (NS Energy, 2021).

6. Key roles development finance institutions can play in the hydrogen economy

This study has assessed the hydrogen economy in terms of three phases: hydrogen production, hydrogen storage, transmission and distribution and hydrogen present and potential usage. For hydrogen to be a sustainable energy source, green hydrogen should be used, and this section looks at the roles development finance institutions can play in the green hydrogen economy based on the three phases of the hydrogen economy. These roles can also be interchanged with those the DBSA can play in the green hydrogen space.

6.1 Scaling up renewable energy capacity

Green hydrogen is largely dependent on the capacity of renewable energy sources which are required for its production. DFIs have already played a significant role in renewable energy development as an alternative source of electricity. For renewables to meet the growing demands of hydrogen production however, their capacity should be scaled up significantly. Therefore, DFIs have a role to play in significantly increasing the capacity of renewables such as solar, wind and hydro to meet the growing demands of hydrogen production and the existing demand of green electricity.

6.2 Creating an enabling environment for green hydrogen investments

As the demand for green hydrogen increases, regulatory frameworks play a crucial role in fostering a supportive environment for investment, ensuring safety standards, and promoting sustainable practices. In creating an enabling environment for green hydrogen investment, DFIs have a role to play in supporting government's capacity in establishing regulatory, contractual and policy regimes for green hydrogen (Alix & Burns, 2023).

Such frameworks can include common procurement standards for public sector projects financed by DFIs. Such consistent standards can help reduce the administrative burden in hydrogen projects and subsequently reduce project costs (GH2, 2022). DFIs can also provide technical assistance to governments in order to support the integration of green hydrogen into their national energy mix by identifying policy instruments that can increase green hydrogen demand such as carbon taxes.

6.3 Hydrogen infrastructure development

The transmission and distribution of hydrogen requires development of new infrastructure, particularly pipelines and shipping networks to allow for large-scale hydrogen transportation. The shipping supply chain requires new infrastructure such as storage, liquefaction plants, conversion, and reconversion plants. With DFIs' vast experience in infrastructure development, they have a role to play in facilitating the development of new hydrogen storage, transmission, and distribution infrastructure.

6.4 Project preparation facilities

DFIs have a role to play in supporting early project development in terms of scoping and feasibility studies for green hydrogen projects. This can be achieved through a dedicated facility or fund with fast approval procedures to tackle specific bottlenecks in renewable and green hydrogen sectors. DFIs can also support catalytic projects in the green hydrogen space, as they demonstrate the bankability of such projects and introduce the potential for modern technologies and innovations within that space.

6.5 Scale up innovative financing instruments to catalyse green hydrogen investment

DFIs have vast experience in scaling up innovative financing instruments, such as green bonds, to catalyse investment into renewable energy sources. The same experience can be channelled into scaling up green hydrogen investment through innovative financing such as green bonds specifically for hydrogen projects. Concessional and blended financing as well as grants which can be used in emerging and developing economies to de-risk and crowd in private investment through co-financing. Guarantees, as climate financing commitments, can also play a significant role in improving and de-risking investments in green hydrogen projects (GH2, 2022).

7. Conclusion

The first objective of this research was to define the properties of hydrogen, its production from different sources, its different uses, and challenges in establishing a hydrogen economy. The second objective was to identify key opportunities and roles for DFIs in the establishment of the hydrogen economy in South Africa with reference to the broader Southern African context by analyzing selected founding initiatives on different green hydrogen projects and plans led by development finance institutions.

The research first analyzed hydrogen production from both renewable and non-renewable energy sources, focusing on the costs and challenges associated with each method of production. The research then assessed hydrogen storage, transmission, and distribution as well as hydrogen’s current and potential uses and the likely socio-economic impact of the transition to a green hydrogen economy. The socio-economic impacts included potential impacts on food security, the transport sector, and geopolitical issues such as employment.

Findings from the study highlighted key opportunities for DFIs in the establishment of a green hydrogen economy, such as climate finance commitments, risk reduction capacities and the knowledge and expertise they can provide in support of green hydrogen projects. The study further identified roles that DFIs can play in the green hydrogen space such as scaling up renewable energy capacity in order to produce green hydrogen, creating an enabling environment for green hydrogen investments, hydrogen infrastructure development, green hydrogen project preparation facilities, and scaling up innovative financing instruments to catalyze green hydrogen investment.

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