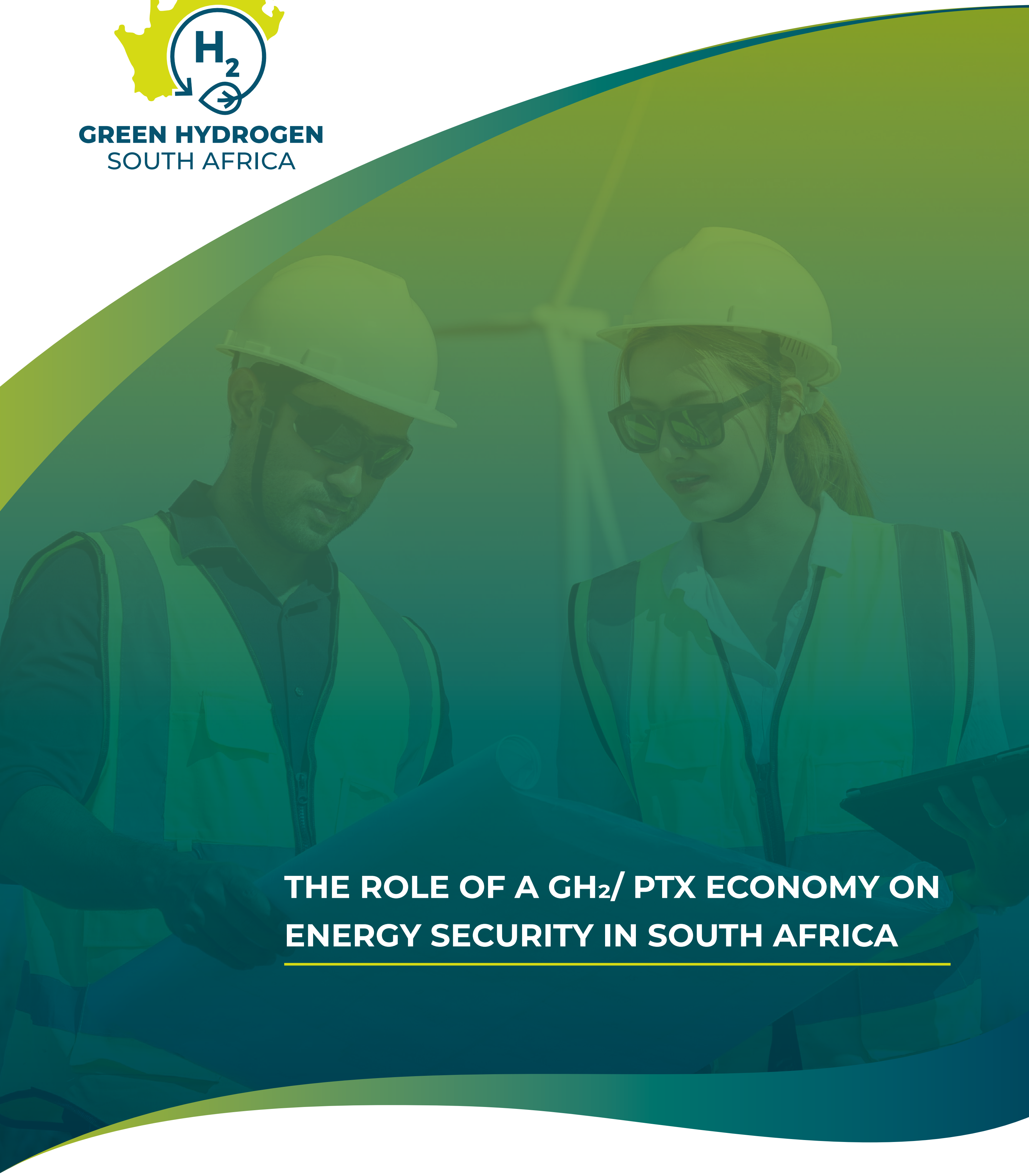
GREEN HYDROGEN
SOUTH AFRICA



THE ROLE OF A GH_2/ PTX ECONOMY ON ENERGY SECURITY IN SOUTH AFRICA

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giz Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH

GFA CONSULTING GROUP

THE ROLE OF A GH_2/ PTX ECONOMY ON ENERGY SECURITY IN SOUTH AFRICA

PUBLICATION: The Role of a GH_2/ PtX Economy on Energy Security in South Africa

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LAYOUT AND DESIGN: Studio112

PUBLICATION DATE: February 2025

FUNDED BY: Promoting a Green Hydrogen Economy Program (H2.SA), funded by the German Federal Ministry of Economic Cooperation and Development, BMZ)

RESPONSIBLE INSTITUTIONS

Green Hydrogen South Africa (GHSA): GHSA is a multi-stakeholder initiative that promotes South Africa as a leading green hydrogen producer and investment destination of choice. It is led by The Presidency of South Africa and home of the South African Green Hydrogen Summit (SAGHS).

H2.SA: H2.SA is a project of the German Development Cooperation with South Africa. It is commissioned by the German Federal Ministry for Economic Cooperation and Development (BMZ) and implemented by the Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH in close cooperation with the South African Government (I've added this instead of the Presidency to avoid the risk of not having the Presidency's logo on the document- everything else remains the same) . H2.SA's main objective is to promote a South African green and sustainable hydrogen economy. Working closely with its partners from Government, private sector, and civil society, H2.SA provides expertise, resources, and builds capacity for a secure and sustainable energy future that holds opportunities for all South Africans

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Contents

List of Figures

List of Tables

Acronyms

	Definition
BMZ	German Federal Ministry of Economic Cooperation and Development
CBAM	Carbon Border Adjustment Mechanism
CEF	Central Energy Fund
CfD	Contracts for Difference
CoLS	Cost of Load Shedding
CSP	Concentrated solar power
DFFE	Department of Forestry, Fisheries and the Environment
DMRE	Department of Mineral Resources and Energy
DoEE	Department of Electricity and Energy
DoT	Department of Transport
DPE	Department of Public Enterprises
DPWI	Department of Public Works and Infrastructure
DSI	Department of Science and Innovation
DSM	Demand Side Management
DTIC	Department of Trade, Industry and Competition
EAF	Electricity Availability Factor
EU	European Union
EUR	Euro currency
FDIR	Fault Detection, Isolation, and Restoration
FT	Fischer-Tropsch
FTE	Full-Time Equivalent
GESI	Gender, Equality, and Social Inclusion
GH_2	Green Hydrogen
GH_2CS	Green Hydrogen Commercialisation Strategy
GHG	Greenhouse gas
GHSA	Green Hydrogen South Africa
GIZ	Deutsche Gesellschaft für Internationale Zusammenarbeit
GW	Gigawatt
GWh	Gigawatt-hour
HVDC	High-Voltage Direct Current

	Definition
HSRM	Hydrogen Society Roadmap
HySA	Hydrogen South Africa
IDC	Industrial Development Corporation
IIO	Investment and Infrastructure Office
IPT	Independent Power Transmission
IRP	Integrated Resource Plan
JET	Just Energy Transition
KfW	Kreditanstalt für Wiederaufbau
kV	kilovolt
kW	Kilowatt
kWh	Kilowatt-hour
$LCOH_2$	Levelized Cost of Hydrogen
LPG	Liquefied petroleum gas
MW	Megawatt
NERSA	National Energy Regulator of South Africa
NPC	National Planning Commission
PEM	Proton Exchange Membrane
PGM	Platinum Group Metals
PMG	Parliamentary Monitoring Group
PPA	Power Purchase Agreement
PPP	Public–Private Partnerships
PtX	Power-to-X
PV	Solar photovoltaics
RE	Renewable Energy
REDZs	Renewable Energy Development Zones
REIPPPP	Renewable Energy Independent Power Producer Procurement Programme
SAF	Sustainable Aviation Fuels
SAREM	South African Renewable Energy Masterplan
SEZ	Special Economic Zone
USD	United States Dollar
ZAR	South African Rand

Executive summary

Executive summary

Introduction

To ensure sustainable growth, the South African government must expand renewable energy (RE) capacity to address domestic needs while supporting green hydrogen (GH_2) development. A Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ)-commissioned study explores these dynamics, analysing energy security impacts and providing recommendations to maximise GH_2/PtX benefits for South Africa. The report includes detailed analyses of the energy sector, challenges, international case studies, and policy recommendations for infrastructure and economic growth.

Sector overview

South Africa's energy sector is heavily reliant on coal, which accounted for 72.4% of its 53.9 GW installed capacity as of June 2024, contributing 78.5% of the 216.6 GWh supplied in 2023/24. RE, driven by the Renewable Energy Independent Power Producer Procurement Programme (REIPPPP), contributed only 8.8% of electricity generation, highlighting its growing yet modest share. The country has 23,000 km of transmission lines and over 850 substations, with plans to modernise and expand through initiatives like the Transmission Development Plan. In 2023, South Africa consumed 26.04 billion litres of liquid fuels, importing 13.2 billion litres of crude oil due to the absence of domestic reserves. While synthetic fuels partially offset import reliance, the sector remains vulnerable to global price fluctuations, emphasising the need for diversification and infrastructure modernisation.

Energy supply challenges in South Africa

South Africa's energy challenges are deeply entrenched, with power generation being the most critical issue due to aging infrastructure, operational inefficiencies, and financial constraints. Reliance on coal, which supplies over 75% of the country's electricity, has exacerbated environmental concerns, hindered sustainability, and limited the adoption of RE. Eskom, the national utility provider, faces severe financial instability, with debt projected to reach ZAR 3.1 trillion by 2050, affecting its ability to maintain and modernise infrastructure. Aging coal-fired plants, commissioned in the 1970s and 1980s, suffer from frequent breakdowns and inefficiencies, contributing to loadshedding and operational disruptions. High maintenance costs and outdated technology further strain Eskom's finances, increasing electricity prices and reducing industrial competitiveness.

Furthermore, South Africa's liquid fuels sector faces challenges from aging infrastructure and carbon transition risks. Refineries and pipelines dating back to the 1950s require substantial investments to remain operational and environmentally compliant, adding to the financial burden. These systemic issues highlight the urgency for comprehensive reforms, significant capital investment, and a decisive transition to renewable energy to ensure energy security, economic stability, and environmental sustainability.

South Africa's GH_2 landscape

South Africa is advancing its GH_2 economy through pivotal programmes such as Hydrogen South Africa (HySA), the Hydrogen Society Roadmap (HSRM), and the Green Hydrogen Commercialisation Strategy (GH_2CS). The HySA programme, initiated in 2008 with a 15-year timeline and extended to 2033, has been instrumental in building South Africa's intellectual property, expertise, and technological capacity in hydrogen. The HSRM, launched in 2021, provides a framework to align hydrogen technologies with the country's decarbonisation goals, outlining 70 actions across six outcomes, including decarbonising heavy-duty transport and energy-intensive industries. Four major projects, such as the Platinum Valley Initiative and Boegoebaai Special Economic Zone (SEZ), demonstrate the country's commitment to hydrogen technology with applications ranging from sustainable fuels to industrial processes.

The GH_2CS, approved in 2023, aims to position South Africa as a global leader in GH_2, requiring an estimated investment of USD 164 billion over 15 years. Its focus includes fostering domestic and export markets, attracting foreign direct investment, and enabling local industry participation. The strategy integrates SEZs and strategic hubs to drive value creation and emphasises sector coupling, efficient supply chains, and cost minimisation. Over 300 stakeholders, including key institutions, such as the Department of Mineral Resources and Energy (DMRE) and the Department of Forestry, Fisheries, and the Environment (DFFE), contribute to South Africa's comprehensive approach to the hydrogen economy.

Global strategies on hydrogen as energy supply

Hydrogen has emerged as a critical component of energy security strategies worldwide, addressing vulnerabilities related to fossil fuel dependence, market volatility, and climate change. Nations like the UK, Germany, Japan, Australia, Morocco, and Namibia are leveraging hydrogen's flexibility, storability, and potential to complement RE sources to stabilise energy grids and enhance resilience. The UK is targeting 5 GW of low-carbon hydrogen production by 2030, while Germany aims for 10 GW, integrating hydrogen to decarbonise industries and secure imports. Japan is prioritising international hydrogen supply chains to offset geographic limitations, and Australia aims to capitalise on vast RE resources for hydrogen export and grid stability. Morocco and Namibia will focus on reducing fossil fuel reliance, with Morocco aiming to export to Europe and Namibia targeting 10–12 million tonnes annually by 2050, fostering socio-economic development. These strategies collectively illustrate hydrogen's role in advancing sustainable and adaptable energy systems.

Intersections/contact points between energy security and GH_2/PtX

GH_2 intersects significantly with energy security and the energy sector through its impact on grid electricity demand, transmission infrastructure, system stability, energy imports, greenhouse gas (GHG) emissions, and investment allocation. GH_2 facilities can enhance grid stability and flexibility by storing excess RE and addressing energy demand fluctuations, but they can also strain existing electricity grids and compete with other renewable demands if not properly regulated. In South Africa, transitioning to domestic GH_2 production could reduce the USD 17.1 billion annual dependence on imported refined petroleum, enhance energy self-sufficiency, and support decarbonisation. GH_2's role in reducing GHG emissions is pivotal, particularly for hard-to-abate sectors, with EU policies like CBAM driving its adoption. However, unbalanced investment in GH_2 risks diverting resources from other renewable technologies, necessitating a strategic and inclusive approach to energy transition.

Effects of GH_2/PtX economy on energy security in South Africa

The transition to a GH_2/PtX economy in South Africa presents both opportunities and challenges for energy security. Positive effects include the expansion of RE capacity, where the development of GH_2 and PtX technologies can provide excess renewable power, alleviating issues like loadshedding and reducing electricity costs. With goals to produce 1.9 Mt of GH_2 for both domestic and export markets, South Africa will need 41 GW of electrolyser capacity and 80 GW of RE capacity by 2050. This will generate up to 39 GW of excess electricity during peak renewable generation. However, integrating this excess into the national grid faces infrastructure constraints, requiring upgrades to transmission lines and substations. GH_2 also enhances grid reliability through energy storage, frequency regulation, and voltage support, contributing to stability and resilience. The storage potential of GH_2 further strengthens energy security by providing a flexible buffer for low-demand periods and helping reduce reliance on fossil fuels. Additionally, the transition requires substantial infrastructure investments to accommodate the increased renewable generation, with upgrades to the electricity grid essential for supporting GH_2 production systems.

Recommendations for enhancing GH_2/PtX benefits of energy security

South Africa's energy security could be significantly enhanced through the integration of GH_2 and PtX technologies. Key recommendations include *improving governance and coordination by establishing a central body,* such as the "Green Hydrogen Just Energy Transition Secretariat," which will facilitate stakeholder collaboration and provide support for project development. This body will help standardise processes, secure initial offtake agreements, and address technology incubation and skills development. Additionally, *harmonising national energy planning documents like the Integrated Resource Plan (IRP), Hydrogen Strategy and Roadmap (HSRM), and Green Hydrogen and Carbon Sequestration (GHCS)* is crucial. Aligning these frameworks will optimise resource allocation, streamline decision-making, and ensure South Africa's energy transition supports decarbonisation goals, job creation, and energy security.

Further recommendations emphasise *developing comprehensive guidelines for GH_2/ PtX production*, which would include sustainable sourcing of electricity, water, and land, along with robust community engagement and health and safety standards. Establishing a power balancing market mechanism would allow GH_2 producers to sell surplus energy during peak renewable electricity production, thus improving grid stability and enhancing financial viability. *A transparent framework for electricity* wheeling would also facilitate private sector participation by simplifying costs and procedures, helping to integrate RE into the grid and accelerating GH_2 production. These measures are integral to ensuring South Africa's transition to a sustainable, resilient, and secure energy system.

Required infrastructure to maximise GH_2/PtX benefits for energy security

Integrating GH_2 and PtX technologies into South Africa's energy system requires significant infrastructure investment and upgrades. South Africa's electricity grid, with a total capacity of approximately 52,000 MW, faces constraints, including aging infrastructure, capacity shortages, and financial challenges, particularly impacting regions with RE projects. To accommodate GH_2 and PtX, critical upgrades include expanding transmission capacity through new lines and advanced technologies like high-voltage direct current (HVDC) transmission, improving grid reliability with smart grid solutions and real-time monitoring, and enhancing energy storage systems for better integration of intermittent renewable sources. Furthermore, South Africa's fuel infrastructure, including a robust liquid fuel pipeline network, will require adaptations to handle hydrogen and PtX products safely. Integrating these technologies will involve compliance with regulatory frameworks and substantial investment to modernise the grid and fuel infrastructure, ensuring a resilient and reliable power supply.

Economic and financial implications

The development of South Africa's GH_2 sector offers transformative economic and energy benefits. By leveraging RE resources for hydrogen production, the country can address energy challenges, reduce emissions, and improve energy security. Captive RE generation for GH_2 optimises hydrogen production and adds surplus capacity to the grid, stabilising energy supply and reducing electricity costs. The sector supports industrial decarbonisation, energy import substitution, and cost-effective energy transport, enhancing self-sufficiency and economic resilience. GH_2 projects can mitigate the economic losses from loadshedding, with estimated savings of ZAR 312 billion by 2030, while reducing reliance on volatile fossil fuel imports, which constituted 21% of commodity imports in 2022. These initiatives align with global decarbonisation efforts, position South Africa as a leader in sustainable energy, and ensure broad economic and financial stability.

Chapter 1

Introduction

1. Introduction

GH_2 and PtX technologies present substantial opportunities for South Africa, offering a pathway to decarbonise hard-to-abate sectors, reduce GHG emissions, and generate new revenue streams through exports. The development of these GH_2/PtX technologies can also stimulate job creation and economic growth, playing a critical role in the country's transition away from coal-based electricity supply. Additionally, GH_2/PtX can expand RE generation, with the potential for surplus energy to be stored, fed into the national grid, or sold to a third party.

- South Africa is well-positioned to become a key player in the emerging GH_2/PtX market, thanks to several competitive advantages (DSI, 2022), including:
- South Africa's abundant land and high-quality RE resources, that reduce GH_2 production costs, attract investments, and boost competitiveness
- Home to the world's largest reserves of Platinum group metals (PGMs), crucial for producing proton exchange membrane electrolysers and hydrogen fuel cells
- Existing Fischer-Tropsch technology, infrastructure, and expertise provide a competitive edge in e-fuel production
- Existing natural gas infrastructure can be adapted for GH_2/PtX transport, export, and storage
- Government support programmes like Green Hydrogen South Africa foster innovation and workforce development in GH_2/PtX technologies.

To leverage these advantages and enter the growing GH_2/PtX market while decarbonising the country's economy, South Africa has designated GH_2 as a top priority among its "Big Five Frontiers[1]" of strategic investment opportunities. Under the "GH_2 Frontier," South Africa aims to become a leading global producer of GH_2 and green ammonia for export (The Presidency, 2022).

While most relevant stakeholders agree that developing the GH_2 economy in South Africa offers benefits for energy security, economic growth, and socioeconomic development, there are concerns about potential drawbacks. The rapid growth of GH_2/PtX raises concerns about the impact on South Africa's energy security, particularly considering existing electricity shortages and the strain on the national grid. Additionally, there are concerns that exporting GH_2/PtX could lead to the diversion of local resources to the global north, potentially disadvantaging domestic needs.

1. *The Big Five Frontiers are the government's top strategic investment opportunities. These include: GH2, Next gen digital, Special Economic Zones, industrial cannabis, and hyper-scaling environmental, social, and governance impact investments.*

A key issue is the possibility that diverting renewable electricity for GH_2 production could worsen the country's energy shortages, leading to public opposition, especially if the focus is on exports while domestic energy needs remain unmet. To address this issue, it is essential for the government to ensure that the expansion of RE capacity is beyond current plans (additionality principle) to address both domestic demand and the requirements of the emerging GH_2 sector. Balancing these priorities will be essential for sustainable growth.

To assess the impact of a GH_2/PtX economy on energy access and recommend conditions for achieving a net positive outcome, the GIZ commissioned a study titled *"Impact Analysis of a Green Hydrogen/Power-to-X Economy on Energy Security in South Africa."* This report presents the study's findings and offers recommendations to enhance GH_2/PtX benefits for energy security.

This report is structured as follows: Chapter 2 provides an overview of South Africa's energy sector, followed by Chapter 3 on the country's energy supply challenges. Chapter 4 outlines the GH_2 landscape in South Africa, while Chapter 5 reviews examples of countries that view GH_2 as key to energy security. Chapter 6 examines intersections between energy security and GH_2/PtX, with Chapter 7 analysing their effects on South Africa. Chapter 8 offers recommendations to enhance GH_2/PtX benefits, and Chapter 9 discusses necessary infrastructure. Chapter 10 evaluates economic implications, and Chapter 11 concludes with key findings and recommendations.

Chapter 2

Overview of South Africa's energy sector

2. Overview of South Africa's energy sector

South Africa's energy landscape is heavily reliant on coal, which has been the primary energy source for decades, especially in electricity generation. This reliance has shaped the country's energy infrastructure but has also raised sustainability and environmental concerns. Alongside coal, the liquid fuels sector is a crucial component of the economy, underpinning energy security by fuelling transportation, industry, and households.

2.1 South Africa's electricity sector

For decades, coal has been the dominant energy source in South Africa. The figure below displays South Africa's annual energy mix by technology from 2010 to 2023.

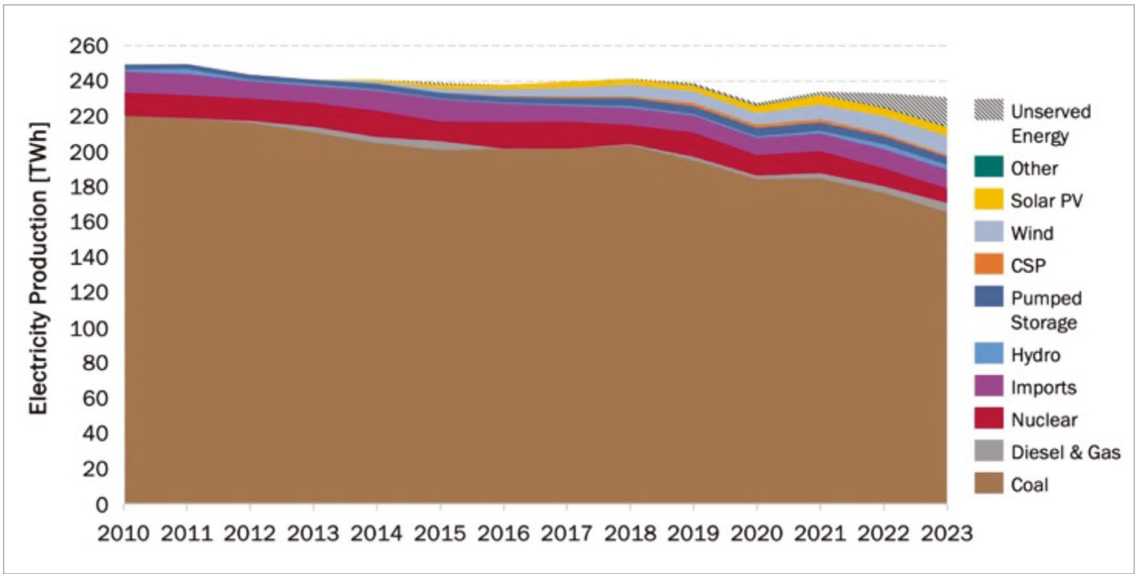

Figure 1: South African annual energy mix for the 2013–2023 period

Source: CRSES (2024)

Since 2011, however, South Africa has shifted towards a more diversified energy mix, with growing contributions from RE, primarily driven by the REIPPPP. This programme, praised globally for its efficiency and cost-effectiveness, has made South Africa a key market for RE, attracting major international developers. As in other countries, increased scale and experience in South Africa have lowered RE costs. Figure 1 shows the evolution of RE capacity (concentrated solar power (CSP), solar PV and wind) from 2013–2023, while Figure 3 presents electricity generation for the same period.

As shown in Figures 2 and 3, RE installed capacity and production are growing in South Africa but still represent a small portion of the total installed capacity and energy mix. By June 2024, for instance, the country's installed capacity was 53.9 GW[2], with RE (CSP, solar PV and wind) contributing only 11.5%, while coal-based power plants accounted for 72.4% (CRSES, 2024). In the 2023/24 financial year, RE contributed only 8.8% compared to coal's dominant share of 78.5% of the 216.6 GWh supplied.

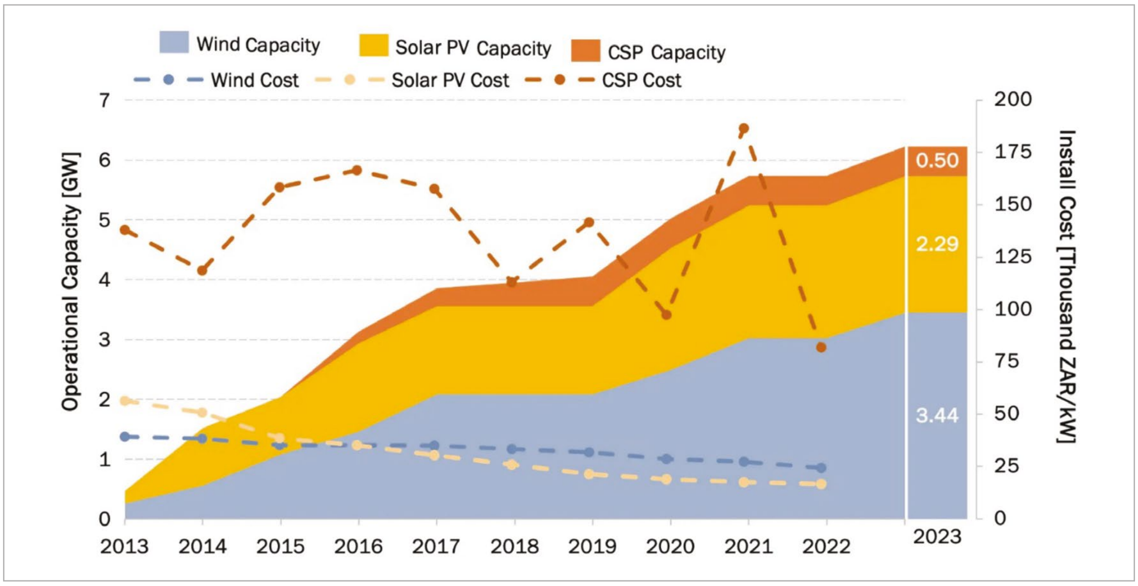

Figure 2: RE installed capacity in South Africa (in GW) and global production cost (in ZAR/kW)

Source: CRSES (2024)

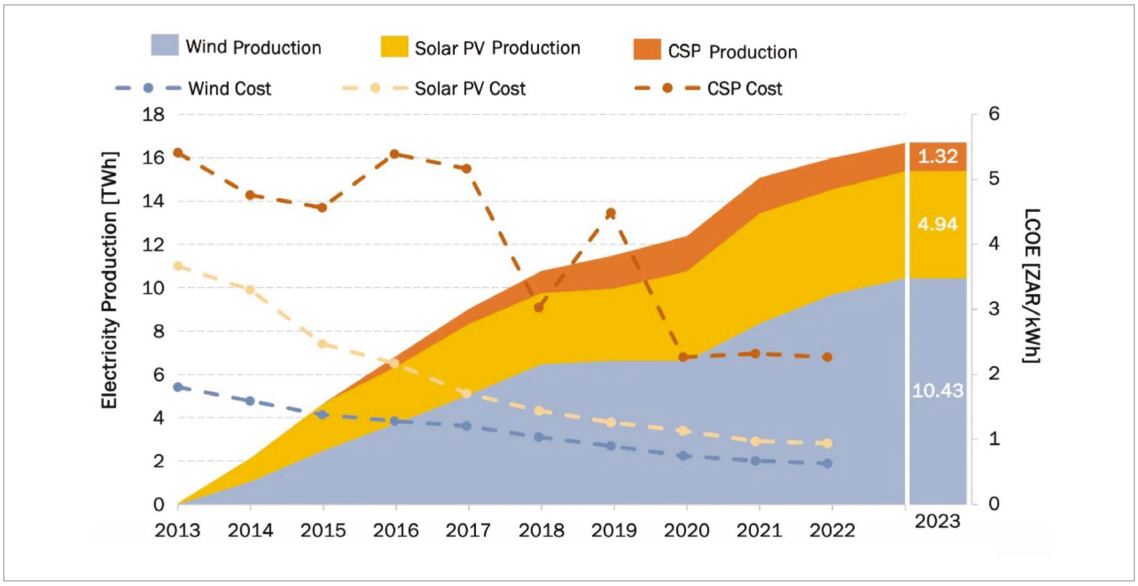

Figure 3: RE production in South Africa (in TWh) and global production cost (in ZAR/kWh)

Source: CRSES (2024)

2 *Excluding embedded and private generation.*

2.2 Existing electricity infrastructure

The existing electricity infrastructure can be grouped into six main categories: Eskom supply areas, RE Development Zones (REDZs), electricity grid corridors, REIPPP power generation plants, and transmission and substation infrastructure.

2.2.1 Eskom supply areas

Eskom supplies electricity to almost the entire country. Its distribution network covers nearly all nine provinces, catering to both urban and rural areas. The specific "supply areas" accessible through the visual map (Figure 4) refer to the main electricity grid covering metropolitan areas, major towns, and industrial hubs. It connects most of the country's power generation plants, major substations, and transmission lines.

2.2.2 RE Development Zones

South Africa is aggressively pursuing RE to diversify its energy mix, combat climate change, and boost its economy. One key initiative is the establishment of REDZs (Figure 5); designated areas with streamlined permitting processes and grid infrastructure specifically aimed at attracting and facilitating large-scale RE projects. As of January 2024, the South African government has declared 11 REDZs, with plans for additional zones in the future, targeting areas with high RE potential and opportunities for grid connection.

The benefits of REDZs include:

- **Streamlined permitting:** REDZs simplify the environmental permitting process for developers, saving time and costs.
- **Grid readiness:** Dedicated grid infrastructure planned within REDZs could reduce the need for costly transmission upgrades for individual projects.
- **Reduced investment risk:** The pre-developed infrastructure and streamlined permitting process de-risk investments for RE project developers.

REDZs declared as of January 2024:

1. *Copperton (Northern Cape): ideal for solar PV due to ample sunshine and proximity to existing grid infrastructure.*
2. *Great Karoo (Western Cape): suitable for both wind and solar PV with strong wind resources and ample land availability.*
3. *Namakwa Sandveld (Western Cape): excellent for wind power due to strong and consistent winds.*
4. *Upington (Northern Cape): suitable for both concentrated solar power and solar PV with abundant sunshine and suitable land*
5. *Umsobomvu (Eastern Cape): promising for wind energy with high wind speeds and close proximity to existing ports.*
6. *COEGA (Eastern Cape): potential for both wind and solar PV with good resource availability and land access.*
7. *Cornelia (Free State): suitable for wind energy with reliable wind resources and existing grid infrastructure.*
8. *Delmas (Mpumalanga): seeks to support the region's transition from coal by promoting RE projects, particularly solar PV.*
9. *Beaufort West (Western Cape): good wind resources.*
10. *Klerksdorp (North West Province): good solar potential.*
11. *Emalahleni (Mpumalanga): aims to accelerate the region's transition to a cleaner energy future.*

2.2.3 Transmission Lines

South Africa has a vast and complex network of transmission lines (Figure 6) and substations that form the backbone of the country's power grid:

- Over 23,000 kilometres (km) of transmission lines traverse the country, spanning various voltages from 400 kilovolt (kV) to 765 kV (Figure 6).
- The highest concentration lies in Mpumalanga, where coal-fired power stations generate a significant portion of the nation's electricity.
- The lines radiate outwards from Mpumalanga to major load centres like Johannesburg, Durban, and Cape Town.
- Transmission capacity varies depending on voltage, with 765 kV lines offering the highest capacity for bulk power transfer.

2.2.4 Substations

- Eskom operates over 850 substations across the country (Figure 7), acting as critical connection points between generating stations, transmission lines, and distribution networks.
- The voltage levels vary, with higher voltage substations (400 kV and above) typically located near power stations and major urban centres.
- Lower voltage substations (132 kV and below) step down the voltage for distribution to smaller towns and rural areas.
- Key substations like Koeberg (Cape Town), Perseus (Dealesville), and Gamma (Northern Cape) play crucial roles in connecting major RE resources to the grid.

While Eskom's infrastructure covers a vast area, it faces challenges:

- **Aging infrastructure:** Much of the network is aging, requiring maintenance and upgrades to ensure reliability and stability.
- **Grid congestion:** Existing lines in some areas struggle to handle the increasing demand and variable nature of RE sources.
- **Limited capacity:** Bottlenecks in certain segments restrict the full potential of RE integration.

To address these challenges, Eskom is undertaking various initiatives:

- **Transmission Development Plan:** A multi-billion-rand plan to expand and upgrade the transmission network by 2032, including new lines, substations, and smart grid technologies.
- **Integration of renewables:** Prioritising investments in connecting RE projects to the grid, especially in wind-rich areas like the Western Cape and solar-rich areas like the Northern Cape.
- **Grid modernisation:** Exploring smart grid technologies and energy storage solutions to improve flexibility and resilience.

Existing and planned substations

A vast network of substations manages the flow of power across the country. Over 850 substations dot the landscape, stepping down high voltage power from power stations for efficient distribution to various regions. The planned substations (Figure 7) will play a crucial role in:

- **Addressing grid congestion:** Easing overburdened lines and ensuring efficient power flow.
- **Boosting RE integration:** Connecting wind and solar farms to the grid, diversifying the energy mix.

- **Enhancing grid resilience:** Providing redundancy and improving stability in case of disruptions.

The substations, both existing and planned, are the silent workhorses of the national grid, quietly ensuring power reaches homes and businesses. As the country pursues a cleaner energy future and GH_2, these crucial infrastructure hubs will play an even more vital role in integrating renewable resources and creating a sustainable power system for generations to come. The visual map provides relevant information for each substation.

2.2.5 Electricity grid corridors

As of February 2018, South Africa has identified seven key Strategic Transmission Corridors (Figure 8): Central, Eastern, International, Northern, Western, Expanded Eastern, and Expanded Western. These corridors are pre-assessed for environmental sensitivities and considered strategically important for future electricity infrastructure development.

Each corridor serves specific purposes, depending on its location and connection points. Some connect coal-fired power stations in Mpumalanga to major load centres, while others facilitate cross-border power exchange with neighbouring countries.

2.2.6 REIPPPP power generation plants

The REIPPPP has been instrumental in driving South Africa's RE revolution. Bid windows 1–4, held between 2011 and 2014, represent a significant milestone in this journey, laying the foundation for the country's current RE capacity (Figure 9). The allocated capacity of more than 4,700 MW of RE capacity was allocated across these four bid windows, primarily consisting of wind and solar projects.

Figure 4: Eskom supply areas

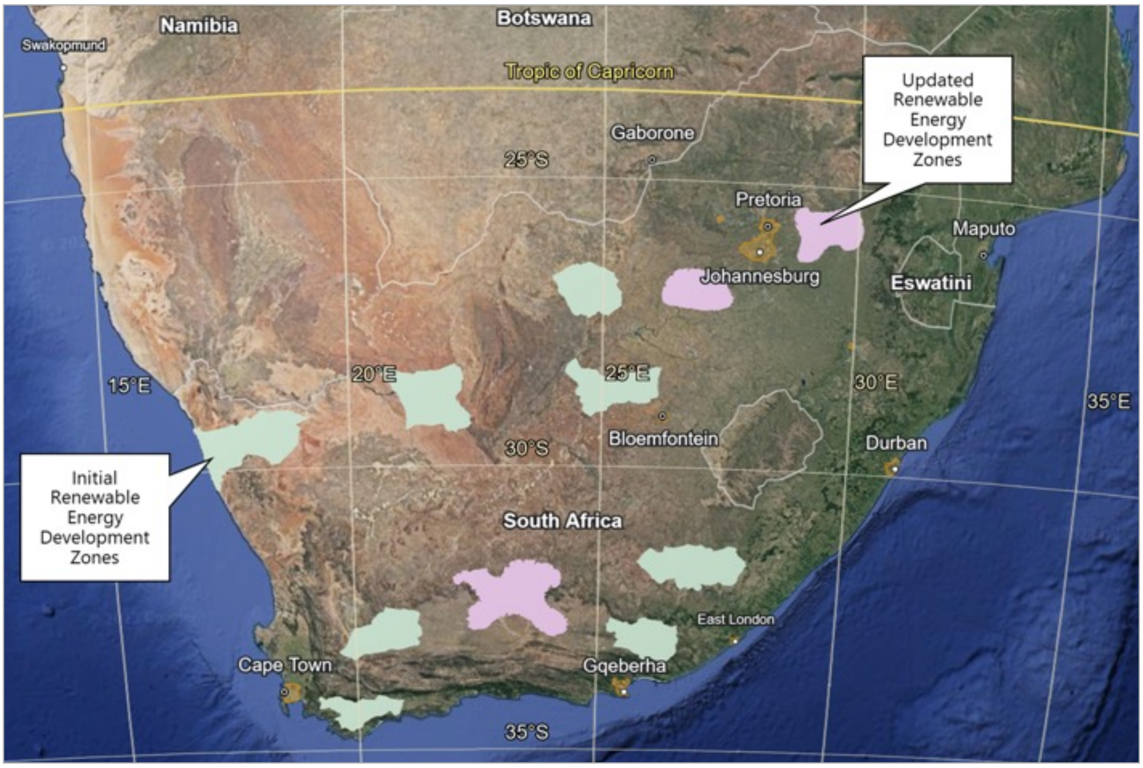

Figure 5: RE Development Zones

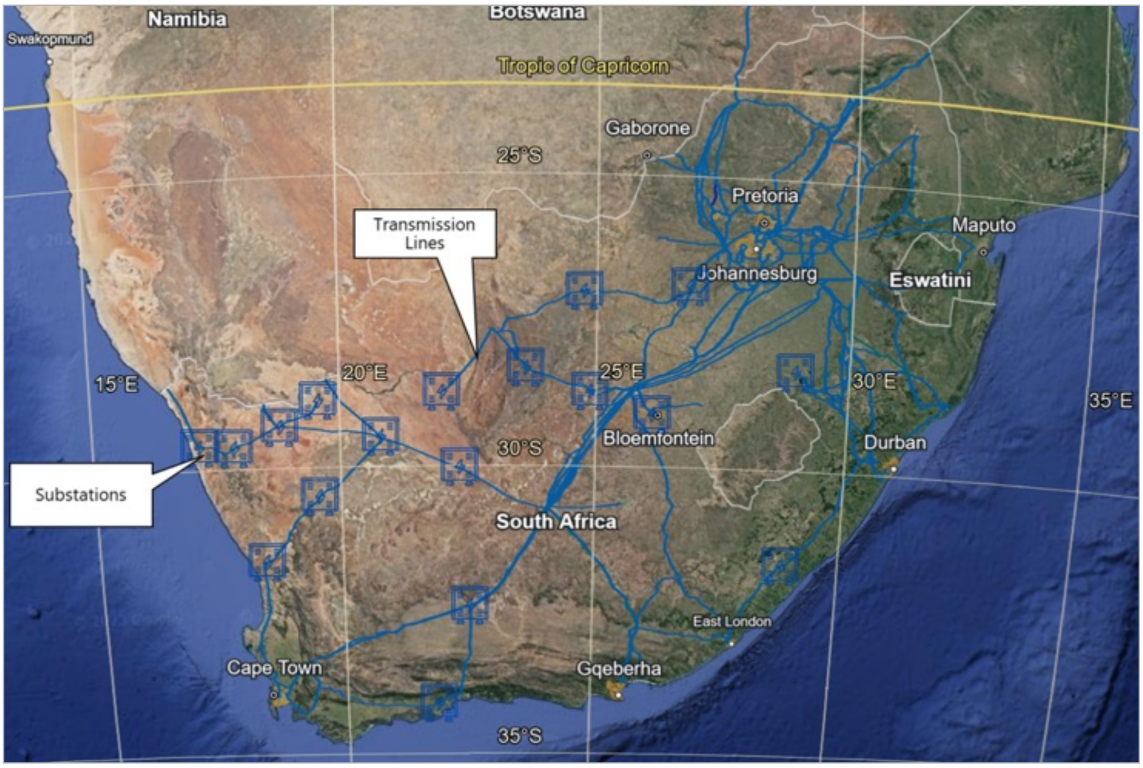

Figure 6: Existing transmission line and substation infrastructure

Figure 7: Existing (blue) and planned (red) substation infrastructure

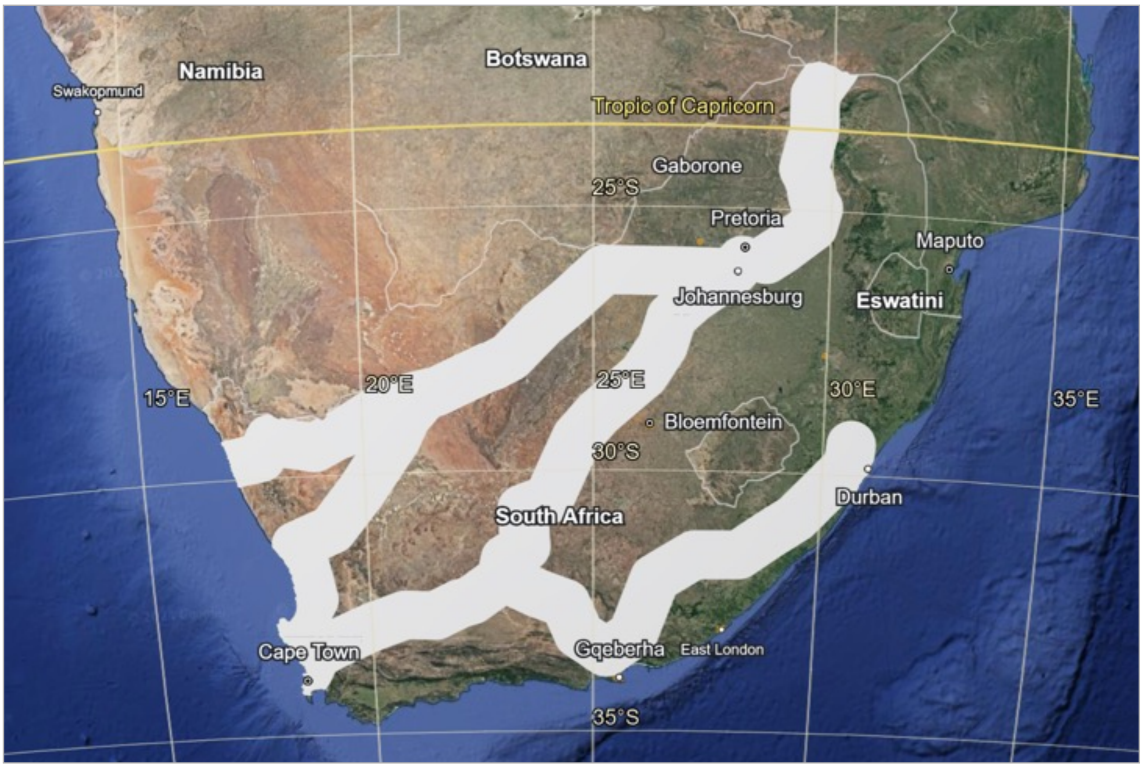

Figure 8: Electricity grid corridors

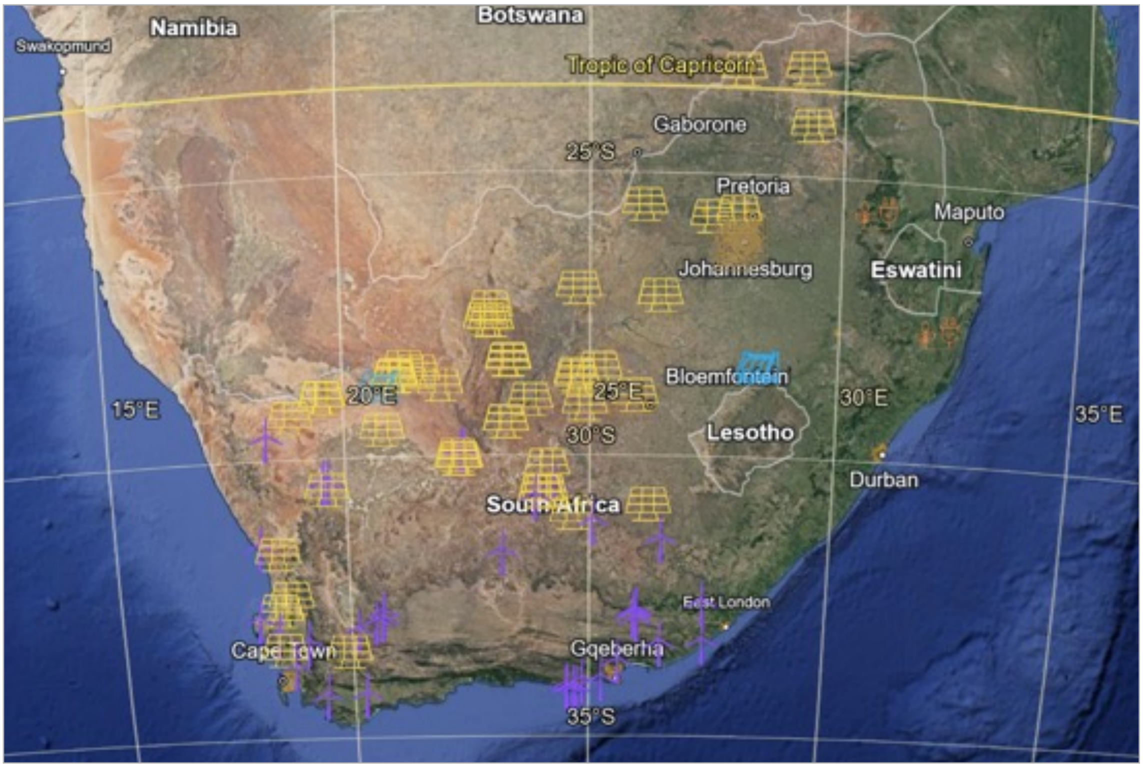

Figure 9: REIPP Bid Window 1-4 implemented power plants

2.3 South Africa's liquid fuels sector

South Africa's liquid fuels sector plays a vital role in sustaining the economy and supporting energy security, especially ensuring energy security, as it powers transportation, industry, and households. South Africa's key petroleum products include petrol, diesel, jet fuel, illuminating paraffin, furnace oil, bitumen, and liquefied petroleum gas (LPG). In 2023, the country's total liquid fuel consumption amounted to 26.04 billion litres, with petrol and diesel being the predominant fuels, as illustrated in the below figure.

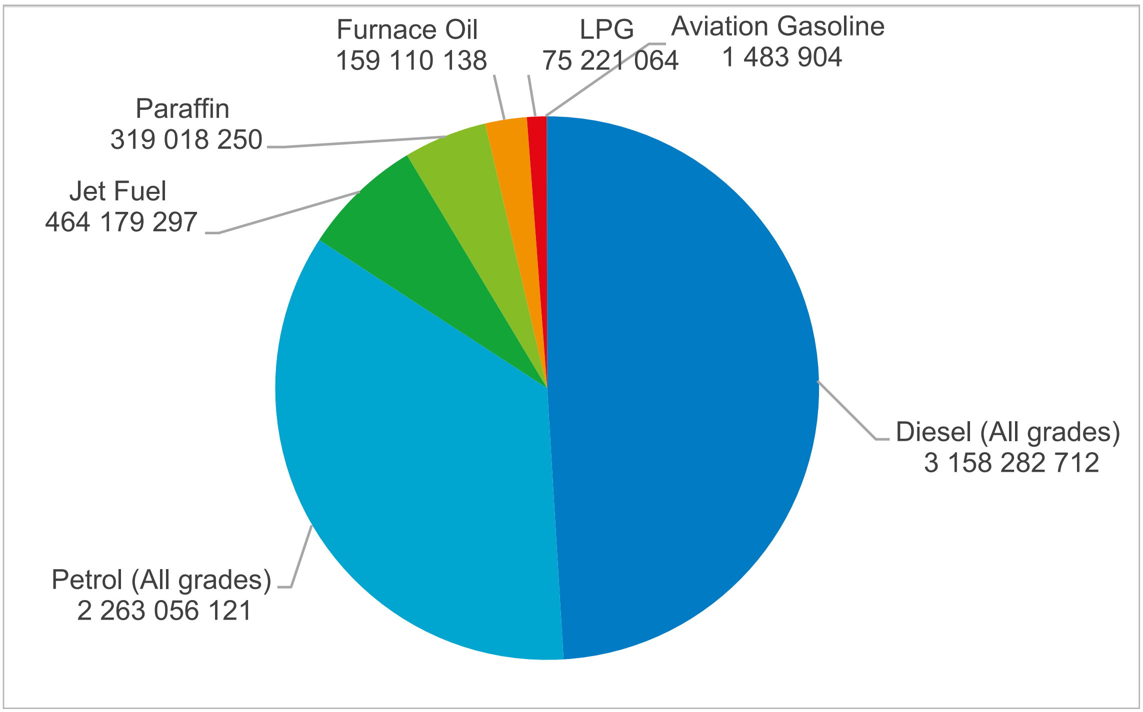

Figure 10: South Africa's liquid fuel consumption in 2023

Source: author based on data from DMRE (2024)

South Africa lacks domestic crude oil reserves and thus depends significantly on imports, mainly from the Middle East and Africa. This reliance exposes the sector to fluctuations in global oil prices. In 2023, South Africa imported 13.2 billion litres of crude oil, 12.8 billion litres of diesel, 4.5 billion litres of petrol, 871 million litres of LPG, and 674 million litres of jet fuel (DMRE, 2024).

In addition to its significant reliance on imports for liquid fuels, South Africa's energy sector is notably characterised by its production of synthetic fuels (synfuels) derived from coal and natural gas. While the country has refining capacity, its facilities are relatively modest compared to global standards. The government is actively involved in the sector through key institutions like the Central Energy Fund (CEF) and the National Energy Regulator of South Africa (NERSA), which play crucial roles in oversight and regulation.

The South African liquid fuels sector confronts several challenges in the context of a global shift towards RE sources, which pressures traditional liquid fuel markets. The aging infrastructure of refineries and pipelines also demands substantial investment for modernisation and efficiency improvements. Additionally, South Africa's fuel quality standards lag behind international benchmarks, potentially impacting vehicle performance and emissions. The European standard "Euro 5" limits sulphur content in diesel to 10 ppm (i.e., 0.001%), whereas South Africa's current legislation allows a sulphur content of up to 500 ppm (i.e., 0.05%) (Roos, Chauke, Oloo, & Mbatha, 2022). However, there is a promising opportunity to promote LPG as a cleaner alternative for cooking and heating, bolstered by government support. The sector also holds potential for job creation, particularly in the expanding renewable fuel distribution segments.

As the liquid fuels sector faces both significant challenges and promising opportunities, South Africa finds itself at a crucial crossroads. The country must adeptly manage the transition from fossil fuels to cleaner energy sources while ensuring energy security and affordability. Successfully balancing these factors is essential for fostering growth and diversification within the sector.

Chapter 3

Energy supply challenges in South Africa

3. Energy supply challenges in South Africa

Since 2007, South Africa has encountered significant and complex energy security challenges deeply rooted in its historical, economic, and environmental contexts. These issues impact the reliability of power supply, economic stability, and long-term sustainability. To address these challenges effectively, it is essential to understand their underlying causes and implications for the nation's energy future.

A wide range of researchers and institutions have undertaken in-depth analyses of various aspects of South Africa's energy security. These studies provide a holistic understanding of the complex challenges the country faces, which can be broadly categorised into seven key areas:

1. Power generation
2. Ageing liquid fuels infrastructure and Sasol's transition risks
3. Political and policy issues
4. Corruption
5. Environmental factors
6. Supply chains and logistical issues
7. Infrastructure bottlenecks.

3.1 Power generation

Power generation in South Africa is confronted with several critical issues, including aging infrastructure, financial constraints, operational inefficiencies, and challenges related to its energy mix and dependency.

3.1.1 Aging power generation infrastructure

Aging energy facilities in South Africa face several significant issues that impact their operational efficiency and reliability. Many of South Africa's power plants, particularly coal-fired stations, are outdated and increasingly prone to breakdowns, which significantly exacerbates frequent power outages and threatens national energy security. The advanced age of this infrastructure is a major contributor to the country's energy instability. Furthermore, maintenance issues exacerbate the problem;

regular upkeep has frequently been neglected or inadequately performed, leading to additional inefficiencies and operational disruptions.

Avordeh et al. (2024) identified several significant challenges associated with outdated power plants. Firstly, frequent technical failures plague plants commissioned in the 1970s and 1980s, as these facilities, burdened by wear and tear on outdated components, are unable to meet modern operational demands, leading to increased breakdowns and unplanned outages. Secondly, the maintenance of these aging plants is both costly and complex; repairing outdated equipment incurs higher expenses than newer technologies and requires specialised skills and parts that may no longer be available, placing a substantial financial strain on utility companies. Lastly, operational inefficiencies are inherent in these old power plants, which, due to outdated technology, fail to operate at optimal energy conversion levels and struggle to meet current environmental standards. This inefficiency results in inconsistent energy output, impacting the stability of the power supply and increasing operational costs.

Maintenance related issues are also highlighted in Eskom's "Integrated Report 2019," which details several critical maintenance problems that have significantly impacted its operational efficiency. The report reveals that inadequate maintenance of the company's aging equipment has led to a deteriorating performance of power generation and transmission/distribution infrastructure (Eskom, 2019). This deterioration exacerbated the country's energy security issues, leading to frequent power outages and diminished reliability of electricity supply. Consequently, both industrial productivity and residential energy access were negatively impacted. Eskom highlights the urgent need for a strategic revamp of maintenance practices and a significant boost in capital investment to restore and improve the reliability of its operations.

3.1.2 Financial constraints

South Africa's power sector is significantly impacted by financial constraints, which undermine the stability and efficiency of its electricity supply. The financial difficulties faced by the sector are multifaceted, involving high debt levels, operational inefficiencies, and escalating costs, all of which contribute to a precarious energy landscape.

According to the Parliamentary Monitoring Group (PMG), Eskom's financial instability is one of the major obstacles to improving South Africa's energy security. In his media address on July 8, 2024, Minister of Electricity and Energy Dr. Kgosientsho Ramokgopa announced that municipalities collectively owe Eskom ZAR 78 billion, much of which is considered irrecoverable. He also added that this debt could reach ZAR 3.1 trillion by 2050, which could lead to Eskom's collapse if immediate measures are not taken (SANEWS, 2024). This financial burden is the result of years of operational and financial challenges. This not only hampers the company's ability to invest in new infrastructure but also restricts its capacity to maintain existing assets. The debt crisis severely limits

Eskom's ability to invest in new infrastructure, technology upgrades, or RE projects. The lack of financial resources also hampers the utility's ability to attract investment and secure necessary funding for operational and maintenance expenses.

In addition to funding shortages, the rising costs of power generation have made it increasingly challenging to maintain affordable electricity supply. The rising cost of electricity, driven by inefficiencies and financial challenges, creates additional economic pressures on both households and businesses. As operational costs rise, due to factors such as outdated infrastructure and high maintenance expenses, the price of electricity increases, leading to affordability issues for consumers. This situation is compounded by the necessity for Eskom to undertake costly repairs and upgrades, which are frequently deferred due to financial constraints, thereby perpetuating a cycle of rising costs and diminishing service quality.

Furthermore, the financial difficulties of the power sector have broader implications for South Africa's economic stability. The high cost of energy affects the competitiveness of South African industries, leading to reduced economic growth and potential job losses. The inability to invest in modernising power infrastructure also hampers the sector's ability to transition to more sustainable energy sources, limiting long-term energy security and environmental sustainability.

3.1.3 Operational inefficiencies

Operational inefficiency is a critical issue affecting South Africa's power sector, significantly impacting its reliability and effectiveness. This inefficiency is manifested in various forms, including frequent loadshedding, technical failures, and suboptimal performance of power plants, which collectively undermine the stability of the nation's energy supply. For instance, operational inefficiencies within Eskom and the broader power sector are cited as significant factors contributing to the frequent loadshedding experienced in South Africa. Loadshedding, which involves planned power outages to manage supply–demand imbalances, is a direct consequence of the sector's operational shortcomings. Various publications, including Mashilo and Kgobe (2023), Mlambo (2023), Erero (2023), Inglesi-Lotz (2023) and Aidan Horn (2024), emphasise that the root causes of loadshedding include aging infrastructure, inadequate maintenance practices, and systemic inefficiencies within Eskom's operations. These issues lead to a reduced capacity to generate and distribute electricity effectively, resulting in recurrent power shortages and disruptions that affect both households and businesses.

3.1.4 Energy mix and dependency

South Africa's heavy reliance on coal for electricity generation is a critical issue for energy security, with coal-fired power plants accounting for over 75% of the country's total electricity supply mix (CRSES, 2024). This dependence poses several risks, including significant environmental degradation, health impacts, and concerns about long-term sustainability. The environmental consequences of coal mining and combustion, such as air pollution and GHG emissions, contribute to global climate change, while the finite nature of coal resources raises doubts about the long-term viability of this energy source. In addition to environmental concerns, the continued reliance on coal poses significant challenges to South Africa's economic and social well-being. This reliance not only undermines efforts to improve air quality and public health but also limits the potential for economic diversification.

Additionally, the transition to RE sources has been slow and challenging. Todd and McCauley, for instance, assessed policy barriers to the energy transition in South Africa and concluded that regulatory uncertainties, insufficient investment, and a lack of comprehensive policy frameworks are major barriers to this transition (2021). Despite efforts to advance RE through initiatives like the REIPPPP, progress has been impeded by bureaucratic delays and policy inconsistencies. This slow adoption of RE technologies limits South Africa's ability to diversify its energy mix and reduce its dependence on coal.

3.2 Ageing liquid fuels infrastructure and Sasol's transition risks

South Africa's liquid fuels sector, reliant on aging infrastructure and dominated by Sasol, faces major challenges in shifting to a low-carbon economy.

3.2.1 Ageing liquid fuels infrastructure

South Africa's liquid fuels infrastructure, including refineries and pipelines, is facing significant challenges due to its age. Operating since the 1950s, this aging infrastructure is increasingly prone to breakdowns, inefficiencies, and safety risks, which compromise its reliability. The backlog in maintenance and necessary upgrades requires substantial investment to ensure that these assets continue to provide a dependable fuel supply while meeting environmental standards. This financial burden of upgrading the infrastructure not only poses a challenge for investment but can also result in higher fuel prices, ultimately affecting consumers and businesses alike.

3.2.2 Sasol's transition risks

As one of the world's largest carbon emitters, Sasol faces considerable risks in its transition to a low-carbon future. Increasing carbon taxes and stricter environmental regulations impose significant financial pressure on the company. Additionally, the global shift towards RE and electric vehicles threatens to reduce demand for liquid fuels, which could adversely impact Sasol's revenue. Furthermore, the development and implementation of new low-carbon technologies, such as carbon capture and storage, present technological and financial uncertainties, adding to the complexity of the transition.

3.3 Political and policy issues

Political and policy issues are significant barriers to enhancing South Africa's energy security, primarily due to regulatory uncertainty and governance challenges. Regulatory uncertainty poses a major obstacle, as inconsistent and unclear energy policies create an unstable environment for investors and energy producers (U.S. DOJ, 2023). The absence of a coherent and stable regulatory framework undermines confidence in the energy sector, deterring investment in new projects and technologies. Establishing clear, consistent, and transparent policies is crucial for creating a conducive environment for investment and development in the energy sector. Additionally, operational and financial issues within Eskom and other state entities severely impact energy security.

3.4 Corruption issues

Corruption at Eskom is one of the key factors exacerbating its operational crises. The PMG (2020) highlighted that corruption has led to mismanagement, project delays, and inefficiencies within the sector. A lack of effective oversight and accountability has allowed corrupt practices to proliferate, further complicating the sector's challenges.

Sophisticated crime syndicates, involving corrupt officials, police, and trucking companies, have infiltrated Eskom's supply chain. As detailed by Timse (2022), coal theft is a major issue, where high-quality coal meant for Eskom is stolen and replaced with inferior coal, significantly impacting the utility's power generation capabilities. Another major issue is cable theft, which is estimated to cost the economy between ZAR 5 billion and ZAR 7 billion annually (Ngqentsu, 2022).

A Judicial Commission of Inquiry into Allegations of State Capture, Corruption, and Fraud in the Public Sector revealed several corrupt private companies that secured irregular contracts worth ZAR 16 billion (Chabalala, 2021). The evidence presented to this commission demonstrates how corrupt elements within the public sector were able to: (i) appoint willing collaborators in all kinds of key positions; (ii) hobble the law enforcement agencies, even making some of them complicit in corruption; (iii) weaken parliamentary oversight; and (iv) capture parts of the independent media (IMF, 2023).

This era of corruption has led to a weakened Eskom by consolidating corruption and reducing accountability (BusinessTech, 2021). Furthermore, multinational corporations have also been implicated in corrupt activities, with a Swiss-based firm being forced to repay R2.5 billion for corruption-related crimes during the state capture era (McCain, 2022).

These layers of corruption have not only worsened Eskom's operational inefficiency but have also undermined trust in the company's leadership. Addressing these governance issues necessitates comprehensive reforms, enhanced transparency, and stronger enforcement of anti-corruption measures to improve the overall effectiveness and reliability of the energy sector.

3.5 Environmental factors

Environmental factors significantly influence South Africa's energy sector, particularly through climate variability and stringent environmental regulations. Climate variability, including recurrent droughts and shifting weather patterns, impacts the energy sector by affecting water availability for hydroelectric power and the cooling systems of coal-fired plants. These challenges underscore the need for adaptive strategies to mitigate the impacts of climate variability on energy production. In addition, environmental regulations play a crucial role in shaping the country's energy landscape. The DFFE explains that compliance with these regulations influences the operational costs and management practices of power plants (DFFE, 2018). Stricter environmental standards necessitate investments in cleaner technologies and more sustainable practices, which can drive up operational costs. Finding a balance between environmental protection and maintaining energy security is essential for developing a sustainable energy system that meets both environmental and economic objectives.

3.6 Supply chain and logistics issues

Supply chain and logistics issues present considerable challenges to South Africa's energy sector, with coal supply problems and infrastructure bottlenecks being particularly impactful. Eskom's Annual Report 2020 (2020) highlights significant problems related to coal procurement, transportation, and quality control, which critically affect the reliability of power generation. Issues such as poor coal handling, logistical inefficiencies, and quality discrepancies lead to delays and operational disruptions, straining the overall functionality of the energy sector. These challenges underscore the urgent need for enhanced supply chain management and more effective logistical strategies to improve the consistency and efficiency of coal supply.

In addition to the challenges related to the coal supply chain, the power sector supply chain is also affected by local content requirements. Unrealistic local content mandates for RE supply chain could hinder market development. South Africa currently has limited local RE manufacturing capabilities, which are often not cost-competitive with imports. While there is significant potential for local manufacturing to become more competitive over time, there are concerns that overly ambitious or poorly timed localisation requirements could disrupt supply chains or increase the cost of renewable electricity. Experience with RE in South Africa and other regions underscores the importance of establishing a minimum scale and demand certainty to ensure that localisation efforts are successful.

3.7 Infrastructure bottlenecks

Infrastructure bottlenecks are a significant challenge for South Africa's energy sector, critically impacting energy security. Key issues include outdated transmission networks, limited capacity, inefficient distribution systems, insufficient investment, and maintenance backlogs. Aging transmission and fuel/gas distribution infrastructure, built decades ago, struggles with inefficiencies, increased transmission losses, and frequent outages, exacerbated by the inability to handle peak loads (RoSA, 2012). The transmission and distribution networks often operate at or near full capacity, causing bottlenecks and outages, especially during peak demand periods (SARB, 2019). Inefficiencies in the distribution network, due to outdated equipment and poor maintenance, lead to high energy losses and uneven supply, affecting rural areas. Investment in upgrading infrastructure is hampered by financial constraints and bureaucratic hurdles, which delay necessary improvements and perpetuate inefficiencies (SARB, 2019). Deferred maintenance, caused by prioritisation issues and financial limitations, further strains the already overburdened infrastructure, leading to increased breakdowns and repair costs (NERSA, 2019). Additionally, delays in developing new infrastructure, including power plants and renewable facilities, are due to regulatory delays and land acquisition problems, slowing the expansion of energy supply capacity and diversification of the energy mix (RoSA, 2012). Addressing these issues requires coordinated investments, improved regulatory processes, and enhanced maintenance practices to build more resilient energy infrastructure.

3.8 Tackling energy supply challenges: Plans and progress

To address some of the challenges in South Africa's power sector, Eskom launched the Generation Recovery Operational Plan (GRP) in April 2023. Developed after extensive consultations with stakeholders, the plan aims to improve the country's electricity availability factor (EAF) within two years. It targets key issues such as power shortages, loadshedding, and aging power plants, and is part of a broader effort to stabilise and enhance the reliability of South Africa's electricity supply.

Key objectives of the GRP include (Eskom, 2024):

- **Restoring capacity:** The GRP focuses on restoring the operational capacity of South Africa's aging power generation plants, especially the coal-fired plants, many of which are prone to breakdowns due to outdated infrastructure. This includes accelerating maintenance, repairs, and extending the operational life of existing power plants.
- **Addressing energy supply shortages:** The plan aims to mitigate loadshedding and energy supply shortages by stabilising the grid and increasing available capacity. This includes efforts to ramp up generation from existing plants and improve the overall efficiency of Eskom.
- **Ensuring energy security:** Part of the GRP involves diversifying the energy mix by integrating RE sources, such as solar and wind power, alongside improving the performance of existing coal plants. This shift is crucial to reduce South Africa's heavy reliance on coal, which contributes to both environmental degradation and long-term sustainability risks.
- **Infrastructure investment:** The plan also highlights the need for significant investment in new energy infrastructure, including both generation and transmission systems, to ensure a stable and sustainable energy future. It includes constructing new power plants and upgrading transmission networks to prevent bottlenecks and grid failures.
- **Operational efficiency and management:** A key focus of the GRP is improving the operational efficiency of Eskom through better management, strategic hiring of skilled personnel, and implementing robust maintenance schedules to prevent breakdowns.
- **Public and private sector collaboration:** The plan emphasises collaboration between the government and private sector to secure additional investments and expertise, particularly in the RE sector, as part of South Africa's longer-term energy transition strategy.

The GRP has shown encouraging progress and results over recent months. As of November 8, 2024, for instance, loadshedding has been suspended for 226 consecutive days since March 26, 2024. Additionally, the Unplanned Capacity Loss Factor (UCLF) has decreased to 25.2% for the financial year-to-date (April 1 to November 7, 2024), down from 33.6% during the same period last year. The EAF for this period stands at 63.1%, marking a notable 7.5% improvement from last year's 55.6% (Eskom, 2024). The goal is to reach a 70% EAF by March 2025, ensuring a stable power supply and lowering diesel costs.

Chapter 4

South Africa's GH_2 landscape: Overview

4. South Africa's GH_2 landscape: Overview

South Africa is one of the pioneers in developing a hydrogen economy. The country's involvement in hydrogen technology began with the HySA Programme, laying the foundation for subsequent initiatives such as the HSRM and the GH_2CS. Together, these programmes outline a comprehensive approach to positioning South Africa as one of the global leaders in the emerging hydrogen economy.

4.1 HySA Programme

The HySA programme marked the beginning of South Africa's ambitions to foster a hydrogen-based economy. This initiative stems from the South African National Hydrogen and Fuel Cells Technologies (HFCT) Research, Development, and Innovation (RDI) Strategy, approved by Cabinet in May 2007 and officially launched in September 2008. Initially, the HySA programme was a 15-year initiative aimed at stimulating and guiding innovation across the hydrogen value chain, by focusing on developing:

- South African intellectual property and technological expertise
- Human capital through capacity building and skills development
- Products and components for hydrogen technologies
- Processes to support hydrogen as both an energy carrier and feedstock for industrial use.

The HySA programme significantly contributed to advancing the hydrogen economy by:

- Establishing expertise in hydrogen technologies
- Creating knowledge and technical capabilities
- Laying the groundwork for the HSRM
- Extension of HySA.

The programme was originally set to run from 2008 to 2023. However, in September 2021, Cabinet approved a 10-year extension to 2033. This extension aims to:

- Build on HySA's achievements
- Provide technical expertise for implementing the HSRM
- Support the development and implementation of the GH_2CS.

4.2 Hydrogen Society Roadmap

In March 2020, the Department of Science and Innovation (DSI), in collaboration with other government departments, initiated development of the HSRM. The roadmap was approved by Cabinet in September 2021 and publicly released in February 2022. The HSRM serves as a national coordinating framework to integrate hydrogen-related technologies across various sectors of the South African economy, aligning with the country's decarbonisation and industrialisation goals.

The roadmap outlines **70 priority actions** under six high-level outcomes (DSI, 2022):

- Decarbonising heavy-duty transport (8 actions)
- Decarbonising energy-intensive industry (8 actions)
- Enhancing and greening both the main and micro power grids (16 actions)
- Developing a centre of excellence in manufacturing for H_2 products/FC components (9 actions)
- Creating an export market for South African GH_2 (9 actions)
- Transitioning from grey to blue to GH_2 towards a net-zero economy (20 actions).
- These actions embed principles of gender, equality, and social inclusion, a just transition, and continuous RDI.

To accelerate the development of South Africa's hydrogen economy, four catalytic projects have been identified, each progressing through different stages of implementation, as detailed in the table below.

Table 1: GH_2-related catalytic projects

Projects	Project purpose	Key project partners
Platinum Valley Initiative (South African Hydrogen Valley)	Cluster H_2 projects in Johannesburg, Durban/Richard's Bay and Mogalakwena/Limpopo and establish a hydrogen corridor linking the three cities to facilitate the conversion of heavy-duty diesel trucks to heavy-duty FC trucks, while supporting the upscaling of hydrogen demand in the transport sector.	DSI, South African National Energy Development Institute (SANEDI), Anglo American Platinum, Bambili Energy & Engie.

Projects	Project purpose	Key project partners
$CoalCO_2$-X Project	Produce value-added products (ammonium bicarbonate fertiliser, ammonia, diesel, and sulphuric acid) by combining CO_2, SOx, and NOx in flue gases from coal-fired boilers with GH_2.	DSI, RDI, government, research and technology firms, large industrial emitters of GHGs, and commercial offtakes of the products.
Boegoebaai SEZ	Construction of a 40 GW capacity electrolyser for ammonia production at Boegoebaai (a port on the Northern Cape coast), mainly for export. The first phase of the project comprises a 30 GW solar photo voltaic (PV) and wind farm and a 5 GW electrolyser.	Sasol, the South African IDC, Gauteng Provincial government, Northern Cape Economic Development, Trade and Promotion Agency (NCEDA), etc.
Sustainable Aviation Fuels (SAF)	SAF production from either biofuel (bio-kerosene) or via chemical synthesis of GH_2 and sustainable[3] CO_2 either by Fischer-Tropsch or methanol synthesis and its refining to kerosene (E-kerosene).	Linde PLC, Enertrag AG, Navitas Holdings (Pty) Ltd, and Sasol (the LENS Consortium)

4.3 Green Hydrogen Commercialisation Strategy

Building on the foundations of the HySA programme and the HSRM, the GH_2CS seeks to position South Africa as a global leader in GH_2 and green chemicals. Approved by Cabinet in October 2023, the GHCS outlines the country's GH_2 opportunities and presents a detailed action plan for advancing both export and domestic markets.

The strategy is built on six foundational pillars (dtic, 2023):

- Prioritising exports – secure long-term global GH_2 market share and competitive trade position
- Stimulating the domestic GH_2 market
- Securing investment and finance – Foreign direct investment and low-cost green finance
- Considering economic and socio-economic development
- Supporting localisation by enabling local industrial capability and participation

3 *Sustainable or climate-neutral CO_2 is obtained either by the expensive DAC technology or from more affordable biomass, which has been certified/documented to have been produced sustainably.*

An estimated total capital investment of USD 164 billion will be required over the next 15 years to support the entire GH_2 value chain (Figure 11). The GHCS highlights the importance of fostering SEZs and state-supported strategic hubs to enhance value creation throughout the GH_2 value chain. It places a strong emphasis on localisation opportunities and strategic partnerships with industry players for the production and assembly of critical components. The strategy aims to incentivise direct user-case projects and private sector-led initiatives, ensuring broad-based industry participation. Key principles such as sector coupling, integrated planning, minimising capital costs, and developing efficient supply chains are central to maintaining the competitiveness of GH_2 projects.

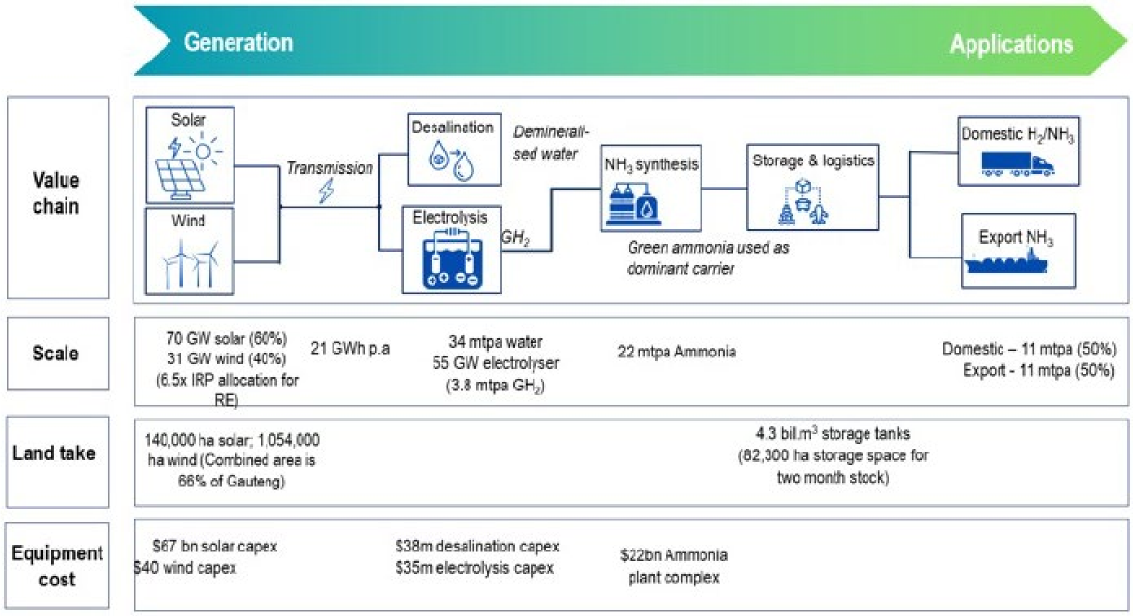

Figure 11: South African GH_2 value chain components and investment estimates

Source: DTIC (2023)

4.4 Stakeholder landscape

The stakeholder landscape for GH_2 and PtX in South Africa is inherently complex, given the wide-ranging aspects involved, including water and land use, RE generation, infrastructure development, storage, transportation, distribution, and environmental, social, and safety considerations. For example, a GH_2 stakeholder mapping conducted in 2023 as part of the study *Renewable Hydrogen Market Potential and Value Chain Analysis* by the GIZ identified over 300 domestic and international entities, reflecting strong interest in the local GH_2 sector.

The table below provides an overview of the key policy and regulatory institutions that play a significant role in the development of the GH_2 economy.

Table 2: Institutional framework and governance of GH_2

No	Institution	Roles and responsibilities related to GH_2
1	**Department of Forestry, Fisheries and the Environment (DFFE)**	Overseeing sustainable development and environmental integrity, granting environmental authorisations under the National Environmental Management Act (NEMA) to ensure hydrogen projects comply with regulations and support sustainability objectives.
2	**Department of Mineral Resources and Energy (DMRE): Department of Mineral and Petroleum Resources (DMPR) and Department of Electricity and Energy (DoEE).**	DMRE serves as the principal authority for policy formulation and strategic planning in South Africa's energy sector, focusing on ensuring energy security by diversifying the energy portfolio to include renewable sources. Following Cabinet's 30 June 2024 announcement, the DMRE will be replaced by the DMPR and the DoEE. The DMRE will remain operational until legislation and the transfer of human and financial resources are complete.
3	**Department of Public Enterprises (DPE)**	DPE acts as the main shareholder and oversight body for Eskom, South Africa's sole power off-taker. The DPE's role is critical in ensuring that Eskom integrates hydrogen into its energy portfolio, supporting the transition to RE sources and enhancing sustainability of the national power supply.
4	**Department of Public Works and Infrastructure (DPWI)**	The DPWI oversees more than 500,000 public sector buildings and has introduced the Public Works and Infrastructure Green Building Policy. This policy emphasises integrating green technologies, including hydrogen, into public buildings to enhance sustainability and minimise the environmental impact of public infrastructure
5	**Department of Trade, Industry and Competition (DTIC)**	The DTIC drives the development of local industries and trade, prioritising green industries and job creation. Its initiatives to attract foreign investment are crucial for expanding the hydrogen sector, supporting the establishment of a green economy, and promoting economic growth through sustainable practices.

No	Institution	Roles and responsibilities related to GH_2
6	**Department of Science and Innovation (DSI)**	DSI oversees national research, development, and innovation, emphasising new energy technologies. Since 2008, DSI has led the implementation of the HySA, advancing hydrogen research and development and positioning the country as a key player in the global hydrogen economy.
7	**Investment and Infrastructure Office (IIO) of The Presidency**	Ensure an integrated, cross-sectoral approach to policymaking and align sectoral priorities with national strategies. IIO is a key coordinating body focusing on infrastructure development, investment planning, and mobilisation.
8	**Industrial Development Corporation (IDC)**	IDC leads the GH_2 sector by coordinating the formulation of strategies, investing in pilot projects, and promoting public–private partnerships. Its mission is to industrialise GH_2 technologies, drive economic growth, and establish South Africa as a global leader in GH_2, supporting the nation's 2050 net-zero emissions target
9	**National Energy Regulator of South Africa (NERSA)**	NERSA regulates the energy sector in line with national policy and strategic frameworks. Its duties include licensing new energy infrastructure and setting tariffs for electricity and hydrocarbons infrastructure. NERSA's oversight is critical for developing and integrating GH_2 infrastructure, ensuring compliance with regulatory standards and alignment with national energy goals.
10	**National Treasury**	National Treasury governs fiscal and procurement policies in South Africa, ensuring the efficient allocation of financial resources, including for the GH_2 sector. Its role includes funding research, development, and infrastructure projects that are crucial for advancing hydrogen technologies and integrating them into the national energy mix.
11	**Provincial departments and municipalities**	Provincial departments and municipalities regulate private RE generation through by-laws and policies, overseeing the local implementation of hydrogen projects to align with regional energy and sustainability goals. Municipalities are key in integrating RE producers, power consumers, and electrolysers, managing legal, financial, technical, and economic aspects, as well as developing tariff guidelines for fair and transparent pricing in electric systems.

Regarding financing institutions, South Africa is actively progressing the development of GH_2 projects with support from various national and international funding sources. The table below highlights key national financial institutions that are backing these initiatives.

Table 3: Key funding institutions

No	Institution	Initiative	Description
1	**Government initiatives**	CoalCO2-X RDI Programme	This programme has received EUR 3 million (about ZAR 4 billion) from DSI to promote the use of GH_2 in reducing emissions from coal power plants.
		Green Fund	Established by DFFE, this ZAR 800 million fund supports various green initiatives, including those related to RE and hydrogen production.
2	**Blended finance initiatives**	SA-H_2 Fund	Launched by the IDC in collaboration with national and international partners, this innovative blended finance fund aims to raise USD 1 billion (approx. ZAR 17.5 billion) to support the development of the GH_2 sector. By combining public and private capital, it enhances access to risk capital for developers at various stages of GH_2 project development.
		KfW Development Bank	KfW has initiated a EUR 200 million (about ZAR 4 billion) concessional financing programme specifically for GH_2 projects in South Africa, focusing on pre-feasibility and strategic projects.
3	**International collaborations**	Partnerships with Germany	South Africa has partnered with the German government on several initiatives, including a EUR12.5 million project to develop a regulatory framework for the country's GH_2 economy. Additionally, the German Federal Ministry of Economic Cooperation and Development (BMZ) has committed EUR 40 million in grant funding to support the promotion of South Africa's GH_2 sector.

No	Institution	Initiative	Description
3	**International collaborations**	Partnering for Accelerated Climate Transitions (UK-PACT) Programme	This UK Government-funded programme is designed to support countries in reducing emissions. Currently, the programme includes GBP 10.3 million in energy, finance and mobility projects for supporting job creation in the GH_2 sector, emphasising a just transition for affected communities.
		Investment strategy	By October 2024, IIO was developing a "Country Investment Strategy" to attract both foreign and domestic investments, which is crucial for scaling up GH_2 production and infrastructure.
4	**Private sector sources**	Institutional investors	Infrastructure funds and insurance companies
		Private equity and venture capital	Targeted through security arrangements for early-stage funding and risk capital to support GH_2 projects, e.g., Agile Equity, BNA Capital, Thrive Capital Partners.
		Commercial banks	Offer loans and financial products tailored to GH_2 projects, often with government-backed initiatives, e.g., African Finance Corporation, Investec, MUFG.
		Blended finance initiatives	Combine public and private funds to reduce risks and attract private investment, e.g., BMZ Germany, KfW Germany, IFC, Norfund, SANEDI.
		Corporate financing	Corporations, especially in energy and industrial sectors, invest in GH_2 as part of sustainability strategies, e.g., Amplats, Itochu, Mitsui, Sumitomo.

Source: GFA compilation

These diverse sources of finance are vital for the development and scaling of GH_2 projects in South Africa. A framework providing long-term offtake arrangements towards sustainable risk profiles for financings structures will be crucial in the early stages of private sector involvement. The economic and regulatory terms guiding investment decisions must be designed to ensure that energy security is made a key objective in project considerations.

In terms of energy security in South Africa, the critical considerations in enabling sufficient financial resources for GH_2 as well as RE investment and their resulting contributions to energy security can be summarised as follows:

- **Investment shortfall:** The significant investment gap hinders the development of robust energy infrastructure, affecting the reliability and sustainability of energy supply both to power and GH_2 consumers. On a global scale, the hydrogen sector is estimated to face an investment gap of approximately USD 700 billion by 2030.
- **High-risk perception:** The perceived high risk of new technologies can limit private sector investment, slowing down the adoption of innovative energy solutions essential for energy security. For GH_2, this includes identifying accessible downstream consumers.
- **Limited blended finance:** The lack of effective blended finance mechanisms reduces the ability to leverage public funds to attract private investment.
- **Project bankability issues:** The difficulty in achieving bankability for projects due to high upfront costs and long payback periods can delay or prevent implementing critical energy projects. The market ramp-up of GH_2 adds to the uncertainty requiring mitigating financial instruments.

Chapter 5

Global strategies on hydrogen for energy supply

5. Global strategies on hydrogen for energy supply

Energy security has been a key focus of national policy, ensuring reliable access to energy for economic stability and societal well-being. However, evolving geopolitical dynamics, fossil fuel market volatility, and the urgent need to combat climate change has revealed the vulnerabilities of traditional energy systems, often reliant on imported fossil fuels and centralised infrastructure. In response, many nations are adopting diversified energy strategies that reduce dependence on external sources, enhance resilience, and prioritise sustainability. By integrating emerging technologies in energy production, storage, and distribution, countries are building more adaptable and sustainable energy systems capable of withstanding external shocks and supporting long-term economic growth.

This chapter analyses how selected countries—the United Kingdom, Germany, Japan, Australia, Morocco, Namibia, United States, and Brazil—consider GH_2 as part of their energy security strategies. These counties were selected because of their maturity level in the GH_2 economy, and similar economy structure and proximity to South Africa. By examining their national hydrogen strategies, roadmaps, and related policy documents, this chapter seeks to identify common themes, strategic approaches, and regional differences in how GH_2 is being integrated into national energy frameworks.

5.1 Countries with strategies to consider connecting GH_2 as part of energy security

United Kingdom

The United Kingdom's approach to energy security focuses on transitioning to a more resilient and sustainable energy system in response to global market volatility and the need to reduce carbon emissions. The risks of relying on imported fossil fuels, particularly highlighted by events such as the Russian invasion of Ukraine, have driven the UK to position GH_2 as a critical part of its strategy. By expanding domestic GH_2 production, the UK aims to reduce its dependency on imported natural gas, a significant vulnerability in its energy matrix, and enhance its energy independence.

The UK's Hydrogen Strategy, published in 2021, outlines how GH_2 can support both decarbonisation and energy security goals. The ability of hydrogen to store excess RE and complement variable sources like wind and solar makes it a vital component for maintaining grid stability and preventing blackouts. The government's goal of achieving 5 GW of low-carbon hydrogen production by 2030 is central to this strategy, and the development of hydrogen infrastructure—including production, storage, and distribution systems—is seen as essential to achieving a stable energy supply.

The UK is committed to international collaboration to ensure a diversified and stable hydrogen supply. While domestic production is prioritised, the UK is positioning itself as a leader in the global hydrogen economy by engaging in international partnerships to secure imports and foster technology exchange. This approach enhances the UK's energy security and strengthens its geopolitical standing as it aligns with global efforts toward energy transition and sustainability.

Germany

Germany's approach to energy security has evolved significantly, driven by its Energiewende (energy transition) and geopolitical factors like the energy crisis triggered by Russia's invasion of Ukraine. Historically reliant on imported natural gas, particularly from Russia, Germany's vulnerabilities have led to a strategic shift toward more diversified and sustainable energy sources. GH_2 has emerged as a central element in reducing Germany's dependence on imported fossil fuels, providing a flexible and storable energy solution to complement the intermittent nature of RE sources like wind and solar.

Germany's updated National Hydrogen Strategy sets an ambitious goal of doubling the country's electrolysis capacity to at least 10 GW by 2030, ensuring a stable hydrogen supply for key industrial sectors such as steel, chemicals, and heavy transportation. This strategy is essential for decarbonising these energy-intensive sectors while maintaining industrial output. Additionally, Germany is focused on building a robust hydrogen infrastructure, including pipelines and storage facilities, to ensure efficient hydrogen distribution and grid stability, thereby enhancing the country's energy resilience.

Beyond domestic production, Germany recognises the importance of securing diversified and reliable hydrogen imports from international partners to mitigate risks associated with reliance on any single energy source. By establishing itself as a leader in hydrogen technology and fostering international supply chains, Germany aims to strengthen its energy independence and position itself competitively in the emerging global hydrogen economy, further safeguarding its long-term energy security while advancing climate goals.

Japan

Japan's energy security strategy is shaped by its geographical constraints and heavy reliance on imported fossil fuels, such as oil and natural gas. As an island nation with limited domestic energy resources, Japan is particularly vulnerable to global energy market fluctuations and geopolitical risks. To address these challenges, Japan has identified GH_2 as a key element in diversifying its energy mix and reducing its dependence on imported fuels, especially as part of its updated Basic Hydrogen Strategy.

GH_2 offers Japan a flexible and storable energy carrier that can complement RE sources like solar and wind, which are limited by space constraints for large-scale projects. Hydrogen's ability to store energy and provide grid stability makes it crucial for ensuring a continuous and reliable energy supply. Japan is focused on developing domestic GH_2 production, but also plans to import hydrogen produced from renewable sources abroad, thereby diversifying its energy sources and enhancing resilience.

To secure a stable and diversified hydrogen supply, Japan is also investing in international hydrogen supply chains by forming partnerships with countries that have abundant RE resources. This international cooperation, combined with significant investment in hydrogen infrastructure such as production facilities, pipelines, and storage systems, strengthens Japan's energy security while positioning the country as a leader in the global hydrogen economy.

Australia

Australia's energy security strategy is closely tied to its abundant RE resources and its role as a major exporter of fossil fuels. With the global shift toward decarbonisation and the volatility of fossil fuel markets, Australia has recognised the need to transition to a more sustainable and resilient energy system. GH_2 has emerged as a key component of Australia's strategy to reduce reliance on fossil fuels and enhance energy independence while positioning itself as a global leader in the hydrogen economy.

Australia's National Hydrogen Strategy (launched in 2019) outlines plans to leverage the country's vast solar and wind resources to produce hydrogen at scale. By investing in large-scale hydrogen production facilities and integrating hydrogen with RE projects, Australia aims to stabilise its energy grid, store excess RE, and reduce curtailment of renewable generation. This will help create a more resilient domestic energy system capable of withstanding external shocks, such as disruptions to global energy supply chains.

Australia is also focused on becoming a leading hydrogen exporter, with the aim of diversifying its export base beyond traditional fossil fuels. The country is developing hydrogen infrastructure, including pipelines, storage, and export terminals, while establishing hydrogen hubs to scale up production and distribution. This dual focus on domestic energy security and export opportunities positions Australia as a key player in the global hydrogen economy, supporting both national and international decarbonisation efforts.

Morocco

Morocco's energy security strategy is focused on reducing its reliance on imported fossil fuels and becoming a regional leader in RE. With abundant solar and wind resources, Morocco has invested heavily in RE projects to transition to a low-carbon economy. GH_2 has become a key component of this strategy, as it offers a domestically produced, sustainable energy source that can help reduce Morocco's dependency on volatile fossil fuel markets while contributing to its economic and environmental goals.

The country's GH_2 roadmap, "Feuille de Route de l'Hydrogène Vert," outlines Morocco's vision for integrating hydrogen into its energy system. By using hydrogen as a storage medium, Morocco can stabilise its energy grid, store excess RE, and provide a reliable supply during periods of low generation. This capability is crucial for improving the resilience of the country's energy infrastructure, particularly as it continues to expand its solar and wind capacities.

In addition to strengthening domestic energy security, Morocco aims to position itself as a key exporter of GH_2, particularly to Europe. By creating hydrogen production hubs and investing in hydrogen infrastructure such as pipelines and storage facilities, Morocco seeks to diversify its energy exports and create new revenue streams. This export potential supports both Morocco's long-term energy security and its economic resilience in the global energy transition.

Namibia

Namibia's energy security strategy is focused on reducing its dependence on imported energy, particularly from South Africa, and addressing the vulnerabilities of its underdeveloped energy infrastructure. With limited domestic energy production capacity, Namibia faces significant risks from supply disruptions and price volatility. GH_2 has emerged as a central element in Namibia's efforts to achieve energy independence by leveraging its abundant solar and wind resources to produce hydrogen domestically.

Namibia's GH_2 strategy aims to establish the country as a major producer of GH_2, targeting the production of 10–12 million tonnes of hydrogen equivalent annually by 2050. The development of "hydrogen valleys" in regions with high RE potential is key to this strategy. These hubs will serve as centres for hydrogen production, storage, and export, allowing Namibia to stabilise its energy supply and mitigate the risks associated with its reliance on external energy sources.

In addition to enhancing energy security, Namibia sees GH_2 as a driver of socio-economic development, with the potential to create jobs, diversify the economy, and strengthen its geopolitical standing. By becoming a global leader in GH_2 production, Namibia aims to contribute to global decarbonisation efforts while boosting its domestic economy and securing a sustainable, reliable energy supply for the future.

United States

The United States' energy security strategy is centred on its extensive energy resources, including RE potential and significant fossil fuel reserves. Historically focused on energy independence, the U.S. has recognised the strategic importance of GH_2 in diversifying its energy mix and reducing reliance on fossil fuels. GH_2 is seen as a versatile and storable energy carrier that complements renewable sources like wind and solar, helping to stabilise the grid and increase resilience against disruptions from natural disasters, geopolitical events, or market volatility.

The U.S. National Clean Hydrogen Strategy, published in 2023, outlines the country's plans to significantly expand domestic GH_2 production by deploying electrolysis technologies powered by RE. The government has set ambitious targets to produce substantial volumes of low-carbon hydrogen by 2030. A key focus is on developing robust hydrogen infrastructure, including production facilities, pipelines, storage systems, and refuelling stations, to facilitate the transport and distribution of hydrogen across various sectors such as industry, transportation, and power generation.

In addition to domestic efforts, the U.S. sees GH_2 as a crucial component for decarbonising hard-to-abate sectors like heavy industry and long-haul transport, which have traditionally relied on fossil fuels. By expanding GH_2 production and usage, the U.S. aims to enhance its energy sovereignty, reduce GHG emissions, and secure a stable energy supply. Furthermore, public–private partnerships and government support through regulatory frameworks and incentives are crucial to accelerating the adoption of GH_2, ensuring both energy security and economic growth in the transition to a low-carbon economy.

Brazil

Brazil's energy security strategy is closely tied to its leadership in RE, particularly hydroelectric power. However, with increasing challenges related to the variability of hydroelectric generation due to seasonal droughts and climate change, Brazil is turning to other renewable sources like wind and solar to diversify its energy mix. In this context, GH_2 is emerging as a strategic solution to enhance Brazil's energy security by providing a flexible and storable energy source that reduces reliance on imported fossil fuels.

Brazil's National Hydrogen Programme (PNH_2) highlights the potential of GH_2 to support both domestic energy needs and international markets. Leveraging its vast RE resources, particularly in the northeast region, Brazil is well-positioned to produce GH_2 at scale. By integrating hydrogen into its energy system, Brazil can ensure a stable and reliable energy supply, especially during periods of low hydroelectric output. GH_2 also plays a crucial role in decarbonising key industrial sectors such as steel and chemicals, which are significant energy consumers.

In addition to domestic benefits, Brazil aims to become a key player in the global hydrogen economy by exporting GH_2 to international markets. The country is focused on developing the necessary infrastructure, including pipelines, storage solutions, and hydrogen hubs, to support both domestic consumption and export. By investing in GH_2, Brazil not only strengthens its energy security but also supports its economic resilience while contributing to global decarbonisation efforts.

Implications for Global Energy Security

The integration of GH_2 into national energy security strategies across these diverse countries reflects a global shift towards more resilient, sustainable, and independent energy systems. As countries continue to develop their hydrogen industries, the global energy landscape is likely to become more diversified, reducing the geopolitical risks associated with fossil fuel dependency and enhancing overall energy security.

Moreover, the rise of GH_2 as a key energy carrier has the potential to drive significant technological innovation, economic growth, and international cooperation. Countries that invest early in hydrogen technology and infrastructure are likely to gain a competitive advantage in the global hydrogen economy, securing energy supplies and economic benefits for the future.

5.2 Good practices and lessons learnt in addressing energy security through GH_2

Exploring the global landscape of GH_2 reveals a wealth of strategies and practices those various countries have adopted to integrate GH_2 into their energy security frameworks. These international efforts highlight the strategic importance of hydrogen as a key component in the transition to sustainable energy systems, providing valuable insights into how different nations are navigating this complex transition. By examining the approaches of leading countries such as Germany, Japan, Australia, the United Kingdom, and the United States, it becomes evident that successful hydrogen implementation is underpinned by comprehensive policies, robust regulatory frameworks, coordinated institutional efforts, and effective governance structures.

Each of these countries has developed distinct yet interconnected strategies that offer important lessons for regions looking to expand their hydrogen initiatives. Germany's National Hydrogen Strategy, for instance, provides a detailed roadmap for integrating hydrogen into the industrial sector, emphasising the role of hydrogen in decarbonisation and aligning closely with broader European Union climate goals. Similarly, Japan's focus on establishing a "hydrogen society," supported by government-driven public–private partnerships, underscores the importance of coordinated efforts across sectors to foster innovation and scale up hydrogen usage. Australia's strategy, which leverages its abundant renewable resources to develop hydrogen hubs, demonstrates the critical role of infrastructure development in supporting both domestic and export-oriented hydrogen economies.

The regulatory frameworks in these countries are also key to their success, ensuring that hydrogen technologies are deployed safely and efficiently. In the UK and US, comprehensive regulations have been established to cover the entire hydrogen value chain, from production to storage and distribution, facilitating innovation while maintaining safety and environmental standards. Furthermore, the institutional and governance models employed by these nations emphasise the need for clear oversight and strategic coordination, ensuring that hydrogen initiatives are not only ambitious but also effectively implemented and aligned with national energy and climate objectives.

Below are the good practices of GH_2 implementation in five countries: Germany, Japan, Australia, United Kingdom, and the United States, based on different aspects of policy, regulations, institutional frameworks, and governance.

United Kingdom

- **GH_2 role in enhancing energy security:** The UK's hydrogen strategy centres on developing domestic GH_2 production capacity, with an ambitious target of 5 GW of low-carbon hydrogen by 2030. This focus on domestic production aims to reduce dependency on imported energy and enhance national energy security, leveraging the UK's RE potential for hydrogen production to align with sustainability goals. Additionally, integrating GH_2 into the energy mix is part of a broader effort to diversify energy sources, critical for minimising risks associated with reliance on any single source, especially as the UK phases out coal and reduces natural gas consumption. This approach fosters a more resilient and adaptable energy system capable of withstanding supply disruptions.
- **Policy:** The UK's Hydrogen Strategy focuses on decarbonising the economy and enhancing energy security through the adoption of hydrogen. The strategy includes significant government investment in hydrogen production and infrastructure, aiming to integrate hydrogen into sectors like transportation, industry, and power generation (Kendall, 2022).
- **Regulations:** The UK has developed regulations that support the safe and effective deployment of hydrogen technologies. These include standards for hydrogen production, transport, and storage, aligned with European and international guidelines. The UK also focuses on regulatory innovation to support the hydrogen economy.
- **Governance:** The UK's governance model for hydrogen includes strategic oversight by government bodies, with clear objectives for hydrogen deployment. This model ensures that hydrogen initiatives contribute to broader energy and climate goals, with strong government support and industry participation.

Germany

- Germany's approach to enhancing energy security through GH_2 focuses on expanding domestic GH_2 production with a target of at least 10 GW of electrolysis capacity by 2030. This effort aims to reduce dependency on fossil fuel imports, diversify energy sources, and ensure a stable hydrogen supply for industrial sectors, including steel and chemicals. GH_2 plays a vital role in Germany's transition to a more resilient and secure energy system, especially in response to geopolitical risks such as the disruption caused by the Russia–Ukraine conflict. Moreover, Germany plans to secure hydrogen imports from international partners, further safeguarding its energy security while establishing itself as a leader in hydrogen technology.
- **Policy:** Germany's National Hydrogen Strategy is a comprehensive framework that aims to integrate GH_2 into the energy system as a cornerstone of decarbonisation and energy security. The policy is closely tied to the European Union's Green Deal, emphasising the use of hydrogen in industrial decarbonisation, particularly in sectors like steel and chemicals (Ringsgwandl, Schaffert, Brücken, Albus, & Görner, 2022).
- **Regulations:** Germany has developed a roadmap for hydrogen regulation, focusing on harmonising national regulations with European and international standards. The Hydrogen Regulation, Codes, and Standards (H_2 RCS) are aligned with European directives and international bodies like ISO and IEC, ensuring that hydrogen technologies are safe, reliable, and widely adopted (Wurster & Hof, 2020).
- **Governance:** Germany's governance model for hydrogen is highly integrated, involving various ministries, federal agencies, and industry stakeholders. This model ensures that hydrogen initiatives are well-coordinated, with clear responsibilities and robust support from public policies and funding programmes.

Japan

- Japan views hydrogen as a crucial component of its energy security strategy, particularly considering its limited domestic fossil fuel resources and reliance on energy imports. The country's Basic Hydrogen Strategy, established in 2017 and updated in 2023, underscores hydrogen's role in reducing dependence on imported fossil fuels by integrating it into power generation, industry, and transportation sectors. This approach enhances Japan's energy resilience by enabling the use of domestically produced hydrogen and creating international supply chains. Moreover, hydrogen offers a flexible energy solution for grid stability, which is vital for a country with limited space for large-scale RE projects. Japan's commitment to building hydrogen infrastructure and international partnerships ensures a reliable supply of hydrogen, thus supporting its long-term energy security goals.
- **Policy:** Japan's Basic Hydrogen Strategy, established in 2017, was the world's first national hydrogen policy. It emphasises the creation of a "hydrogen society" where hydrogen is used as a primary energy source across various sectors, from residential use to transportation and industrial applications (Behling, Williams, & Managi, 2015).

- **Regulations:** Japan's regulatory framework includes stringent safety and environmental standards for hydrogen production, storage, and usage. These regulations are continually updated to reflect advancements in hydrogen technology and ensure public safety and environmental protection. The country also collaborates with international bodies to harmonise its regulations with global standards.
- **Governance:** Japan's hydrogen governance is characterised by strong government leadership and coordinated efforts across different sectors. The government provides strategic direction and support, ensuring that hydrogen initiatives align with national energy security and climate goals.

Australia

- Australia's National Hydrogen Strategy emphasises GH_2 as a key factor in improving the nation's energy security. By leveraging its vast RE resources, Australia aims to position itself as a global hydrogen exporter, reducing reliance on imported fossil fuels and enhancing its energy independence. The strategy outlines plans to develop hydrogen production hubs, integrate hydrogen into various sectors like heavy transport, and establish international hydrogen supply chains. This approach not only strengthens domestic energy resilience but also supports global decarbonisation efforts, particularly by supplying clean hydrogen to major trading partners like Japan and Korea.
- **Policy:** Australia's National Hydrogen Strategy aims to position the country as a global leader in hydrogen production and export. The strategy focuses on building a strong hydrogen value chain, integrating hydrogen into the domestic energy system, and developing export markets, particularly in Asia.
- **Regulations:** Australia's regulatory framework is evolving to support the hydrogen industry, with a focus on safety, environmental protection, and market facilitation. Regulations are being developed to cover hydrogen production, transport, storage, and use, ensuring that the industry can grow sustainably.
- **Governance:** Australia's governance structure for hydrogen includes clear roles for federal and state governments, with efforts to align policies and strategies across different levels of government. This alignment is crucial for scaling up hydrogen production and developing export opportunities.

United States

- The United States is positioning clean hydrogen (GH_2) as a central element of its strategy to enhance energy security and decarbonise its economy. Through initiatives like the Hydrogen Energy Earthshot and the Bipartisan Infrastructure Law, the U.S. is investing heavily in clean hydrogen production, targeting sectors such as heavy industry, transportation, and energy storage where few decarbonisation alternatives exist. By 2030, the U.S. aims to produce 10 million metric tonnes of clean hydrogen annually, reducing reliance on imported fossil fuels, building a resilient energy infrastructure, and securing energy independence. This strategy also focuses on developing regional hydrogen hubs, reducing production costs, and fostering public–private partnerships to drive clean hydrogen deployment.

- **Policy:** The US Clean Hydrogen Strategy is part of a broader effort to transition to a low-carbon economy. The strategy focuses on developing hydrogen as a key component of the energy system, with substantial public investment in research and development, infrastructure, and market development (Moura & Soares, 2023).
- **Regulations:** The US regulatory framework for hydrogen is being developed to support the safe and widespread adoption of hydrogen technologies. This includes regulations for hydrogen production, transportation, storage, and use, with a focus on environmental protection and public safety.
- **Governance:** The US governance model for hydrogen is characterised by decentralised decision-making, with strong roles for federal and state governments. This allows for flexibility in implementing hydrogen initiatives, ensuring that they are tailored to regional needs and priorities.

The global exploration of GH_2 integration into energy security frameworks underscores the transformative potential of hydrogen in addressing both energy and climate challenges. Countries like Germany, Japan, Australia, the United Kingdom, and the United States have each implemented unique strategies that align hydrogen development with their national energy security and decarbonisation goals. These strategies offer valuable lessons that can be tailored to the specific needs and context of South Africa.

As South Africa considers how to develop its GH_2 economy, the practices of these leading countries provide a roadmap for aligning hydrogen development with broader national objectives. By examining the policy frameworks, regulatory environments, institutional coordination, and governance models employed by these countries, South Africa can design a comprehensive and effective hydrogen strategy. This strategy will not only contribute to enhancing energy security and achieving climate goals but also ensure that hydrogen initiatives support economic growth, job creation, and social equity, making the transition both sustainable and inclusive.

Policy framework development

South Africa is at a critical juncture in its energy transition, where the development of a GH_2 economy offers substantial opportunities for enhancing energy security, supporting industrial growth, and achieving climate goals. A well-defined national hydrogen strategy, similar to Germany's and the UK's, is crucial for guiding South Africa's efforts in this direction. According to IRENA, such a strategy should include clear targets, policy support mechanisms, and integration with broader energy and climate policies to maximise impact. South Africa's policy framework can benefit from aligning hydrogen development with its Just Energy Transition goals, ensuring that hydrogen initiatives contribute to socio-economic objectives such as job creation, economic diversification, and sustainability. By setting clear national targets for hydrogen production and usage in key sectors like mining and heavy industry, South Africa can position itself as a leader in the global hydrogen economy while addressing its domestic energy challenges.

Regulatory and legal frameworks

Establishing a robust regulatory framework is essential for the safe, efficient, and effective deployment of hydrogen technologies in South Africa. Drawing on lessons from Germany, Japan and the US, where hydrogen regulations are closely aligned with respective countries' standards, South Africa should prioritise developing regulations that cover safety standards, environmental protections, and market facilitation. This regulatory certainty will not only attract international investment but also build market confidence, enabling South Africa to scale up its hydrogen economy in a sustainable manner.

Investment initiatives and incentives

The strategies described also aim to attract significant investment and strategic initiatives across various nations. With robust financial incentives, comprehensive regulatory frameworks, and extensive international cooperation, these countries are creating compelling opportunities for investors. For instance, the United States has introduced the Clean Hydrogen Production Tax Credit, offering up to EUR 2.80 per kilogram for low-carbon hydrogen production, along with a commitment of EUR 7.5 billion to develop Clean Hydrogen Hubs (The White House, 2023). Australia, in turn, provides a refundable tax offset of approximately EUR 1.20 per kilogram (2 AUD/kg) through its Hydrogen Production Tax Incentive (Commenwealth of Australia, 2024), while also allocating around €2 billion through the Hydrogen Headstart programme to accelerate large-scale hydrogen projects (Australian Renewable Energy Agency, 2024). Germany is investing EUR 8 billion in 62 large-scale projects to boost its domestic hydrogen economy (Meza, 2021) and has also set aside specifically for South Africa EUR 32 million[4] for GH_2 initiatives. The United Kingdom is supporting its hydrogen strategy with several funding schemes aimed at developing production networks and storage facilities to secure a stable hydrogen supply (Department for Energy Security & Net Zero, 2024). Meanwhile, Japan is advancing with a substantial public–private investment plan of 15 trillion yen, equivalent to roughly EUR 99 billion, to promote the creation of a comprehensive "hydrogen society" (Kutty, 2024). These varied and substantial investments reflect a collective drive towards fostering a competitive global hydrogen market, enhancing energy security, and achieving climate goals, ultimately positioning GH_2 as a central pillar in the global transition to sustainable energy.

4 *Joint Media Statement by The European Union, the Ministry of Electricity and Energy and the Department of Trade, Industry and Competition of the Republic of South Africa - Global Gateway: European Union supports South Africa's Green Hydrogen Ambitions, 9th September 2024.*

Chapter 6

Contact points between energy security and GH_2/PtX

6. Contact points between energy security and GH_2/PtX

GH_2 intersects with the energy sector and energy security in multiple ways. When designed and managed effectively, GH_2 can help address various energy security challenges, but if not handled properly, it has the potential to exacerbate these issues. The key areas where GH_2 intersects with the energy sector and energy security include:

- Grid electricity demand
- Transmission and distribution infrastructure
- System operation: stability and flexibility of electricity supply
- Energy imports (liquid fuels, natural gas and LPG)
- GHG emissions
- Diverting investments

6.1 Grid electricity demand

Grid-connected GH_2 facilities may divert power from the grid, potentially reducing the availability of green electricity for other sectors and delaying their electrification and decarbonisation. To address this, relevant regulations must be developed to ensure that the electricity used to produce GH_2 does not result in any competition between existing renewable electricity demands.

In the European Union (EU), for instance, this issue is managed through the additionality requirement. This rule mandates that any RE generation plant providing electricity to a GH_2 facility must be new and not receive any operating or investment subsidies. In addition, the power outputs from these new RE generation plants need to be aligned in space (geographical correlation) and time (temporal correlation) with GH_2 production.

In contrast, when properly designed, grid-connected GH_2 facilities can enhance overall power supply security by supporting grid stability and balancing energy supply. This can be achieved by oversizing RE power plants dedicated to GH_2 production, and selling excess electricity to the grid. This approach helps mitigate supply shortages and enhances the economic viability of GH_2 projects.

6.2 Transmission and distribution infrastructure

Using the power grid to transport electricity from RE power generation plants to GH_2 facilities can create potential bottlenecks and reliability issues. As RE plants often generate electricity intermittently and may be located far from GH_2 production sites, the existing grid infrastructure might struggle to handle these variations in power flow. This can lead to congestion in the grid, where the capacity to transmit electricity is insufficient to meet demand at certain times. Such congestion can compromise the reliability of electricity delivery, affecting both GH_2 production and other critical sectors reliant on a stable power supply. However, when grid capacity is sufficient, GH_2 projects can capitalise on their connection to the power grid to reduce production costs. By utilising existing grid infrastructure to access electricity from RE plants, GH_2 facilities can lower their own energy costs. Additionally, surplus electricity from RE plants that is not used for GH_2 production can be sold to the grid, creating an additional revenue stream and further offsetting GH_2 production costs.

6.3 System operation: Stability and flexibility of electricity supply

With the increasing share of electricity from intermittent RE sources like wind and solar, GH_2 is essential for stabilising and enhancing the flexibility of power supply. GH_2 enables effective energy storage, which is crucial for managing fluctuations in supply and demand. This capability allows excess electricity from RE sources to be stored and released during periods of high demand or low renewable generation. This not only enhances energy security by providing a more reliable and consistent power supply but also facilitates the transition to a greener and more resilient energy system.

6.4 Energy imports

During the 2023/24 financial year, 5.1% of South Africa's total electricity supply was sourced from imports (CRSES, 2024), primarily from neighbouring countries such as Mozambique, Namibia, and Lesotho. In addition to importing electricity, South Africa also depends on liquid fuel imports. In 2022, for instance, the country imported USD 17.1 billion (i.e., over ZAR 290 billion[5]) worth of refined petroleum (OEC, 2024). South Africa's heavy reliance on imported liquid fuels makes it vulnerable to price fluctuations, supply chain disruptions, and geopolitical risks. Transitioning to domestic production of GH_2 and PtX could significantly reduce the country's dependence on fossil fuels by utilising its RE resources. By focusing on GH_2 production, South Africa could enhance its energy security, decrease foreign energy reliance, and build a more self-sufficient energy landscape. GH_2

5 *Using an exchange rate of R17.02/USD1) according to https://www.focus-economics.com/economic-indicator/exchange-rate/*

offers a viable solution to these challenges, as it can improve energy security by reducing fossil fuel imports, create economic opportunities through job creation and foreign investment, support decarbonisation efforts by lowering GHG emissions, encourage technology transfer and innovation, and provide value-added products like synthetic fuels, ammonia, and methanol, thus expanding export prospects.

6.5 Greenhouse gas emissions

All sectors of the economy – such as agriculture, commerce, industry, public administration, and transportation – depend on energy to produce goods and deliver services vital for daily life and economic growth. Therefore, the GHG emissions associated with energy supply directly impact the carbon footprint of these sectors. South Africa's updated Nationally Determined Contribution aims for net-zero emissions by 2050, a goal that mainly depends on effectively decarbonising the energy sector. The role of GH_2 in achieving this goal is crucial, as it enables the storage of green electricity and its release during peak demand periods, which reduces reliance on fossil fuel-based peaking plants and helps lower GHG emissions in the power sector. For sectors that are challenging to electrify or transition directly to RE (known as hard-to-decarbonise or hard-to-abate[6] sectors), GH_2/PtX technologies provide a viable solution. These technologies convert RE into a variety of products, such as GH_2, green ammonia, green methanol, and sustainable aviation fuel. By enabling the use of RE in these hard-to-abate sectors, GH_2/PtX technologies enable the decarbonisation of these sectors.

In addition to South Africa's net-zero commitment supporting GH_2 offtake, the EU Carbon Border Adjustment Mechanism (CBAM) is expected to drive further adoption of GH_2 technologies. Launched in October 2023, CBAM imposes a carbon price on imports like cement, steel, aluminium, fertilisers, hydrogen, and electricity to align with EU emissions standards. As a result, South African exports to the EU will likely adopt GH_2 technologies to meet CBAM requirements, creating new market opportunities in the country.

6.6 Diverting investments

While GH_2 has the potential to play a crucial role in the transition to a low-carbon economy, it is important to balance investments across various RE technologies to ensure a comprehensive and resilient energy transition. For instance, investors may find RE projects unrelated to GH_2 production less attractive if they perceive GH_2 as offering better returns or more immediate benefits. The same applies to research and development where the focus may shift towards optimising GH_2-related technologies and away from advancing other RE technologies. This can slow the development and deployment of alternative RE sources.

6 *Hard-to-decarbonise/abate sectors: Heavy-duty long-distance transport (comprising long-haul road transport, maritime shipping, aviation) and industrial chemical processes (making of steel, cement, ammonia and chemicals).*

Chapter 7

Effects of GH_2/PtX economy on energy security in South Africa

7. Effects of GH_2/PtX economy on energy security in South Africa

The transition to a GH_2/PtX economy has the potential to significantly transform South Africa's electricity sector, particularly in terms of energy security. This chapter examines both the positive and negative effects of the GH_2/PtX economy on the country's energy security. On the positive side, the integration of GH_2 and PtX technologies offers a range of benefits, such as expanded renewable power capacity, improved grid reliability, enhanced energy storage, and the development of additional infrastructure, all of which strengthen energy resilience. However, challenges such as electricity diversion from the grid, strain on existing infrastructure, and short-term price increases must be addressed. By analysing these factors, this chapter provides a thorough understanding of how the GH_2/PtX economy influences energy security, highlighting its potential benefits while also exploring ways to mitigate any associated risks.

7.1 Positive effects of GH_2/PtX economy on energy security

The development of GH_2/PtX projects offers a range of significant benefits for South Africa's electricity system and broader economy. By leveraging RE sources, these projects can create synergies that enhance grid stability, reduce carbon emissions, and drive economic growth. Below is a detailed exploration of these positive outcomes, highlighting their potential to support South Africa's energy transition and alleviate current challenges such as loadshedding.

7.1.1 Additional renewable power capacity

RE plants dedicated to GH_2 and PtX production are usually oversized to ensure operational stability for GH_2 and PtX facilities by providing consistent power, preventing issues like pressure drops in ammonia synthesis, or damage to catalysts from thermal cycling. This results in high utilisation rates for electrolysers, lowering hydrogen production costs, and improving project viability. During periods of high solar or wind, these plants often generate surplus electricity, which can be redirected to the national grid or supplied to consumers via mechanisms like wheeling or direct sales. This approach enhances electricity supply, potentially reduces costs for consumers, and helps mitigate South Africa's loadshedding crisis by adding capacity to the system.

South Africa has significant potential to leverage excess renewable electricity generation to produce GH/PtX. According to South Africa's GHCS by DTIC (2022), the country aims to produce 1.9 Mt equivalent of GH_2 for the domestic market and an additional 1.9 Mt for export. To achieve these substantial production targets, South Africa will need 41 GW of electrolyser capacity, power by RE plants of 80 GW of capacity in total, which includes 56 GW from solar energy and 24 GW from wind energy. This means that during periods of high wind and solar generation, RE power plants dedicated to GH_2 production will generate additional or excess capacity of up to 39 GW.

The figure below summarises the projected electrolyser capacity and the corresponding RE capacity at five-year intervals from 2025 to 2050.

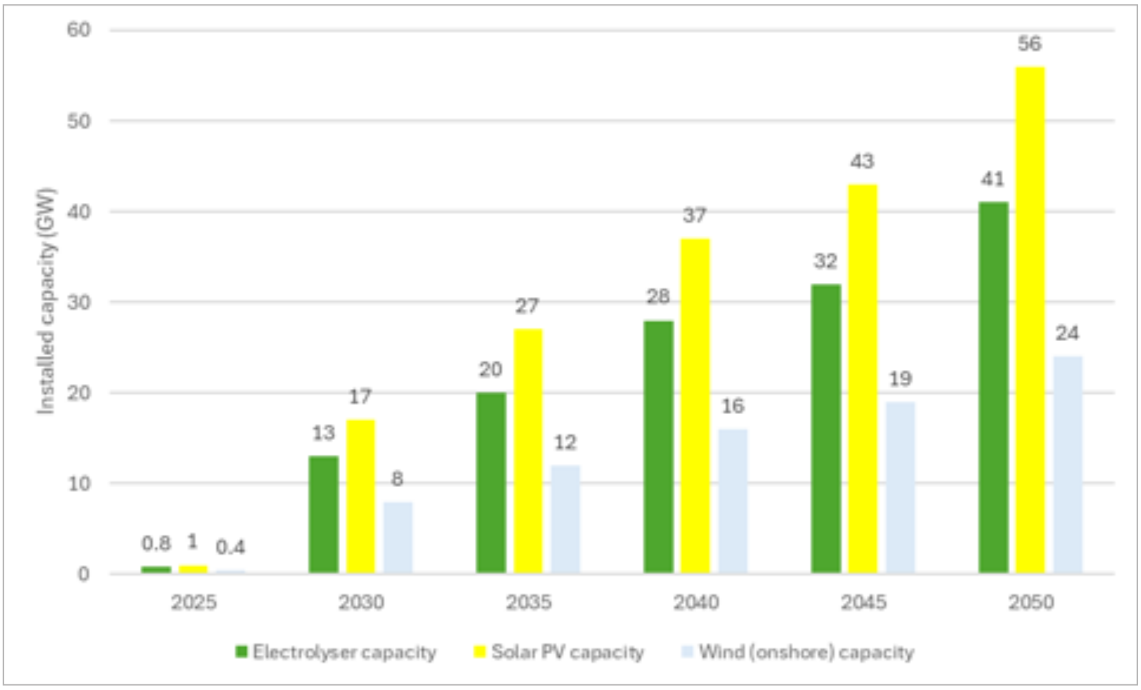

Figure 12: Total installed capacities in 5-year increments to meet the projected GH_2 demand

Source: based on DTIC (2022)

From the above figure, it can be concluded that each 1 MW of electrolyser capacity will lead to about 1 MW of excess electricity capacity. The development of hydrogen-specific power plants will necessitate the construction of between 42,000 and 88,000 km of additional transmission lines every five years from 2025 to 2050 (DTIC, 2022). The above estimates are supported by the catalytic projects identified in the GHCS as indicated in the below table, which shows that nine projects with a total electrolyser capacity of 7.7 GW would produce about 7 GW of excess renewable electricity.

Table 4: Identified strategic infrastructure projects

Project	Location	Market	RE capacity (MW)	Electrolyser capacity (MW)	GH_2 (tpa)	Ammonia (tNH3)	Capex (US$m)
Sasol, Enertrag, Linde, Navitas	Sasolburg	Domestic	400	220	15,000		720
Sasol	Sasolburg	Domestic	50	26	1,800	10,200	90
NCP Chlorchem South Africa	Chloorkop	Domestic	40	22	1,520		70
Phelan Green Energy	Saldanha	Domestic	3,750	2,500	85,000		2,500
e-Methanol	Eastern Cape	Export	3,200	1,800	120,000	682,000	4,700
GH Production	Northern Cape	Export	1,600	880	60,000	341,000	
Mainstream GH Production	Northern Cape	Export	115	62	4,300	24,300	220
Ubuntu GH_2 Project	Northern Cape	Export	20	12	800	4,500	40
Prieska Energy Cluster	Northern Cape	Export	1,900	1,000	70,000	398,000	3,700
Hive Project	COEGA Eastern Cape	Export	3,600	1,200	158,451	900,000	5,800
Total			**14,675**	**7,722**	**516,871**	**2,360,000**	**17,840**
Required RE capacity				**7,722**			
Excess RE capacity			**6,953**				

Source: DTIC (2022)

The expected electricity excess resulting from the development of GH_2/PtX projects would benefit consumers by increasing supply and potentially lowering electricity costs. The surplus power could play a vital role in alleviating energy shortages and frequent loadshedding, while also reducing the country's carbon footprint and dependence on coal-fired power stations.

To utilise this excess electricity, it would need to be integrated into the national grid or distributed directly to consumers through three primary mechanisms: direct sales to consumers, wheeling arrangements for distribution to consumers, or direct transactions with the grid operator.

- **Direct to consumers:** RE producers can sell excess power directly to consumers through bilateral agreements. This can be facilitated by net metering, where consumers can offset their electricity consumption with their own generation.
- **To consumers by wheeling:** wheeling involves the transmission of electricity from a RE producer to a consumer through the existing grid. This requires a wheeling agreement with the grid operator.
- **Direct to the grid operator:** RE producers can sell their excess power directly to the grid operator at a predetermined price. This allows for greater flexibility and potentially higher revenue streams.

Integrating excess electricity from RE power plants dedicated to GH_2/PtX production into South Africa's transmission grid poses substantial challenges. Eskom, which manages the existing infrastructure, faces issues like maintenance backlogs, capacity constraints, and frequent loadshedding. While excess renewable electricity can alleviate some problems, concerns about grid capacity, stability, and regulatory compliance arise.

The current grid is insufficient to accommodate the scale of electricity generated by GH_2 facilities, requiring significant upgrades, including expanded transmission lines and substations. Smart grid technologies could enhance supply and demand balance, and one potential solution is wheeling—transmitting electricity directly to consumers over long distances using existing infrastructure. However, regulatory hurdles, such as grid fees and transmission losses, complicate wheeling arrangements, potentially favouring larger consumers while leaving smaller users reliant on traditional systems.

Key challenges include:

- **Capacity constraints:** Aging infrastructure, especially in rural areas, and transmission bottlenecks hinder the transport of electricity from remote RE sources to load centres.
- **Operational constraints:** The intermittent nature of RE sources complicates supply-demand matching and frequency regulation, crucial for system stability.
- **Stability issues:** Voltage fluctuations from rapid changes in generation can affect electricity quality, risking blackouts or loadshedding.
- **Regulatory challenges:** A complex regulatory environment may impede RE integration and compliance with grid codes.

To overcome these challenges and maximise the benefits of RE, South Africa should:

- Invest in grid infrastructure
- Implement smart grid technologies
- Promote energy storage
- Reform regulatory frameworks to facilitate integration and competition in the electricity market.

7.1.2 Improved grid reliability

GH_2 has the potential to revolutionise power system operations by enhancing grid stability, reliability, and flexibility. It serves as both an energy carrier and a storage solution, helping address challenges posed by intermittent RE sources. GH_2 contributes to various aspects of grid management, including frequency regulation, demand response, and voltage support, ensuring a seamless and efficient energy supply.

- **Frequency regulation**

  GH_2 plays a crucial role in frequency regulation by helping balance the supply and demand of electricity in real time. Electrolysers, which produce hydrogen by splitting water using electricity, can adjust their power consumption quickly to stabilise grid frequency. During periods of excess RE generation, electrolysers can ramp up, absorbing surplus electricity and preventing frequency deviations. Conversely, during a power shortage, hydrogen stored earlier can be converted back into electricity using fuel cells, ensuring a steady supply. This flexibility in operation enables GH_2 to contribute significantly to grid stability and frequency management.

- **Demand response**

  GH_2 enables effective demand response mechanisms by acting as a flexible load that can manage and mitigate peak electricity demands. Electrolysers can operate during off-peak hours or when renewable generation is high, reducing stress on the grid. Additionally, industries and power plants using hydrogen as a fuel source can shift their consumption patterns based on grid needs, helping avoid blackouts and optimise energy usage. By aligning energy consumption with supply availability, GH_2 improves the efficiency and reliability of the overall energy system.

- **Voltage support**

  Voltage support is another critical area where GH_2 contributes to grid operations. Electrolysers and hydrogen fuel cells can be integrated with advanced power electronics to provide reactive power control, stabilising voltage fluctuations in the grid. Furthermore, GH_2 systems equipped with fault ride-through capabilities can remain operational during disturbances, ensuring continuity in power delivery. This support strengthens grid infrastructure and facilitates the smooth integration of RE sources, ultimately improving the resilience and sustainability of power systems.

- **Blackstart (grid restoration)**

  GH_2 can provide essential support for grid restoration during blackouts, a process known as blackstart. Hydrogen-powered generators or fuel cells, which operate independently of the grid, can supply the initial power needed to restart other generators and gradually restore grid operations. This capability is especially valuable in systems with high RE penetration, where traditional fossil-fuel-based blackstart solutions are less feasible. By enabling a faster and cleaner recovery from grid outages, GH_2 contributes to overall system resilience and reliability.

- **RE integration**

  GH_2 facilities facilitate the seamless integration of RE by absorbing excess power during periods of high solar or wind generation, which would otherwise be curtailed. Electrolysers convert this surplus electricity into hydrogen, allowing RE to be stored and utilised later. This reduces power curtailment, optimises the utilisation of renewable resources, and minimises waste, ultimately enhancing the stability and efficiency of the energy system. By acting as a flexible load, GH_2 facilities also help balance fluctuations in RE supply.

7.1.3 Energy storage

GH_2 storage enhances grid stability by providing a flexible energy buffer. When RE production exceeds immediate demand, this excess electricity can be diverted to produce GH_2, which can be stored for future use. When renewable generation is low or when demand spikes, hydrogen can be converted back into electricity using fuel cells or combustion turbines, feeding it back into the grid. This flexibility helps balance supply and demand, reducing the need for fossil fuel-based power generation, which is often deployed during periods of high demand or low renewable generation. In this way, hydrogen acts as a stabilising force in the grid, supporting energy security by filling gaps in generation.

Moreover, large-scale hydrogen storage can help mitigate the risk of energy shortages by creating a reserve of stored energy that can be accessed when needed. The ability to store GH_2 for months ensures that energy is available during seasonal fluctuations in RE production. This seasonal storage capability is a key factor in enhancing energy security and reducing reliance on fossil fuel imports or backup fossil power plants, which can be vulnerable to price volatility or supply disruptions.

GH_2's role in energy security extends beyond electricity generation. Hydrogen can be used as a fuel for various sectors, including transport and heavy industry, which are difficult to electrify. In these areas, hydrogen can provide a stable and high-energy-density solution. For instance, in transport, hydrogen-powered vehicles, trucks, buses, and trains offer an alternative to fossil-fuelled options, helping to reduce energy dependence on oil and gas imports. Similarly, hydrogen can be used in industrial processes, such as steel manufacturing and chemical production, where electricity alone may not be sufficient to meet energy demands.

GH_2 storage contributes to long-term energy security by enabling the transition to a low-carbon economy, while maintaining reliability and resilience. As nations, including South Africa, continue to diversify their energy mix and reduce dependency on fossil fuels, the role of GH_2 will become increasingly central. Storage infrastructure for GH_2 not only ensures that RE can be effectively harnessed and stored but also facilitates the continued operation of key sectors during periods of low renewable output or grid instability.

In the context of South Africa's energy landscape, where coal still plays a dominant role in electricity generation, GH_2 offers a pathway toward reducing fossil fuel consumption and minimising GHG emissions. By investing in hydrogen storage technologies, South Africa can create a more self-sufficient and resilient energy system, less susceptible to energy shortages or supply disruptions caused by external factors.

7.1.4 Additional/improved energy infrastructure

Due to the fact that the scale of renewable electricity required for GH_2 production is substantial, the current electricity grid in South Africa lacks the capacity to accommodate this influx without significant upgrades. As a result, GH_2 project developers will need to either build their own dedicated grid infrastructure or upgrade the existing public electricity grid to ensure it can handle the additional load and support the smooth operation of GH_2 production systems.

The construction or upgrade of infrastructure to support GH_2 projects directly contributes to energy security in several important ways. One key benefit is enhanced grid resilience. By building or upgrading grid infrastructure, GH_2 projects can ensure that there is sufficient transmission and distribution capacity to transport additional renewable electricity to the necessary locations. This makes the grid more capable of managing and balancing supply and demand, ensuring a reliable and stable energy supply even as RE generation fluctuates.

Furthermore, the development of new grid infrastructure to support GH_2 production can also stimulate economic growth and job creation. The construction of new transmission lines, energy storage systems, and hydrogen transport infrastructure will require significant investment and a skilled workforce in fields such as construction, engineering, manufacturing, and technical services. This not only strengthens the country's economic resilience but also creates new industrial opportunities within the green energy sector, fostering local job creation and innovation.

7.1.5 Cost reduction thanks to economies of scale

The increase in production volumes of RE components to support GH_2 production brings substantial benefits through economies of scale, significantly enhancing the resilience and affordability of energy systems. As production scales up, manufacturers can achieve efficiencies through bulk production, optimised processes, and streamlined supply chains. This scaling effect reduces per-unit manufacturing costs for essential components like solar panels, wind turbines, and batteries. The resulting cost savings are often passed down to consumers, making RE technologies more affordable and accessible. This affordability widens the adoption of RE solutions, promoting their integration into diverse applications and fostering a more sustainable energy ecosystem.

Moreover, economies of scale improve the financial viability of RE and GH_2 projects by lowering upfront investment costs and enhancing the competitiveness of green technologies compared to fossil fuels. This shift reduces reliance on traditional energy sources, bolstering energy security through diversified and sustainable energy supplies. The reduced costs and broader accessibility also encourage accelerated deployment of RE infrastructure, creating a stable, cost-effective energy system capable of supporting growing energy demands while mitigating risks associated with price volatility and supply disruptions in conventional energy markets.

7.2 Negative effects of GH_2/PtX economy on energy security

While GH_2 and PtX projects bring promising opportunities, they also pose challenges that could strain South Africa's electricity system and have unintended socio-economic consequences. Issues such as increased grid pressure, potential energy deficits, and environmental impacts from infrastructure expansion must be carefully managed to ensure these projects do not undermine the reliability and affordability of electricity for other users.

7.2.1 Diverting electricity from the grid

If GH_2/PtX projects fail to adhere to the **additionality and temporal correlation principles,** these projects could divert existing RE from the grid, causing energy shortages for other consumers and delaying the decarbonisation of other sectors.

To prevent GH_2 projects from diverting electricity intended for other consumers, the following measures should be implemented:

- **Enforce the additionality and temporal correlation principles:** Government should set strict regulations ensuring that GH_2 projects are required to increase RE generation rather than drawing from existing capacity. This can be ensured through certification mechanisms or mandatory RE procurement targets for these projects.
- **Energy storage and backup systems:** GH_2 projects can integrate energy storage systems (like batteries and GH_2/fuel cells) to ensure that excess renewable power generated during peak production times can be stored and used during downtimes or when grid power is needed. This reduces reliance on grid power during low-renewable generation periods.
- **Flexible grid integration:** establishing flexible grid mechanisms that allow GH_2 facilities to scale their demand up or down in response to grid availability could help reduce competition for power during periods of energy shortage.

7.2.2 Grid strain

As highlighted earlier, GH_2/PtX facilities have **high electricity demand,** particularly for electrolysis processes, which may put pressure on existing transmission infrastructure, especially during peak demand periods. This can lead to problems such as **voltage instability, frequency imbalances,** and even **loadshedding**, all of which reduce grid reliability and compromise energy security for regular consumers.

Solutions to address grid strain include, but are not limited to:

- **Investment in grid infrastructure** is crucial to accommodate the growing demand from GH_2 facilities. This could include building new transmission lines, substations, and improving grid management technologies to handle fluctuations in power demand.
- **Implement demand-response systems** that allow GH_2 facilities to reduce their energy consumption during peak periods, thereby preventing grid overloads and stabilising the system. These programmes can help balance supply and demand more effectively.
- **Promoting decentralised RE solutions** like localised solar or wind projects for GH_2 facilities could reduce pressure on the central grid by generating power directly at the point of use, thus alleviating grid congestion.

7.2.3 Short-term price hikes

The anticipated large-scale expansion of GH_2 production is expected to drive a significant increase in the demand for RE equipment and components (e.g., solar panels, wind turbines, transformers, batteries), which may result in short-term price increases. This may make renewable electricity less affordable for smaller consumers and slow down the adoption of RE technologies. To address potential price increases associated with the rising demand for RE components, various measures can be implemented. These include:

- **Enhancing manufacturing capacity:** Government and private sector players should invest in scaling up production to meet growing requirements. Establishing local manufacturing facilities will reduce dependency on global supply chains, which are prone to disruptions. Additionally, providing subsidies or tax incentives to companies that expand their production capacity for critical RE equipment can significantly boost supply and stabilise costs.
- **Diversifying supply chains:** By exploring alternative suppliers and sourcing locations, the risks of bottlenecks can be mitigated. Strategic partnerships with countries that possess abundant raw materials can ensure a steady flow of resources. Such partnerships should prioritise sustainable mining practices to safeguard the environment while supporting long-term resource availability for the RE sector.
- **Promoting recycling and fostering a circular economy to reduce reliance on virgin materials:** Investments in advanced recycling technologies can recover valuable components from outdated RE equipment, such as decommissioned wind turbines or lithium-ion batteries. Governments can further encourage this shift by implementing policies that mandate or incentivise recycling initiatives within the RE sector, making it a core part of the supply chain.
- **Regulating market practices:** To prevent artificial price inflation. Government should implement measures to curb speculative practices or price gouging, especially during periods of heightened demand. Transparent pricing mechanisms and competitive markets should be promoted to keep costs manageable and fair for all stakeholders.

7.2.4 Potential tariff increase

The substantial investment needed to expand and upgrade grid infrastructure to support GH_2/PtX facilities may result in higher electricity tariffs. Such increases could reduce the affordability of electricity, particularly for low-income households, potentially undermining the socio-economic benefits associated with RE adoption.

To mitigate this issue, several preventive measures can be implemented, e.g.,:

- **Public–Private Partnerships (PPPs):** Government can collaborate with private companies to share the costs of grid expansion and infrastructure development. These partnerships can ease the financial burden on taxpayers while ensuring that the grid is upgraded effectively and efficiently.
- **Cost recovery mechanisms:** Establishing fair cost-recovery mechanisms, such as allowing gradual price adjustments or offering subsidies for vulnerable populations, can prevent price hikes from disproportionately affecting low-income consumers.
- **Efficient project management:** Investing in project management practices that focus on cost control and efficiency, including the use of advanced technologies and project monitoring systems, can help minimise unnecessary cost overruns in grid expansion projects.

7.3 Net effects of GH_2/PtX economy on energy security

Despite some challenges associated with integrating a GH_2 economy into South Africa's energy landscape, the benefits far outweigh the drawbacks, offering substantial net positive effects. GH_2 has the potential to revolutionise the nation's energy system and reduce reliance on fossil fuels and foster greater energy independence. It can provide a cleaner, more sustainable energy supply while addressing the intermittency of renewables through efficient storage solutions, ensuring a stable and resilient energy system. Beyond enabling a cleaner energy future, the economic advantages of GH_2 are transformative. The industry is poised to create thousands of jobs across its value chain, from RE generation to hydrogen production and export. By diversifying the economy, GH_2 positions South Africa among the global leaders in GH_2, attracting both national and international investments as well as fostering regional collaboration with neighbouring countries. GH_2's dual impact on energy security and environmental sustainability underscores its transformative potential for South Africa's long-term development. By reducing dependence on volatile global energy markets and aligning with global decarbonisation trends, GH_2 ensures a stable energy future while advancing the country's climate goals. This makes it a cornerstone of South Africa's transition to a low-carbon, inclusive economy.

Chapter 8

Recommendations for enhancing GH_2/PtX benefits of energy security

8. Recommendations for enhancing GH_2/PtX benefits of energy security

GH_2 and PtX technologies have the potential to transform South Africa's energy sector by improving energy security, promoting sustainability, and fostering economic growth. However, realising this potential requires a coordinated approach to policy, regulation, and institutional capacity. This chapter outlines key enablers for integrating GH_2/PtX into South Africa's energy system, focusing on governance, coordination, and harmonising energy planning. It also covers establishing a power balancing market, creating clear requirements for GH^2/PtX projects to access infrastructure, and forming a cross-sectoral regulators forum. Additionally, it highlights the need for a national infrastructure study and strengthening stakeholder capacity, all aimed at aligning GH_2/PtX initiatives with national energy security goals for a sustainable future.

8.1 Enhance the governance and coordination of the GH_2/PtX sector

Hydrogen's interdisciplinary and cross-sectoral nature involves multiple sectors, with its varied supply and value chain segments extending beyond the jurisdiction of any single institution. This complexity challenges comprehensive oversight by a single entity and underscores the need for effective collaboration, strong coordination, and an integrated governance framework among stakeholders to establish a robust hydrogen economy. Following the finalisation of the implementation roadmap for the JET Investment Plan and the GHCS, the IDC is establishing the "Green Hydrogen Just Energy Transition Secretariat". This Secretariat, that is expected to be fully operational by early 2025, will serve as a central point of coordination for public and private GH_2 initiatives (Engineering News, 2024).

The Secretariat will coordinate essential activities for developing South Africa's GH_2 industry, including advocacy in standard-setting, creating frameworks to secure initial offtake agreements critical for project financing, and supporting technology incubation, skills development, infrastructure planning, policy formulation, and community engagement. The establishment of the Secretariat can draw valuable lessons from international models, such as Germany's State Secretaries' Committee on Hydrogen, the structure of which is illustrated in the figure below.

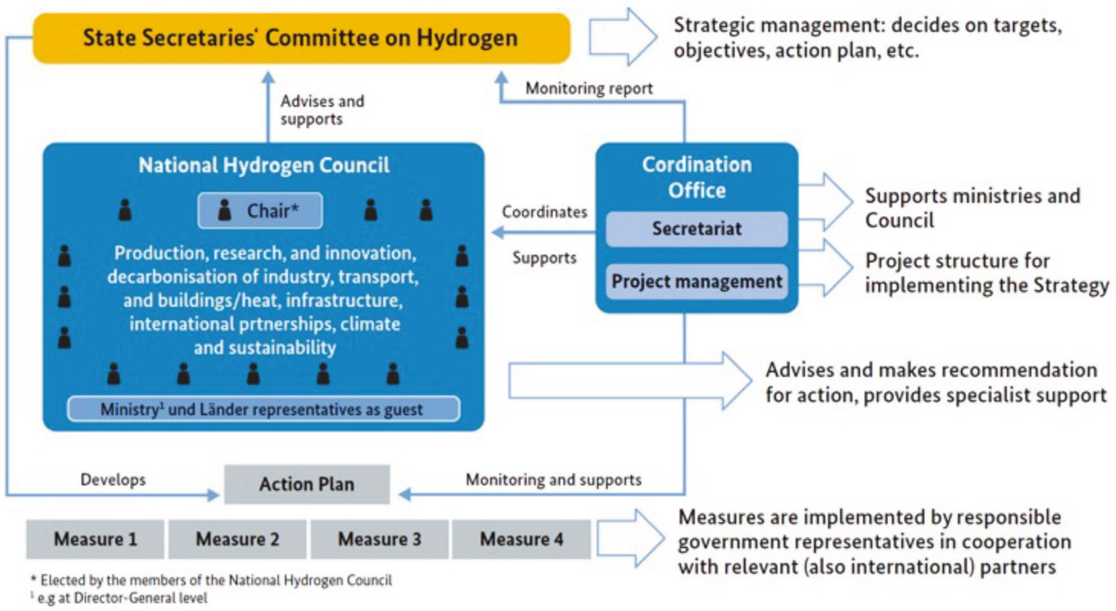

Figure 13: Governance structure of the National Hydrogen Strategy

Source: BMWK (2020, p. 14)

As the figure indicates, Germany's GH_2 governance framework incorporates a structured yet flexible approach, ensuring effective collaboration among key stakeholders. The committee is supported by a high-level advisory body, the National Hydrogen Council, which includes experts from the private sector, academia, and civil society. This integrated structure provides a robust mechanism for coordinating policy, fostering innovation, and addressing cross-cutting issues.

This structure provides valuable input for the establishment of South Africa's "GH_2 JET Secretariat" by adapting and customising the model to suit the local context.

8.2 Harmonise national energy planning documents

South Africa's national planning documents, such as the IRP, HSRM, GHCS, NDC, and others like Energy Action Plan (EAP) and JET serve as crucial pillars in the country's transition to a more sustainable and secure energy future. These documents show significant misalignment that needs urgent harmonisation to optimise their effectiveness and ensure a coherent energy strategy. Currently, the documents operate in silos, with overlapping objectives and priorities that lack seamless integration.

Key discrepancies include:

- **Coal dependency and decarbonisation goals:** The IRP continues to prioritise coal for energy security, delaying decommissioning and even extending lifespans of aging plants, which contradicts the JET and NDC objectives of reducing carbon emissions in line with international commitments. This mismatch undermines South Africa's climate commitments and the pathway to a RE-based economy.
- **RE targets:** The IRP's targets for RE deployment lag behind what is proposed in other frameworks such as the JET and GHCS, which advocate for accelerated investment in RE and GH_2 to meet decarbonisation targets.
- **Implementation and financial viability:** The HSRM and GHCS propose ambitious hydrogen production and export plans, yet these are not fully integrated into the IRP's infrastructure planning. This disconnect raises concerns about the availability of adequate RE to support these projects, considering grid stability issues and Eskom's current challenges.
- **Ambiguity in GH_2 integration:** The integration of GH_2 into South Africa's broader energy system, as outlined in the HSRM and GHCS, relies heavily on substantial RE inputs. However, the IRP's silence on expanding RE capacity for GH_2 projects could hinder the realisation of hydrogen economy goals.

To effectively address the nation's energy challenges, it is essential to harmonise these national frameworks. By aligning relevant planning documents, South Africa can create a more coherent policy environment that ensures synergies between RE targets, GH_2 initiatives, and broader energy security goals. Harmonisation would streamline decision-making, optimise resource allocation, and create a unified approach to attracting investment. Furthermore, it would enable South Africa to maximise its RE potential and achieve its ambitious decarbonisation and job creation targets more efficiently.

Key areas of harmonisation:

- **Shared vision and goals:**
  - Alignment of long-term goals in all documents, such as achieving a low-carbon economy by a specific date.
  - Consistent policy objectives across all documents, including energy security, affordability, and sustainability.

- **Clear roles and responsibilities:**
  - Define clear roles and responsibilities for different government departments and agencies involved in energy planning and implementation.
  - Establish effective mechanisms for stakeholder engagement and consultation to ensure buy-in and support for the energy transition.

- **Integrated planning framework:**
  - Integrate cross-cutting considerations of climate change mitigation, air quality, and water resource management into all energy planning documents.
  - Utilise scenario analysis to assess the potential impacts of different policy choices and technological advancements.

- **Monitoring and evaluation:**
  - Establish a robust monitoring and evaluation system to track progress towards energy goals and identify areas for improvement.
  - Regularly review and update energy planning documents to adapt to changing circumstances and emerging technologies.

Specific considerations for GH_2/PtX integration:

- **Alignment with IRP:** Ensure that GH_2/PtX projects are aligned with the long-term electricity generation mix outlined in the IRP.

- **Integration with EAP:** Identify specific actions and timelines for implementing GH_2/PtX projects within the framework of the EAP.

- **Coordination with HSRM and GHCS:** Coordinate with the HSRM and GHCS to ensure a coherent approach to hydrogen development.

- **Alignment with NDC:** Ensure that GH_2/PtX projects contribute to South Africa's NDC and climate change mitigation goals.

- **Just Energy Transition Plan:** Consider the social and economic implications of the energy transition, particularly for affected communities and workers in the fossil fuel industry. Ensure that GH_2/PtX projects contribute to a just and equitable transition.

8.3 Develop a comprehensive GH_2/PtX production and use guideline

A dedicated and detailed guideline for GH_2/PtX production in South Africa is essential for establishing a structured framework that fosters GH_2/PtX investments, that in return, support the country's energy security. This guideline would provide regulatory clarity and consistency, ensuring a predictable and equitable environment for investors, developers, and users of GH_2 and PtX. By focusing on sustainability criteria, statutory requirements, industry standards, and a robust monitoring mechanism, the guideline would enable effective oversight of projects at various stages while promoting alignment with South Africa's broader energy transition goals. Moreover, the guideline would contribute to enhancing energy security by leveraging GH_2 as a versatile energy carrier, diversifying the energy mix, and reducing reliance on fossil fuels.

The guideline should address GH_2/PtX-related critical elements to facilitate seamless project development, including:

- **Electricity source** in alignment supply with the IRP and other national RE plans.
- Water sourcing specifying sustainable procurement methods, such as desalination, groundwater, or wastewater reuse, alongside licensing, permitting, and authorisation requirements.
- **Land use:** outlining land acquisition requirement and land approval processes.
- **Community engagement** highlighting obligations for inclusive stakeholder engagement to ensure local socio-economic benefits and address concerns effectively.
- **Health and safety standards** providing guidance on national regulations and international best practices for the safe production, storage, and transportation of hydrogen.
- **Project registration** clarifying regulatory steps for registering GH_2/PtX projects with relevant authorities.
- **Local content** emphasising South African-made technologies and materials to bolster industrial growth.
- **Incentives and financing** highlight tax incentives, grants, and green financing options to attract investment.
- **Timelines** defining statutory timelines for each project phase, from feasibility to commissioning, ensuring transparency and predictability.

By providing clarity and guidance on these critical elements, the GH_2/PtX guideline will support the sustainable expansion of South Africa's GH_2 sector, strengthening its role as a global leader while enhancing energy security through renewable and locally produced energy solutions. The GH_2/PtX guideline should incorporate and build upon existing knowledge developed under various initiatives such as the H2.SA programme.

Key resources to be integrated include:

- **A practical guide to developing sustainable green H_2/PtX projects in South Africa** that outlines key development phases for large-scale GH_2/PtX initiatives, including essential techno-economic and environmental studies, as well as permitting, licensing and authorisation requirements.
- **Managing the impacts of a H_2/PtX economy: An Environmental Impact Assessment (EIA) Guideline** that addresses common environmental challenges encountered during the GH_2/PtX environmental authorisation process and provides recommendations for effectively mitigating and managing these impacts.
- **Community development toolkit for GH_2 project developers** that offers accessible, inclusive, and practical guidance for GH_2 project developers. It details the actions needed, their importance, and the appropriate timing and methods for engaging in community development.

8.4 Establish a power balancing market mechanism

Balancing electricity markets ensure the stability and reliability of both electricity supply and grid stability by matching electricity generation with real-time demand. Electrolysis systems, used in GH_2 production, are well-suited for these markets due to their operational flexibility. They can ramp up hydrogen production during periods of high RE production and scale down when energy is scarce, helping to stabilise the grid. Typically, RE plants supplying GH_2 facilities are oversized to maximise GH_2 production efficiency, which results into 20–40% excess energy beyond electrolyser consumption; and without mechanisms to utilise this surplus, the energy is curtailed, increasing the LCOH by 10–20% (The Presidency, 2023).

Allowing GH_2 producers to sell surplus energy in balancing markets could reduce energy waste, improve the financial viability of hydrogen projects, and contribute to grid stability, particularly strengthening energy security. As outlined in Chapter 6, several countries, including Germany, the USA, the UK, and Australia, have incorporated GH_2 into their energy security strategies. These nations have developed regulatory frameworks that allow GH_2 producers to contribute to power balancing markets. This includes selling surplus electricity to wholesale markets, participating in demand response programmes (such as reducing consumption during grid stress), and providing ancillary services like reserve and frequency regulation to stabilise the grid.

These examples underscore the potential of GH_2/PtX producers to contribute both to hydrogen production and grid stability by participating in balancing markets globally. Aligning with South Africa's Just Energy Transition (JET) programme, the country could adopt international practices for GH_2/PtX market participation to stabilise its grid, address loadshedding, and integrate RE effectively. By enabling GH_2 producers to participate in balancing markets, South Africa could advance toward a cleaner, more resilient energy system.

8.5 Develop a clear guide outlining the requirements for GH_2/PtX projects to access and utilise electricity infrastructure

While electricity wheeling offers a promising mechanism to foster the GH_2 economy with significant benefits for energy security, the lack of a transparent and standardised framework for one-to-one wheeling arrangements impedes progress. The current system, reliant on case-by-case negotiations between Eskom, IPPs, and municipalities, is riddled with challenges. Ambiguities in tariff structures create uncertainty for IPPs and their clients, discouraging investment and delaying project timelines. Furthermore, fragmented agreements, especially when electricity must traverse both the Eskom and municipal grids, add administrative burdens and delays. These inefficiencies extend negotiation times, hindering the integration of private-sector electricity into the grid.

To maximise the potential of wheeling, South Africa urgently needs a transparent, standardised framework for one-to-one wheeling arrangements. Such a framework would:

- **Simplify costs and procedures:** Clear and predictable guidelines for wheeling tariffs and contracting would reduce the time and effort required for IPPs to negotiate terms, enabling faster project rollout.
- **Promote fair access:** A standardised approach would ensure fairness and transparency in how IPPs access and utilise electricity infrastructure, fostering trust among stakeholders.
- **Facilitate private sector participation:** By providing certainty, a streamlined framework would attract more private-sector investment, accelerating energy generation and distribution projects.

The development of a transparent and streamlined wheeling framework is essential to unlocking South Africa's RE potential, particularly in promoting GH_2 production. By simplifying the regulatory processes and establishing clear guidelines for electricity wheeling, South Africa can attract more private-sector investment, accelerate energy generation projects, and enhance the integration of RE into the national grid. This will not only drive the growth of the GH_2 industry but also address critical energy security challenges, including reducing reliance on fossil fuels and mitigating the effects of power shortages and loadshedding. A well-structured framework will foster a more resilient, efficient, and sustainable energy system, positioning South Africa as a leader in the global clean energy transition.

8.6 Establish a focused GH_2/PtX value chain regulators forum with representation from all relevant regulatory areas

A focused GH_2/PtX Value Chain Regulators Forum can play a transformative role in bolstering South Africa's energy security by ensuring streamlined regulation, fostering collaboration, and aligning with international best practices and standards. The Forum's key contributions to energy security include:

- **Facilitating infrastructure development:** The forum's collaborative approach to regulation will streamline the development of critical infrastructure, including hydrogen production facilities, pipelines, storage systems, and RE plants. Through regular dialogue and targeted discussions, regulatory bottlenecks that often delay project implementation will be resolved efficiently. This will ensure that infrastructure projects align with South Africa's energy demands, reinforcing grid stability and supporting the nation's broader energy transition objectives.

- **Supporting RE integration:** By enabling clear and efficient permitting and licensing processes for RE projects, the forum will accelerate the establishment of RE plants dedicated to hydrogen production. This will accelerate the integration of RE into the energy system, providing a stable energy output through hydrogen as a flexible energy storage and generation medium.

- **Enhancing resilience to energy price volatility:** A robust GH_2 sector offers a diversified energy mix, reducing South Africa's vulnerability to external energy shocks such as fluctuating global oil prices or supply disruptions. The forum's efforts to ensure alignment with international standards will also bolster export opportunities, providing South Africa with an additional revenue stream that enhances economic and energy resilience.

- **Optimising grid stability:** The integration of hydrogen technologies into the energy mix can play a crucial role in stabilising the electricity grid. Hydrogen production facilities can act as flexible loads, absorbing excess electricity during periods of low demand and releasing it when needed.

- **Promoting sustainable resource management:** By bringing together regulators across environmental, safety, and resource management sectors, the forum will ensure that GH_2/PtX projects adhere to sustainable practices. This will not only protect local ecosystems but also strengthen public trust in the sector, which is essential for long-term energy stability.

- **Capacity building for effective oversight:** By serving as a platform for knowledge sharing and training, the forum will empower regulators to better understand and address the complexities of the GH_2 value chain. Well-informed and capable regulators will minimise inefficiencies, avoid unnecessary delays, and ensure that projects comply with both national and international standards.

- **Driving policy alignment and accountability:** The forum will coordinate and harmonise efforts among various regulatory bodies, including NERSA, the Ports Regulator, DMPR, and the DoEE. This alignment would ensure that policies governing hydrogen and related energy sectors are cohesive and supportive of national energy security objectives. Additionally, by publishing guidelines and tracking progress, the forum will maintain transparency and accountability.

- **Enhancing competitiveness:** The global hydrogen economy is evolving rapidly, with countries establishing strict certification standards for GH_2 imports. By actively engaging with international certification and standardisation processes, the forum will ensure that South African GH_2 products meet these criteria.

8.7 Perform a national-wide study on the GH_2/PtX industry to inform the development of essential public and private infrastructure

One of the key steps to ensure sustainable development of a GH_2 economy is identifying relevant infrastructure needs, including the locations of GH_2/PtX facilities and their dedicated RE power plants, their capacities, anticipated commissioning dates, and other critical details. A national study is therefore necessary to map these elements and guide the planning and development of effective public and private infrastructure. It will also play an integral role in enhancing South Africa's energy security by aligning energy generation and hydrogen production with grid requirements.

The study will help integrate GH_2 production within South Africa's energy system, aligning with the IRP and RE objectives. Identifying regions with high RE potential for GH_2 facilities will enable the optimisation of energy production, mitigate grid instability caused by renewable intermittency, and ensure a secure, sustainable energy future. By strategically aligning GH_2 projects with grid infrastructure, this study will strengthen energy resilience, reduce vulnerability to external energy shocks, and support South Africa's long-term decarbonisation and energy security goals.

Several studies can contribute to this research, including the "South African Green Hydrogen Potentials Atlas" developed as part of the H2.SA programme. This atlas is the result of a multi-criteria analysis that examined key siting variables, highlighting both 'push' and 'pull' factors, such as environmental conditions and sensitivities, land use and stakeholders, and the specific requirements for GH_2/PtX production.

Key objectives of the suggested study would be:

- **Mapping locations for GH_2/PtX facilities and RE plants:** Identifying the sites of existing and potential future GH_2 demand centres, production facilities, and dedicated RE plants. Areas such as the Northern Cape for solar energy and the Western Cape for wind energy hold significant potential for large-scale GH_2 facilities. This mapping should consider proximity to existing and future electricity grid infrastructure to ensure seamless integration of RE into hydrogen production.
- **Estimating capacities and anticipated commissioning timelines:** The study would estimate the required capacities for both GH_2 production and RE plants, considering demand forecasts and export opportunities. Understanding the scaling of GH_2/PtX facilities will enable South Africa to plan for necessary infrastructure upgrades, ensuring the power grid can accommodate increased RE generation and GH_2 production in parallel.
- **Assessing infrastructure requirements:** GH_2/PtX projects require substantial infrastructure, including transmission lines, storage facilities, and hydrogen distribution networks. The study would assess current infrastructure capacities,

identify bottlenecks, and propose necessary upgrades. This will ensure the development of infrastructure to support the expanding GH_2 sector and guide strategic public and private investment.

- **Improving grid integration:** The study would evaluate how GH_2/PtX projects can integrate with South Africa's energy grid. This includes assessing RE storage options, how excess electricity can be directed into hydrogen production during off-peak periods, and how infrastructure can respond to fluctuations in energy demand and hydrogen production. Effective integration will help stabilise the grid, particularly amid South Africa's current energy challenges.
- **Public and private infrastructure investment:** A critical component of the study will be identifying opportunities for PPPs in developing infrastructure for both GH_2/PtX projects and the national power supply as a whole. Promoting collaboration between government bodies, state-owned enterprises like Eskom, and private sector stakeholders will drive investment in the required infrastructure while ensuring that public resources are used effectively.

8.8 Strengthen the capacity of key stakeholders

As previously highlighted, the development of the GH_2 industry in South Africa requires a collaborative effort from a wide range of stakeholders across multiple sectors. Many of these stakeholders are responsible for creating and enforcing policy and regulatory frameworks, as well as issuing the necessary permits, authorisations, and licenses. For them to effectively perform these roles, they must possess substantial expertise in their respective areas of responsibility. This knowledge is essential for ensuring that projects are executed efficiently, minimising delays, and supporting the sustainable growth of the GH_2 industry.

By investing in stakeholder capacity building and fostering collaboration across sectors, South Africa can create a more integrated, resilient, and sustainable energy system that not only supports the GH_2 economy but also enhances energy security in various ways, including:

- **Improved coordination for effective grid integration:** Properly trained stakeholders can facilitate the integration of GH_2 into South Africa's existing energy grid, helping to manage RE intermittency and improve grid stability. By ensuring the alignment of GH_2 projects with RE production and grid requirements, the country can avoid the grid instability that is often caused by the fluctuating availability of RE sources.

- **Optimised infrastructure development:** A better-trained stakeholder landscape will help to identify infrastructure needs more effectively, allowing for strategic investment in energy storage systems, power transmission lines, and hydrogen production facilities. These infrastructure improvements will increase the resilience of South Africa's energy system, making it more capable of handling fluctuating energy demand and reducing reliance on fossil fuels.
- **Increased investor confidence:** As stakeholders become more capable in managing GH_2 projects, the country will see a more attractive investment climate for both local and international investors. Clearer regulatory frameworks and faster approvals will encourage greater private sector involvement in hydrogen and RE projects, which in turn will reduce energy import dependency and contribute to a more sustainable energy future for South Africa.

Chapter 9

Required infrastructure to maximise GH_2/PtX benefits for energy security

9. Required infrastructure to maximise GH_2/PtX benefits for energy security

One of the key challenges in integrating GH_2 into the existing energy system is the need for significant investments in new infrastructure. While some hydrogen-related activities can leverage existing grid infrastructure, dedicated infrastructure offers distinct advantages such as enhanced efficiency, scalability, and safety. However, integrating GH_2 into current electricity infrastructure also has merits, including the ability to utilise existing assets, improve interoperability, and create synergies.

The choice between adopting dedicated or integrated electricity infrastructure for GH_2 depends on various factors, such as regional needs, the availability of existing infrastructure, and economic and environmental goals. In many cases, a hybrid approach may be the most effective strategy to maximise GH_2's benefits while addressing its challenges.

9.1 Existing infrastructure and its constraints

9.1.1 Electricity infrastructure and its constraints

Total capacity:

Approximately 52,000 MW

Current utilisation:

The exact utilisation level fluctuates, but it's generally high due to the country's increasing demand for electricity.

Remaining capacity:

The remaining capacity is limited and varies depending on factors like maintenance schedules, plant performance, and demand fluctuations.

South Africa's electricity grid, primarily managed by Eskom, faces significant constraints that impact the potential for PtX production.

Grid constraints:

- **Aging infrastructure:** Much of the grid infrastructure is outdated, leading to frequent breakdowns and power outages.
- **Capacity shortages:** The grid often lacks the capacity to accommodate additional renewable energy sources, particularly during peak demand periods.
- **Transmission and distribution challenges:** Inefficient transmission and distribution networks contribute to energy losses and hinder the integration of renewable energy.
- **Financial constraints:** Eskom's financial difficulties have limited investments in grid upgrades and maintenance
- **Grid integration:** The intermittent nature of renewable energy sources, a key input for PtX, can strain the grid, requiring advanced grid management systems and energy storage solutions.

The electricity infrastructure in South Africa faces several challenges, including aging infrastructure, a lack of investment, and growing demand.

Transmission Capacity:

- **Eskom:** The primary transmission system operator in South Africa, Eskom, manages a vast network of transmission lines spanning over 28,000 kilometres. However, this infrastructure is aging and requires significant investment to maintain reliability and accommodate future growth.
- **Grid constraints:** The existing grid faces constraints in certain areas, particularly in the Eastern Cape, Western Cape and Northern Cape provinces, where RE projects are concentrated. This limits the ability to evacuate power from these regions to load centres.
- **Transmission expansion:** Eskom has identified several transmission-expansion projects to address these constraints and facilitate the integration of RE. However, these projects require substantial funding and face various regulatory and environmental hurdles.

Overall, South Africa's electricity infrastructure faces significant challenges in terms of transmission and storage capacity. Addressing these challenges will be crucial for ensuring a reliable and sustainable power supply for the country.

9.1.2 Fuel infrastructure and its constraints

South Africa's energy landscape is predominantly reliant on coal, but it is increasingly turning to natural gas as a cleaner alternative. The country has a well-established network for the transmission of liquid fuels, primarily petroleum products. However, the gas infrastructure network is still developing.

The liquid fuel transmission infrastructure consists of:

- **Pipeline network**: South Africa has a robust network of pipelines to transport refined petroleum products, including gasoline, diesel, and jet fuel, from refineries to major consumption centres.
- **Rail and road transport**: While pipelines are the primary mode of transportation for liquid fuels, rail and road networks also play a significant role, especially for shorter distances and smaller volumes.
- **Maritime transport:** South Africa's strategic coastal location allows for efficient import and export of liquid fuels through its major ports, such as Durban, Cape Town, and Richards Bay.

The gas transmission infrastructure consists of:

- **Limited pipeline network:** South Africa's natural gas infrastructure is relatively limited compared to its liquid fuel infrastructure. The primary source of natural gas is the gas produced by Sasol's synfuels operations in Secunda. This gas is transported through a pipeline network to various industrial and power generation facilities.
- **LNG import terminals**: To diversify its gas supply, South Africa is exploring the development of LNG import terminals. The government has selected a consortium to develop an LNG import terminal at the Port of Richard's Bay.
- **Gas-to-Liquids (GTL) plants:** South Africa has GTL plants that convert natural gas into liquid fuels, such as diesel and gasoline. These plants are connected to the existing liquid fuel pipeline network.

Key considerations related to the challenges and future outlook include:

- **Infrastructure investment:** Significant investment is needed to expand and modernise the country's fuels and gas infrastructure, particularly in the areas of pipeline networks and storage facilities.
- **Regulatory framework:** A clear and supportive regulatory framework is essential to attract investment and streamline the development of fuel and gas infrastructure projects.
- **Environmental considerations:** Balancing the development of infrastructure with environmental concerns is a key challenge.

Integrating fuel infrastructure in South Africa into the GH/PtX infrastructure will be a complex but crucial undertaking. Key integration challenges will include:

1. Adapting existing facilities:

- Storage: modifying existing storage facilities to handle hydrogen, which requires specific pressure and temperature conditions, and potentially other PtX products.
- Transportation: upgrading pipelines and tankers to transport hydrogen and other gases or PtX products safely and efficiently.

2. New infrastructure development:

- Conversion plants: establishing facilities to convert hydrogen into various products like synthetic fuels, chemicals, and materials.

3. Safety and regulatory framework:

- Developing robust safety standards and regulations for handling hydrogen and other emerging fuels.

9.2 Power grid access procedures

Integrating electricity from GH_2/PtX producers into the Eskom grid is a complex process that requires careful planning and adherence to specific regulations and technical standards. Here are the key mechanisms and considerations:

- **Initial application:** IPP must submit a formal application to Eskom's Grid Access Unit, providing detailed information about the project, including proposed capacity, location, and connection point.
- **Feasibility study:** A comprehensive feasibility study is required to assess the technical and economic viability of the project, including grid impact assessments, system strength analysis, and environmental impact assessments.
- **Grid connection agreement:** Once the feasibility study is approved, a grid connection agreement is negotiated between the producer and Eskom. This agreement outlines the terms and conditions of the connection, including technical specifications, grid code compliance, metering arrangements, and system use charges.

Independent energy and GH_2/PtX producers in South Africa must adhere to a range of compliance standards to ensure safe, reliable, and environmentally responsible operations. These standards are crucial for seamless integration into the grid and for meeting national and international regulatory requirements.

Key compliance standards:

1. Grid code compliance:

- Adherence to Eskom's Grid Code, which outlines technical standards for grid connection, system protection, power quality, and operational procedures.
- Compliance with international standards like the International Electrotechnical Commission (IEC) and Institute of Electrical and Electronics Engineers (IEEE).

2. Environmental regulations:

- **National Environmental Management Act (NEMA):** compliance with NEMA and its associated regulations, including EIAs and waste management plans.

3. Occupational Health and Safety:

- Compliance with the Occupational Health and Safety Act (OHSA) to ensure worker safety and health.
- Implementation of safety management systems and emergency response plans.

4. International standards:

- **ISO 14001:** environmental management system certification to demonstrate commitment to environmental sustainability.
- **ISO 45001:** occupational health and safety management system certification to ensure workplace safety.

9.3 Uptake of energy from independent producers

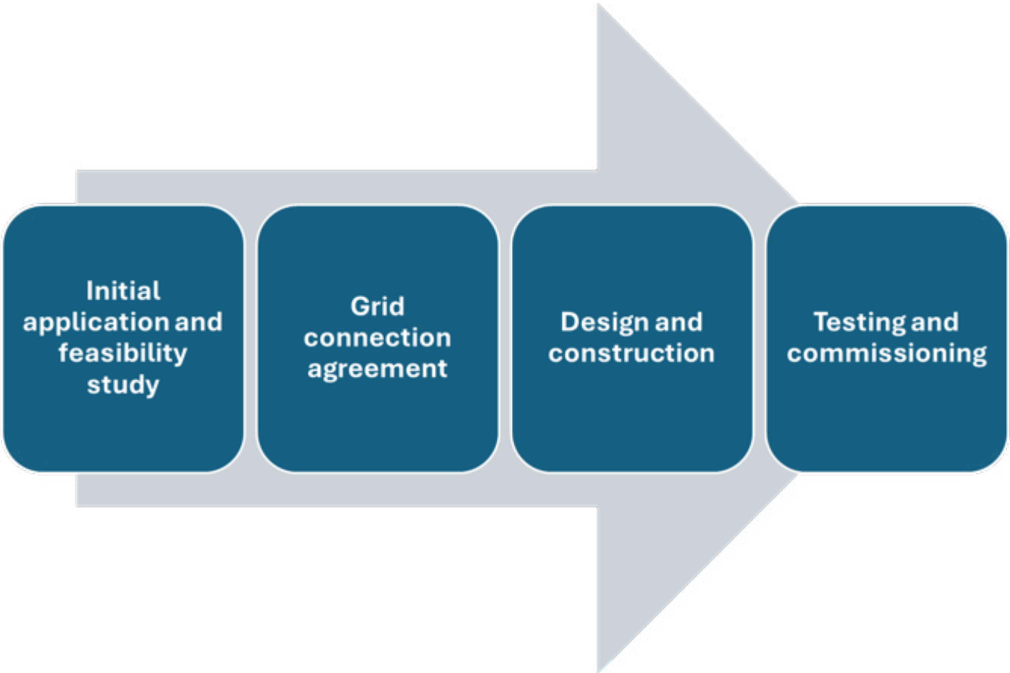

Figure 14: Steps to be taken by GH_2/PtX producers to connect to the Eskom grid

The detailed steps involved for GH_2/PtX producers to connect to the Eskom grid as shown in Figure 14 is listed below:

1. Initial application and feasibility study:

- Submit a formal application to Eskom's Grid Access Unit, outlining the project's details, including proposed capacity, location, and connection point.
- Conduct a comprehensive feasibility study to assess the technical and economic viability of the project. This should include:
  - Evaluating the potential impact of the project on the grid, such as voltage fluctuations and power quality.
  - System Strength Analysis: Determine the grid's capacity to accommodate the generation or usage.
  - EIA: assess the environmental implications of the project.

2. Grid connection agreement:

- Negotiate terms of the grid connection agreement with Eskom, including:
  - Connection fees
  - Technical specifications
  - Grid code compliance
  - Metering arrangements
  - System use charges
- Once the terms are agreed upon, a grid connection agreement with Eskom can be entered into.

3. Design and construction:

- Submit detailed design plans to Eskom for review and approval.
  - Ensure compliance with Eskom's technical standards and grid code.
- Construct the generation facility and associated infrastructure, adhering to approved design plans and industry standards.

4. Testing and commissioning:

- Conduct rigorous testing to ensure the system's reliability and compliance with grid standards.
- Commission the generation facility and synchronise it with the Eskom grid.

Key considerations for GH_2/PtX producers:

- Ensure that the GH_2/PtX facility complies with the relevant grid codes and standards, which may require specific modifications. This is particularly important noting that an electrolyser operates on direct current while the electricity grid transmits electricity as alternating current, which will require a rectifier and incur conversion losses.
- Consider the need for Battery Energy Storage Systems (BESS) to balance intermittent RE sources and optimise grid integration.
- Stay updated on evolving regulations and incentives for RE and hydrogen technologies.

9.4 Required electricity grid infrastructure

Integrating GH_2/PtX technologies into the existing grid requires significant upgrades and expansions to ensure reliable and efficient power delivery. Key areas for enhancement include:

- **Increasing transmission capacity:**
  - Modernising existing transmission lines with advanced materials and technologies to increase capacity and reduce transmission losses.
  - Building new transmission lines to connect remote RE sources, such as wind and solar farms, to load centres.
  - Employing high-voltage direct current (HVDC) transmission for long-distance transmission, as it reduces transmission losses and enables the integration of remote RE sources.
- **Improving grid reliability:**
  - Implementing advanced grid control systems, such as grid automation and intelligent electronic devices (IEDs), to enhance system stability and reliability.
  - Utilising real-time monitoring and control systems to detect and respond to disturbances and anomalies promptly.
  - Implementing fault detection, isolation, and restoration (FDIR) systems to quickly identify and isolate faults, minimising their impact on the grid.
- **Ensuring resilience against energy supply fluctuations:**
  - Deploying energy storage systems, such as batteries and hydrogen storage, to balance intermittent RE generation and meet peak demand.
  - Implementing demand-side management (DSM) to encourage consumers to shift their electricity consumption to off-peak hours, reducing peak demand and improving grid stability.
  - Integrating flexible generation resources, such as gas turbines and combined cycle power plants, to provide backup power and respond to rapid changes in demand.
- **Design recommendations for new grid infrastructure:**
  - Incorporating smart grid technologies, such as advanced metering infrastructure and distributed energy resource management systems, to optimise grid operations and enable the integration of distributed energy resources.
  - Adopting a modular design approach for new grid infrastructure to facilitate scalability and future expansion.
  - Leveraging digital technologies, such as artificial intelligence and machine learning, to improve grid efficiency, reliability, and security.

- Implementing robust cybersecurity measures to protect the grid from cyberattacks and ensure the integrity of critical infrastructure.

By implementing these strategies, the grid can be effectively upgraded to accommodate the integration of GH_2/PtX technologies, ensuring a reliable, efficient, and sustainable energy future.

9.5 Required H_2 storage infrastructure

Hydrogen and ammonia storage solutions for GH_2/PtX include:

- **Hydrogen storage solutions:**
  - **Compressed hydrogen gas storage:**
    - **Compressed hydrogen gas cylinders:** suitable for small-scale applications and mobile storage.
    - **High-pressure compressed hydrogen tanks:** used for larger-scale storage, often integrated into hydrogen refuelling stations.
  - **Liquid hydrogen storage**
    - **Cryogenic tanks:** store hydrogen in liquid form at extremely low temperatures (-253°C). Suitable for large-scale storage and transportation.
- **Ammonia storage solutions:** ammonia, a hydrogen carrier, can be stored in liquid ammonia tanks at ambient temperature and pressure.

Strategies to increase storage capacity include:

1. **Infrastructure upgrades:**
   - Increase the capacity of existing storage facilities, such as compressed hydrogen tanks, liquid hydrogen tanks, and ammonia tanks.
   - Construct new storage facilities, including storage applications using new technologies to store hydrogen and ammonia, like Type 4 compressed hydrogen tanks.
2. **Hydrogen carrier technologies** such as ammonia or methanol, to facilitate long-distance transportation and storage.

By implementing these strategies, it is possible to significantly increase storage capacity for hydrogen and ammonia, ensuring a reliable supply of GH_2/PtX fuels and strengthening energy security.

Chapter 10

Economic and financial implications

10. Economic and financial implications

10.1 Potential synergies between GH_2/PtX and the energy supply

The development of the GH_2 sector in South Africa presents significant opportunities to enhance economic growth, promote sustainability, and strengthen energy security. By capitalising on the captive RE resources established for hydrogen production, the country can address energy challenges, reduce emissions, and gain various cost advantages.

Oversizing captive renewable energy generation

As described in Section 7.1.1 (Additional renewable power capacity from GH_2), the excess capacity is created to optimise hydrogen production. This strategy provides additional RE supply capacity to the grid.

Balancing the grid

Hydrogen plays a crucial role in balancing the energy grid by acting as a flexible energy carrier. It can store excess renewable energy when generation exceeds demand, thereby also avoiding curtailment. Energy can subsequently be released to power production during high-demand periods, helping to stabilise the grid and mitigate the intermittency issues commonly associated with solar and wind energy.

Lowering energy rates

By increasing RE generation capacity from excess captive capacity in GH_2 projects, the cost of electricity can be reduced over time. The integration of GH_2 projects into the energy system can therefore drive down energy costs, benefiting both consumers and businesses in South Africa.

Energy import substitution

The ramp-up of the hydrogen sector allows South Africa to reduce its reliance on energy imports by utilising local RE sources for hydrogen production. This shift enhances energy security, reduces foreign exchange expenditure on imported energy, and strengthens the country's self-sufficiency in energy infrastructure.

Substituting fossil fuels in process industries

GH_2 offers a sustainable alternative to fossil fuels in industries such as steel manufacturing, chemical production, and heavy transportation. This transition not only helps reduce carbon emissions but also positions South Africa as a leader in sustainable industrial processes and products, aligning with global decarbonisation efforts, i.e., low carbon products exported benefit from improved access to trade barriers related to embedded emissions, such CBAM in in the EU.

Cost-effective energy transport

Energy converted to hydrogen provides a flexible and cost-effective solution for long-distance energy transport. Unlike electricity, which requires expensive grid infrastructure, hydrogen can be transported via pipelines, tankers, or in liquid form, making it a more efficient and affordable option for energy distribution, both domestically and internationally.

10.2 Positive economic and financial implications of GH_2/PtX economy on energy security

10.2.1 Cost saving from avoided loss of value added

Rationale

The Cost of Load Shedding (CoLS) serves as a crucial metric for understanding the economic impact of planned power outages, particularly in South Africa, where a severe electricity crisis has persisted since 2007. CoLS quantifies the economic losses incurred due to insufficient power supply, encompassing the reduction in value added across various sectors. This economic cost reflects not only the immediate loss in productivity, measured in terms of diminished GDP, but also the broader, cascading effects throughout the economy.

In South Africa, the cumulative CoLS from 2007 to 2019 was estimated at ZAR 35 billion[7], highlighting the profound economic disruption caused by persistent loadshedding. Sectors such as manufacturing, transport, and agriculture, which are heavily reliant on electricity, experienced significant setbacks. For instance, agricultural operations, dependent on electricity for irrigation and refrigeration, faced interruptions that hindered output and efficiency.

7 *Estimating the economic cost of load shedding in South Africa, Eskom Holdings (SOC) Ltd./nova economics 2020.*

To mitigate these losses, the introduction of excess capacity through GH_2 projects presents a mitigating solution. By investing in RE sources in GH_2 hubs, South Africa can establish hubs that generate additional power, thereby reducing reliance on the grid. This excess capacity not only alleviates the immediate impact of loadshedding but also fosters resilience against future power shortages. By integrating GH_2 projects, the economy stands to regain lost productivity, creating a more stable environment for growth.

Moreover, the benefits of reduced CoLS extend beyond the directly affected sectors. The interconnected nature of supply chains means that disruptions in one sector can reverberate throughout the economy. For instance, when manufacturing suffers due to power outages, it can lead to delays in transportation and logistics, impacting retail and service industries. The ripple effects can diminish overall economic performance, reducing investment attractiveness and inhibiting job creation.

Thus, addressing loadshedding through strategic investments in GH_2 and their captive renewable energy, not only mitigates the CoLS but also stimulates broader economic recovery and growth. By enhancing energy security, South Africa can unlock value across its economy, fostering a resilient framework that supports sustainable development and societal stability. In essence, reducing the CoLS through proactive measures allows for a more robust and dynamic economy, capable of weathering future challenges while promoting innovation and sustainability.

Methodology

The methodology of CoLS provides a critical framework for assessing the economic impacts of power outages.

- In analyses prepared for ESKOM[8], the CoLS was estimated at 12.61 ZAR/kWh for the period 2020 to 2023. This figure reflects the direct costs associated with loadshedding, including lost productivity and economic disruption.
- By correlating these results with projected GDP growth, experts estimate the CoLS will rise to 18.53 ZAR/kWh (approximately 0.85 USD/kWh) by 2030.

Effects on energy security

In the context of renewable energy, the potential excess capacity from the GH_2 sector is notable. With a calculated capacity of 6,953 MW, this translates into a significant excess energy production of 16.8 TWh. Leveraging this excess capacity can effectively mitigate the economic impacts of loadshedding. The avoided costs from not experiencing these outages are substantial, leading to an estimated value of ZAR 312 billion by 2030.

8 *Re-estimating the Economic Cost of Load Shedding in South Africa, Eskom Holdings (SOC) Ltd./nova economics 2023.*

This figure underscores the financial imperative for investments in renewable energy sources embedded in the GH_2 sector, as they not only help to prevent loadshedding but also contribute to broader economic stability.

10.2.2 Energy import substitution

Rationale

Replacing energy imports with RE-based GH_2 in South Africa offers a robust strategy to enhance energy security while mitigating the risks associated with volatile international fossil energy markets.

South Africa, also reliant on fossil fuel imports, faces significant risks from fluctuating global oil and gas prices. These price swings can lead to energy supply instability, negatively impacting economic growth and increasing the cost of living. By investing in renewable energy also for GH_2 production, the country can harness its abundant solar and wind resources to create a sustainable and domestically sourced energy supply. This transition reduces dependence on foreign energy sources, insulating the economy from external price shocks and geopolitical uncertainties.

Additionally, by substituting imports with domestically produced energy, South Africa can achieve significant foreign exchange savings. Importing fossil fuels requires substantial foreign currency, placing a strain on the national balance of payments. In contrast, investing in local renewable energy production shifts expenditure towards homegrown technologies and resources, promoting economic self-sufficiency.

In summary, transitioning to RE-based GH_2 not only enhances South Africa's energy security by reducing vulnerability to international market volatility but also fosters economic resilience through import substitution and foreign exchange savings.

Methodology

South Africa relies on crude and refined oil products as its primary energy imports, crucial for meeting the country's energy demands. They accounted for 21% of all commodity imports in 2022, up from 13% two years earlier. These fossil energy imports can be assessed based on their estimated oil price levels per energy content, measured in Petajoules (PJ). By converting the import value to USD per PJ, South Africa can gauge the financial implications of its oil dependency.

Table 5: Imported products in South Africa from 2020 to 2022

Product Categories	2020	2021	2022
	Value (million USD)		
All Commodities	68,943	93,440	111,880
Petroleum oils, other than crude	3,566	8,384	18,730
Commodities not specified according to kind.	5,124	7,487	7,406
Petroleum oils and oils obtained from bituminous minerals; crude.	5,088	5,419	4,398
Motor cars and other motor vehicles principally designed for the transport.	2,109	3,111	4,500
Electrical apparatus for line telephony or line telegraphy	2,467	3,079	3,642
Medicaments (excluding goods of heading 30.02, 30.05 or 30.06)	1,820	2,009	1,792
Automatic data processing machines and units thereof	1,462	2,045	2,064
Parts and accessories of the motor vehicles of headings 87.01 to 87.05	1,199	1,680	1,769
Unused postage, revenue or similar stamps of current or new issue	1,028	1,645	1,883
Motor vehicles for the transport of goods	510	686	1,020

Source: UN Comtrade, 2022 International Trade Statistics Yearbook, Vol. I

In contrast, the domestic production of GH_2 offers a potential substitute for these imports. Using the average value of imported fossil energy in USD/PJ, the energy content of GH_2 can be valued similarly in USD/PJ, allowing for a comparative analysis.

- Using the World Bank's CMO Pink Sheet and Outlook for oil prices at 75 to 85 USD/bbl the converted equivalent would be in the range of 13 to 15 USD/PJ.
- The energy content of GH2[9] of 1.2 Mt H_2-equiv can be converted to 141 PJ in 2030 increasing to 352 PJ by 2050.

9 *PtX Business Opportunities in South Africa, GIZ 2023.*

Effects on energy security

The equivalent of energy produced for the GH_2 sector valued at the price of imported fossil energy over the medium term at 14 USD/PJ would result in values of import substitution of ZAR 42 billion (USD 1.9 billion) reaching ZAR 168 billion (USD 4.9 billion) by 2050.

This valuation framework enables policymakers to evaluate the economic benefits of investing in RE sources like GH_2, aiming to reduce reliance on fossil fuels.

10.2.3 Creation of a qualified workforce for the energy sector

Rationale

Establishing a GH_2 sector in South Africa promises significant job creation, particularly as the nation transitions from carbon-intensive industries. The GH_2 industry can absorb workers displaced from shrinking fossil fuel sectors, providing a pathway for re-employment in a sustainable field. This transition not only addresses job losses but also enhances human resource development, creating a qualified workforce for the burgeoning energy sector.

The employment potential of GH_2 spans the entire value chain, with varying estimates influenced by project designs, technologies, and market conditions. While uncertainties exist regarding the broader GH_2 market, there is a wealth of reliable data from the RE sector, specifically from the Renewable Energy Independent Power Producer Procurement (REIPPP) programme. This data allows for more accurate projections of job creation linked to GH_2 and RE projects.

As the GH_2 sector develops, jobs will emerge in construction, operation, and maintenance, alongside roles related to decommissioning. By overlaying historical employment data with future GH_2-linked renewable capacity requirements, South Africa can anticipate substantial job creation, thereby fostering a skilled workforce that supports the transition to a sustainable energy future.

Methodology

In its study "Synergies between Green Hydrogen and Renewable Energy in South Africa"[10] GIZ calculated Full Time Equivalent (FTEs) job years based on Capital Expenditures (CAPEX) and Operating Expenditures (OPEX) to be spend in three different scenarios. In the "Realistic" scenario 42,431 FTEs are projected for the interval to 2030, with 25,787 FTEs to 2040, and 56,970 by 2050.

10 *Synergies between Green Hydrogen and Renewable Energy in South Africa - Renewable Hydrogen Market Potential and Value Chain Analysis, GIZ 2023.*

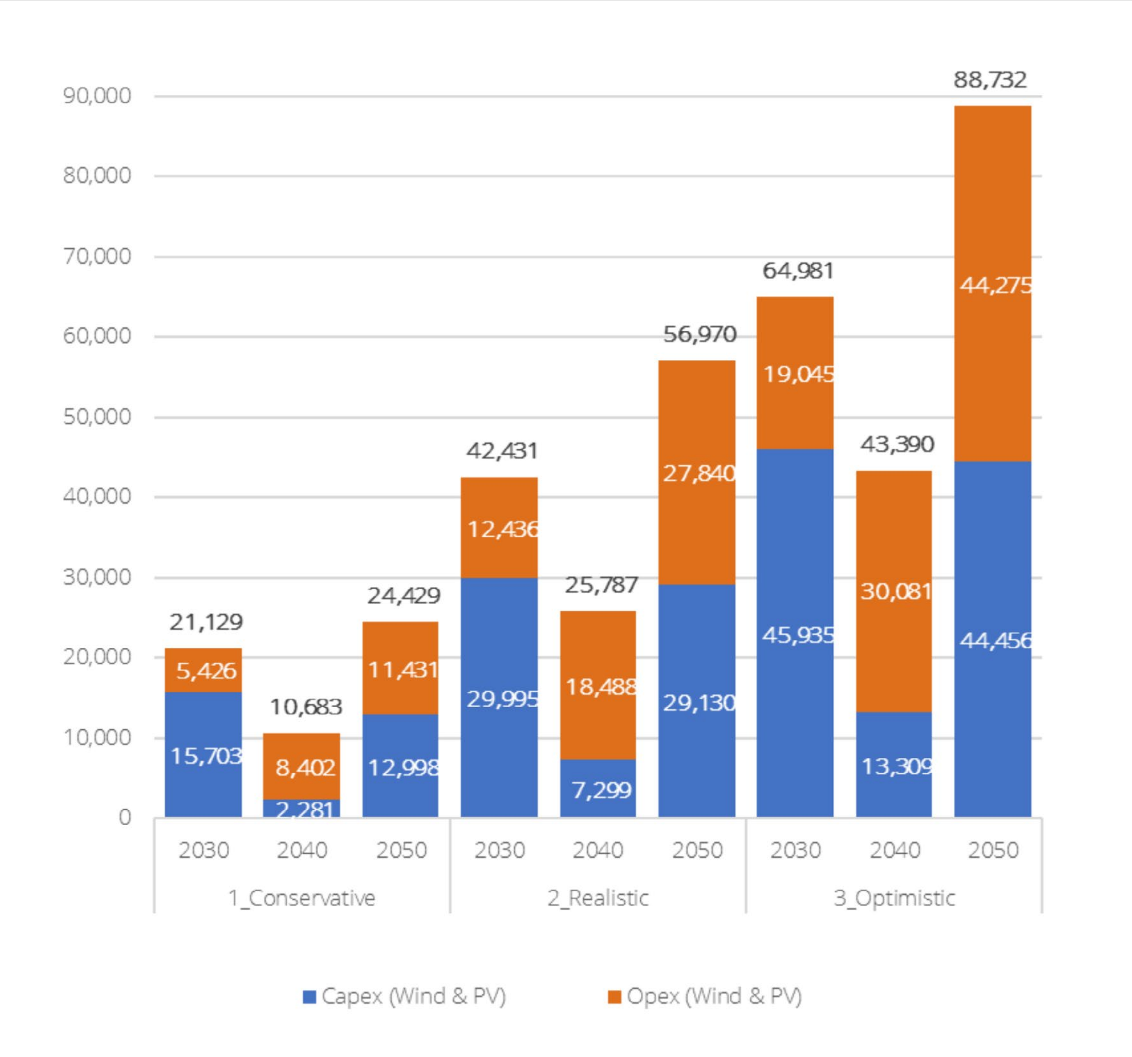

Figure 15: Estimated GH_2-linked RE employment by type and scenario (FTE job years created in a year)

Source: GIZ Synergies between Green Hydrogen and Renewable Energy in South Africa

A valuation of job creation from GH_2 can be developed using the average salary in South Africa[11] as per the International Labour Organisation (ILO) indexed in USD terms to 2030. This valuation represents a contribution of qualified human resources to support the growth of the energy sector.

11 *ILO Stat explorer, South Africa - Avg. Monthly earning 2020.*

Effects on energy security

The annual economic effect of the FTE forecast on the qualified staff available to the energy sectors based on indexed average salaries can be estimated at ZAR 7.2 billion in 2030, increasing to ZAR 23.3 billion by 2050.

10.2.4 Economic valuation of decarbonisation effects

Rationale

The transition to GH_2 offers a significant opportunity to decarbonise the South African economy. By leveraging GH_2's energy content, emissions from traditional fossil fuels can also be drastically reduced in hard-to-abate industries. Moreover, the oversizing of RE production for GH_2 allows for further contributions to zero emission energy consumption.

Methodology

With GH_2 produced via electrolysis powered by renewable sources like wind and solar, it has inherently zero emissions. Decarbonisation through GH_2 arises from its energy content and the strategic oversizing of RE systems replacing fossil fuel usage, leading to significant emissions reductions.

- To quantify these emissions saved, the grid emission factor for South Africa of 1.013 t CO_2e/MWh, as outlined by the DFFE, provides a baseline. This factor represents the average emissions produced per unit of electricity generated, helping to translate the reduced reliance on fossil fuels into measurable carbon savings.
- Additionally, using the International Energy Agency's (IEA) "Global Energy and Climate Model Documentation," one can value the emissions saved by applying long-term price estimates of "Announced Pledges Scenario" developed[12] for the emerging market and developing economies with net zero emissions pledges, including South Africa. These price projections forecast levels of 40 USD, 110 USD and 160 USD per tonne of CO_2 by 2030, 2040 and 2050, respectively.

This comprehensive approach not only highlights the environmental benefits of GH_2 but also emphasises its economic viability in transitioning toward a low-carbon energy future.

Effects on energy security

The economic value of avoided emissions from the implementation of the hydrogen sector would result in ZAR 45 billion in 2030, increasing to ZAR 723 billion by 2050 thereby adding a substantial decarbonised energy source to South Africa's energy supply.

12 *Global Energy and Climate Model Documentation – 2024, International Energy Agency.*

10.3 Negative economic and financial implications of GH_2/PtX economy on energy security

Additional grid infrastructure, including substation and transmission line infrastructure, needs to be in place for GH_2 projects to be connected to the Eskom grid, which will require significant investment. Current GH_2 projects have undertaken grid assessment studies to identify the areas where grid infrastructure strengthening is needed. Additionally, it has been estimated that upgrading infrastructure in specific areas in the grid can enable more RE projects to be connected for electrification. Overall, developing the grid infrastructure for GH_2 projects will require significant investment to ensure successful implementation.

The Green Hydrogen Commercialisation Strategy for South Africa[13] highlights this substantial investment needed to expand GH_2 and related renewable energy capacity. The estimated incremental CAPEX for additional transmission capacity for implementing GH_2 projects is between ZAR 89 to 178 billion (USD 5.6 to 11 billion) by 2030. This significant financial outlay is required to develop the necessary infrastructure, such as transmission networks and substations. This order of magnitude of investments at 5–10 billion USD are estimated in latest revisions of this framework every five years, gradually declining to 2050.

10.4 Potential instruments/mechanisms to cover possible additional costs

Financing grid infrastructure, particularly for power transmission, can be approached through a combination of public, private (e.g., IPP backed), and mixed funding structures (state backed), each with its own advantages and challenges. The further extension from public to private sector funding is seen as key to ensuring efficient development, operation, and sustainability of transmission infrastructure, especially regarding potentially new IPP development areas in the Cape provinces.

10.4.1 Public Funding Structures

Public funding for power transmission primarily involves the use of national budgets, multilateral institutions, and domestic and international financing sources. These sources often provide concessional lending or grants, making them attractive for financing large-scale, capital-intensive infrastructure projects. Government budgets may also be used to underwrite critical transmission projects that are considered too

13 *Green Hydrogen Commercialisation Strategy, DTIC 2022.*

risky for purely private investment. Multilateral institutions, such as the World Bank and African Development Bank, play an essential role by offering financial support, technical expertise, and policy guidance. While these institutions could help mitigate state-backed implementation of projects, Eskom's low creditworthiness and lack of cost-covering tariffs remain major challenges. Low build-out rates and a TDP skewed to late ramp-up of transmission development (beyond 2030) document limited potential for state-backed and Eskom involvement.[14]

10.4.2 Private Funding Structures

Private funding structures in the energy sector have gained traction internationally, particularly through models such as Independent Power Transmission (IPT) Projects and Whole-of-Grid Concessions. IPT projects involve private sector-developed and operated transmission systems that connect specific generation plants to end-users. These projects offer the private sector a more targeted role in transmission, allowing for a focused investment in infrastructure serving specific regions or consumers. Whole-of-Grid Concessions, on the other hand, encompass the development and operation of an entire transmission system under a long-term agreement with the government. This model can allow private investors to assume greater responsibility for a broad segment of the grid infrastructure, but it also requires clear risk allocation and well-defined contractual frameworks to ensure successful implementation. IPT schemes studied for South Africa include collector grids, where connected IPPs could join forces through an IPT reaching up to the 400 kV level.

10.4.3 Public–Private Partnerships

The combination of public and private sector involvement—through PPPs—is considered a viable option for financing South Africa's transmission infrastructure. PPPs enable the government to leverage private sector capital and expertise while maintaining public control over strategic aspects of the grid. Mixed funding structures can ensure that the interests of both parties are balanced, particularly when it comes to risk sharing, project design, and implementation. These partnerships can be particularly valuable in terms of facilitating innovation, driving efficiency, and ensuring that grid infrastructure aligns with broader national goals, such as sustainability and resilience.

10.4.4 Challenges and Opportunities

For South Africa to increase the level of privately financed transmission, several critical issues need to be addressed. First, the development of robust policies and a clear regulatory framework for IPT projects is essential. Such frameworks should include

14 *New business and funding models to resolve grid infrastructure constraints in South Africa, Meridian, Krutham 2024.*

provisions for concessional lending, risk mitigation measures, and performance indicators such as availability-based contractual structures. Credit enhancements and the establishment of an attractive market for bidders will also be vital to making these projects viable and appealing to private investors.

Internationally, models of private financing for transmission, such as privatisations and merchant investments, have been successful in regions like Latin America and Asia. These models could provide useful lessons for South Africa. However, to implement these strategies, South Africa will need to create an environment that is conducive to private investment, characterised by stable regulations, clear performance metrics, and incentives for long-term participation. Specifically, the World Bank recommends[15] a series of issues to be addressed to foster the adoption of IPTs:

- The development of policies and regulatory framework dedicated to IPTs
- Concessional lending available to private sector involving project structures
- Decisions on the development stage to start tendering
- Base contractual structures of IPTs on availability as a performance indicator
- Credit enhancements should be made available
- Project sizes and pipelines should be enticing to create an attractive market for bidders to enter.

10.4.5 Green Hydrogen and Innovative Financing Models

In addition to traditional grid infrastructure, South Africa is also exploring innovative financing options for green energy projects, particularly in GH_2. The complexity and risks associated with these projects necessitate collaboration among the government, development finance institutions, and private investors. International original equipment manufacturers (OEMs) and export credit agencies are key stakeholders in the GH_2 market, providing funding, technology, and expertise.

Government-backed green bonds, levies on carbon fuel consumption, and redirecting carbon tax revenues are other potential funding mechanisms that could support both transmission and green energy projects. By tapping into international funds aimed at fostering green transitions, South Africa can boost investment in a sustainable energy future.

To ensure the sustainable development of South Africa's power transmission infrastructure, a balanced mix of public and private funding is essential. Embracing innovative financing models, strengthening regulatory frameworks, and fostering public–private collaborations will be key to unlocking the full potential of the transmission network and supporting the country's energy security.

15 *Linking Up: Public-Private Partnerships in Power Transmission in Africa, WBG 2017.*

Chapter 11

Conclusions and recommendation

11. Conclusions and recommendation

GH_2 and PtX technologies offer South Africa a unique opportunity to address its energy security challenges by harnessing its abundant RE resources, technical expertise, and increasing policy support. Key opportunities offered by GH_2/PtX technologies include:

- **Diversifying the energy mix** by introducing sustainable, clean alternatives to fossil fuels to reduce environmental impact.
- **Providing energy storage solutions,** enabling efficient storage to mitigate the intermittency of variable RE, especially wind and solar power.
- **Stabilising the electricity grid** by managing surplus RE during peak production and supplying it during high demand or low generation periods.
- **Enhancing energy independence** by boosting self-sufficiency and reducing reliance on imported energy through domestic GH_2 production.
- **Driving economic growth** by creating export opportunities for GH_2 and its derivatives, such as green ammonia and methanol, to strengthen the national economy.

However, the integration of GH_2 into South Africa's energy system encounters substantial challenges despite its promising potential. Key barriers to GH_2/PtX integration include:

- **Grid capacity limitations** such as aging infrastructure, inadequate transmission capacity, and insufficient flexibility hinder RE and GH_2 integration.
- **Regulatory and policy misalignment** where inconsistent frameworks and unclear guidelines create uncertainty for investors and developers.
- **Financial and operational constraints** such as high upfront costs, limited funding, and inefficiencies in existing energy facilities impede progress.

Nevertheless, unlocking GH_2/PtX's full potential requires strategic efforts to overcome integration barriers and ensure their effective incorporation into the broader energy system. The following recommendations are key to enhancing the country's energy security through GH_2 and PtX:

1. **Strengthen policy and regulatory frameworks:**
    - Harmonise key national plans, such as the IRP, GHCS, and JET, to ensure consistency and alignment.
    - Introduce clear guidelines enforcing the additionality principle, ensuring RE for GH_2 projects does not compromise existing electricity supply.

2. Invest in grid modernisation:

- Upgrade transmission and distribution networks to enhance capacity, efficiency, and reliability.
- Implement smart grid technologies to manage intermittent RE and facilitate GH_2 integration.

3. Enhance financial support and public–private collaboration:

- Encourage investments through public–private partnerships and international financing mechanisms.
- Provide targeted subsidies or incentives for early-stage GH_2 projects and supporting infrastructure.

4. Foster stakeholder coordination and capacity building:

- Establish a centralised entity, such as the Green Hydrogen Secretariat, to coordinate GH_2 initiatives across public and private sectors.
- Develop workforce training programmes to ensure the availability of skilled labour for both policy and regulatory institutions as well as for GH_2 production, transport, and usage.

5. Promote international cooperation:

- Strengthen partnerships with global markets, especially regions like the European Union, where demand for GH_2 is growing due to carbon border adjustments and decarbonisation policies.

By addressing these barriers and implementing strategic interventions, South Africa can position itself as one of the leaders in the global GH_2 and PtX economy while ensuring energy security, economic growth, and sustainability. This transition will require a unified commitment from all stakeholders to create a resilient, inclusive, and green energy future.

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