

**The impact of dynamic capabilities on green hydrogen
technology adoption within the South African energy
sector**

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Abstract

South Africa possesses significant potential to produce green hydrogen at an industrial scale; yet the adoption of the green technology within the energy sector lags. This study aimed to assess the impact of dynamic capabilities on green hydrogen technology adoption, with specific reference to the distinct roles of sensing, seizing, and reconfiguring. The study also aimed to assess whether innovation enhances these effects. An explanatory, mono-method quantitative design was implemented through a structured online survey of sector stakeholders; and the statistical analysis was conducted using SPSS software.

The dynamic capabilities showed a positive association with adoption. When the three dimensions were modelled jointly, seizing – the ability to mobilise resources and commit – emerged as the unique predictor of higher adoption. Contrary to expectation, innovation did not strengthen the relationship between dynamic capabilities adoption under current constraints. Strengthening executional capability (seizing) should be prioritised to convert perceived opportunities into implemented projects, while policy and industry programmes should focus on aspects including investment commitment and offtake alignment to accelerate adoption.

Cross-sectional, mono-method evidence and sectoral skew (e.g., energy-centric, private-sector heavy; limited public and end-user input) constrained generalisability. It is therefore recommended that future research should broaden its sampling and employ a mixed-method approach.

Keywords

Dynamic capabilities; green hydrogen; technology adoption; innovation.

Plagiarism Declaration

I declare that this research project is my own work. It is submitted in partial fulfilment of the requirements for the degree of Master of Business Administration at the Gordon Institute of Business Science, University of Pretoria. It has not been submitted before for any degree or examination in any other University. I further declare that I have obtained the necessary authorisation and consent to carry out this research.

Oscar Asumani

1 November 2025

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1. RESEARCH PROBLEM AND PURPOSE

1.1. Introduction

The world's energy demand has increased significantly for the past five decades, and is expected to experience a further rise, mainly driven by factors such as population growth, industrialisation, and evolving technological innovation (OPEC, 2024; International Energy Agency [IEA], 2024). The IEA's projections suggest that the global energy demand will rise by approximately 30 to 50% by 2050 under the current policies (IEA, 2024).

However, the anticipated growth is expected to be uneven across different geographical regions, highlighting disparities in demand growth and policy priorities. This upward trend is driven by the rise in fossil fuel demand, mainly in developing nations, and a corresponding increase in green energy adoption in industrialised nations (Hassan et al., 2024; IEA, 2024).

In general, the rise of the global energy demand, although indicative of economic growth, presents challenges associated with increased greenhouse gas emissions. This is because fossil fuels still account for nearly 82% of global primary energy consumption (OPEC, 2024). This makes the transition of the global energy demand from fossil fuels to clean energy sources a worldwide priority (Ishaq et al., 2022; Ahmad & Zhang, 2020; Kovač et al., 2021).

Clean energy, particularly low-carbon hydrogen (e.g., green hydrogen), has been identified as an alternative to fossil fuels as it offers carbon-free solutions (IEA, 2024; Hassan et al., 2024; McGregor et al., 2025). Consequently, several industrialised countries (e.g., European Union countries) are adopting the demand-pull approach at the national level by promoting a suitable business environment. The objective is to promote sustainable adoption and integration of green hydrogen (GH₂) as an energy carrier across various sectors of their economy to materialise their commitments to the Paris Climate Agreement's goal of zero emissions thereof (IEA, 2024; IRENA, 2023).

Nevertheless, most industrialised nations, which are the primary consumers of green hydrogen (GH₂), are unable to meet their consumption demands through domestic production, primarily due to the restricted availability of renewable resources (e.g., wind, solar, and hydroelectric power stations), which are essential for producing green hydrogen at a lower cost (Béres et al., 2024). These challenges have presented a unique business opportunity for African nations, particularly South Africa, which is endowed with abundant renewable resources (e.g., solar, wind, and accessible seawater), to play a significant role in the global market (Béres et al., 2024; Kweinor Tetteh et al., 2024). However, this has not materialised yet.

Several studies have been conducted to elucidate the disparity between South Africa's considerable technical potential and its current capacity of green hydrogen production and integration as a commodity in the global market (Mukelabai et al., 2022; Lahnaoui et al., 2024). However, most of these studies primarily focused on the capacity of South Africa to produce more affordable green hydrogen (Ayodele & Munda, 2019). Limited studies have examined the necessity for the local energy industry to adopt strategic management tools, such as the dynamic capabilities framework, in support of the South African global role player through the adoption of the green hydrogen technology (Department of Science and Innovation, 2021).

Therefore, this present study aimed to assess the impacts of the dynamic capabilities on the adoption of green hydrogen technology, to enable the South African energy industry to accelerate the adoption of the green hydrogen technology (GHT), and to position the nation as a net exporter of green hydrogen in the global energy market.

In light of the research objective, this chapter provides the background of the research project and a concise overview of the current state of the green energy landscape, encompassing opportunities and challenges – through the lens of the PESTEL analysis approach – leading to the research problem and purpose. This chapter also elucidates the business and theoretical implications, as well as the purpose and relevance of the research. The overarching study project's structure and the intended objective of each following chapter are clearly outlined.

1.2. Problem statement

The integration of clean energy (e.g., GH₂) into the global energy value chain, particularly in the hard-to-abate industries, such as the cement industry, steel industry and marine transport, has become a necessity for achieving sustainable energy solutions, particularly among industrialised nations (IEA, 2024; Hassan, Genovese & Herdem, 2024). Countries all over the world, predominantly industrialised ones (e.g., European Union countries, Australia, Japan, etc.), endeavour to develop and implement policies to support and foster the utilisation of green hydrogen (GH₂) in various sectors of their economy, including petrochemicals, power generation, mobility, manufacturing, etc. (IEA, 2024; Odenweller & Ueckerdt, 2025).

According to the IEA (2024), the global demand for green hydrogen (GH₂) is expected to rise and reach approximately 500 million metric tonnes per annum (MMTpa) by 2050, with the European Union (11-15 MMTpa) and Japan (5-10 MMTpa) being among the largest importers. The recent Australian government's 6.7 billion US dollar hydrogen production tax incentive is a clear signal of support for the clean energy initiatives to unlock further investment opportunities across Australia (Pinsent Masons, 2025).

However, recent studies indicate that the anticipated green hydrogen revolution in these nations, particularly in Europe and Japan, faces significant challenges to materialise to its full potential because of high initial investment costs and risks, mainly caused by limited access to renewable resources such as wind and sunlight, which are essential for GH₂ production (Odenweller & Ueckerdt, 2025).

These challenges have potentially presented a unique business opportunity for developing and emerging countries – particularly those with abundant available renewable resources – to establish themselves as prominent low-cost GH₂ producers in this growing energy market (IEA, 2024; Hassan, Genovese, & Herdem, 2024). However, the trading landscape of low-carbon hydrogen undergoes rapid and continuous changes and has brought new opportunities and numerous challenges (IRENA, 2023). This issue encompasses the lack of a clearly defined common ground for standardisation and certification schemes across various regions and commodity sectors as well as evolving regulatory frameworks. This includes the recent British and

European CO₂ emission regulatory regimes and the carbon border mechanism, which could potentially disrupt the current global market trend (Odenweller & Ueckerdt, 2025).

The literature review revealed that further project development and execution complications are caused by uncertainty in securing long-term purchase agreements and an often-mismatched relationship between the project's final investment decision and offtake contracts (IEA, 2024; IRENA, 2023; Harichandan & Kar, 2023; Teece, 2018). Building upon this argument, Odenweller and Ueckerdt (2025) reported that the lack of offtake agreements, often caused by the limited consumer appetites to procure the green hydrogen at a higher cost, exacerbates the discrepancies between the projected and actual production capacity of the green hydrogen (GH₂).

South Africa's abundant renewable resources (Appendix 2), including solar, wind, and access to seawater, which are essential for producing green hydrogen at a reduced cost, have well-positioned the country as a potential producer of green hydrogen in the global market (Béres et al., 2024; Kweinor Tetteh et al., 2024). Nonetheless, the South African energy industry has been slow in translating these benefits into tangible value propositions and economic benefits, contrary to other sub-Saharan African countries such as Namibia and Egypt (Ayodele & Munda, 2019; Lahnaoui et al., 2024). These findings led the South African government to initiate an inquiry to ascertain why the nation has so far been unable to play a leading role as a global exporter of green hydrogen in the green energy market despite its abundant renewable resources (South African Department of Science and Innovation, 2021).

Consequently, an extensive interest was raised within the industry and academia to elucidate the disconnect between South Africa's significant technical potential and its current green hydrogen production capacity and integration as a commodity (Béres et al., 2024). The industry and academia also aimed to comprehend the slow adaptability of the South African energy industry to a dynamic and evolving energy business environment (Mukelabai et al., 2022; Lahnaoui et al., 2024).

These factors highlight the evolving nature of the low-carbon hydrogen business environment. They also underpin the need for the energy industry in developing countries, particularly South Africa, to pursue a dynamic response approach, one that

is grounded in a more scientific framework, such as the DC theory, to navigate through these challenges (Easterby-Smith et al., 2009; Li et al., 2022; Nawab & Shafiq, 2024; Zhang et al., 2024).

The DC theory, defined by Teece et al. (1997) as “the ability to integrate, build, and reconfigure internal and external competencies to address rapidly changing environments”, has been extensively utilised to study firms’ and organisations’ adaptability in the energy business environments, generally characterised by rapid changes (Arifin & Frmanzah, 2015; Čirjevskis, 2019). Most of the studies carried out to explore the impacts of the DC theory on the green energy industry have primarily focused on industrialised nations (Easterby-Smith et al., 2009). This has led to a considerable gap in the literature regarding the application of the DC theory within the energy sectors of developing nations, especially in the context of South Africa (Kweinor Tetteh et al., 2024).

Furthermore, the literature review revealed that the majority of studies exploring green hydrogen in Africa predominantly employ a qualitative methodology to exclusively analyse the country's economic and technical potential to produce low-cost green hydrogen (AbouSeada & Hatem, 2022; Ayodele & Munda, 2019; Imasiku et al., 2021; Li et al., 2022). To date, limited essential quantitative studies – with particular focus on the distinct role of sensing, seizing and transforming – have been conducted to explore the need for the South African energy industry to embrace the DC concept in order to position the country as a global player through the adoption of green hydrogen technology (Kweinor Tetteh, Sijadu & Rathilal, 2024; Department of Science and Innovation, 2021).

Thus, this present work aimed to address this gap by assessing the impact of the DC on the adoption of green hydrogen technology (GHT) using a quantitative methodology with the objective of enabling the South African energy industry to fast-track the GHT implementation and position the nation as a net exporter of green hydrogen in the global market. The study has examined the distinct roles of the three core attributes of the DC theory – sensing, seizing, and transforming – in evaluating their influence on the adoption of green hydrogen technology.

Hence, the following research question was posed: **“What is the impact of dynamic capabilities on the adoption of green hydrogen technology moderated by innovation?”**

1.3. Research purpose and relevancy

Purpose and relevance to the South African energy sector

The relevance of this work, a research study designed to empirically analyse the nature of the relationship between DC and green hydrogen technology adoption, is underscored by its potential to enable the South African energy sector to harness the potential of the nation’s abundant renewable energy resources. Through the adoption of green hydrogen technology, this work will purposefully support South Africa’s national interests (e.g., the National Hydrogen Strategy) and its commitments to comply with the international climate agreement (e.g., the United Nations 2030 Agenda for Sustainable Development).

Furthermore, this study is expected to contribute to positioning the nation as a key player in the energy transition and as a net exporter of GH₂ in the global energy market (Department of Mineral Resources and Energy, 2021).

The distinct contribution of this study lies in addressing the limited research works on the application of the DC theory following a quantitative approach in the green hydrogen sector. Particularly within the context of South Africa - a country with significant potential to produce cost-effective green hydrogen. Ultimately, the study will provide practical validation of the theory by emphasising the distinct impacts of the three core DC attributes (sensing, seizing, and reconfiguring) on technology adoption.

Purpose and relevance to the African continent’s energy sector

Although this research study focused mainly on the South African energy sector, it was, however, expected that its findings would hold significant relevance for the broader African continent. This is because many African countries share similar structural challenges, energy policy frameworks, and aspirations for a just energy transition (Bhagwat & Olczak, 2020; Bandiri et al., 2024).

Ultimately, the outcomes of this study are expected to equip various stakeholders, including policymakers and industry leaders throughout Africa, with the minimum requirements of strategic approaches necessary for scaling up renewable energy innovations – which will enable the acceleration of green hydrogen development as a pathway toward sustainable energy, economic resilience, and climate action (Department of Mineral Resources and Energy, 2021).

1.4. Business and theoretical implications of the research

1.4.1. Practical implications

The business need of this study is to elucidate the impact of DC on the adoption of green hydrogen technology and its direct implications for the South African energy industry. Key stakeholders (e.g., government, energy professionals, industrialists, and policymakers) in the energy industry must acquire such insight, given the need for the South African energy industry to develop adequate strategies that will enable the nation to navigate the complexities of integrating green hydrogen solutions and to enhance its competitiveness in the global market.

With a good understanding of the factors impacting the adoption of the GH₂ technology, the South African energy industry will be better positioned to effectively support the GH₂ commercialisation strategy. This includes the development of a national GH₂ infrastructure plan, the development and implementation of GH₂ standards and specifications, development of consumer specifications and requirements, as well as the formulation of agreements for GH₂ derivative offtakes with foreign consumers.

Furthermore, policymakers will be equipped with sufficient scientific evidence to formulate policies that are fit for purpose and make informed decisions that would support the development of coherent standardisation and project frameworks across the GH₂ value chain. This would also contribute to enabling South Africa to stabilise its energy supply and reduce its reliance on coal - currently, 85% of electricity - while meeting its commitments to the Paris Climate Agreement (Department of Mineral Resources and Energy, 2021).

1.4.2. Academic implications

Several studies exploring the applicability of the DC theory within the green energy have industry largely focused on industrialised nations (Easterby-Smith et al., 2009), while few of them have focused on developing nations, particularly in the context of South Africa (Kweinor Tetteh et al., 2024). Yet, these studies (Li et al., 2022; Nawab & Shafiq, 2024) generally assume that the terminology “strong dynamic capabilities” implies a high level of strength across all three attributes (e.g. sensing, seizing, and reconfiguring) at similar magnitudes (Teece, 2018).

An extensive body of knowledge has been generated by previous researchers in this field; however, a gap remains, as limited studies acknowledged that in real life, the three attributes may have different levels of contribution. For example, an organisation might excel at sensing new business opportunities but, at the same time, fall behind in seizing and reconfiguring to develop and implement a suitable business strategy that adapts to changing circumstances. Alternatively, the organisation might be adept at creating an effective business strategy but still struggle to implement it (Teece, 2018).

This quantitative research study aimed to elucidate the gap between the theoretical frameworks of the theory and its practical applications in the green hydrogen sector, considering the distinct impacts of the three attributes of the DC (sensing, seizing, and reconfiguring) on technology adoption, particularly within the South African context.

The contribution of this study to the existing body of knowledge lies in offering fresh perspectives on how the DC impacts the adoption of renewable energy technology in South Africa and, to some extent, in other African nations endowed with abundant renewable resources (Department of Mineral Resources and Energy, 2021).

1.5. Scope of the research

This research focussed on DC and the adoption of green hydrogen technology. There are several varieties of hydrogen types (e.g., grey, blue, turquoise, yellow, red and green, etc.). However, this study solely focused on GH₂ produced through the Proton Exchange Membrane electrolysis technology (PEM), which uses electricity generated from renewable sources such as wind, solar, or hydropower to split water molecules into hydrogen and oxygen molecules (Wurbs et al., 2024). Because the PEM process does

not emit greenhouse gases, the hydrogen produced through this technology is characterised as “green hydrogen”. This aligns with the South African commitment to the Paris Agreement.

Although the study’s primary objective concerned the South African energy industry, data collection was not limited to respondents residing in South Africa; individuals living outside the country were also approached. It was expected that such an inclusive approach would enhance the broader applicability of the research findings across different African geographical regions that possess abundant renewable resources.

This project, “a quantitative study”, made use of a structured survey for data collection. The strategy consisted of targeting key stakeholders involved in the green energy sector, who had an adequate understanding of the green hydrogen value chain at both national and international levels (e.g., industry technical experts and engineers, researchers from academia and R&D communities, policymakers, and end-users). The assumption was that the selected population possessed relevant knowledge of the green hydrogen value chain at various stages and could make meaningful contributions to this research project. Additionally, selecting such a population range would ensure consistency of data which are comparable (Pallant, 2020; Saunders & Lewis).

1.6. Research proposal structure

This research work is structured as follows:

Chapter 1 provides a brief overview of the current state of the green energy landscape using the PESTEL analysis approach. It also outlines the research purpose and then leads to the formulation of the research question. The chapter further elaborates on the research problem and highlights both practical and academic needs (i.e., the practical and theoretical justification); and finally, establishes the overall research purpose and the study’s relevance.

Chapter 2 covers the literature review, highlighting the global energy landscape and the importance of green hydrogen in the South African energy sector, and then delves into the DC theory to examine its relevance within the context of renewable energy adoption. The chapter also discusses key practical challenges and contextual factors that affect

the applicability of the DC theory. Lastly, it reviews the fundamentals of technology adoption theory and innovation and concludes by reiterating the formulation of the research question.

Chapter 3 outlines the research question and conceptual model.

Chapter 4 elaborates on the design methodology. The first section of this chapter emphasises the research design aspects, whereas section 2 delves into the research methodology. The research ethics and limitations are discussed in the last section of the chapter.

Chapter 5 presents the analysis and results of the collected data, using the research design and methodology elaborated in Chapter 4.

Chapter 6 analyses and discusses the results presented in Chapter 5, in line with the literature review discussed in Chapters 1 and 2, taking into consideration the academic research question elaborated in Chapter 3.

Chapter 7 presents the findings of the research study, discusses the business implications of these findings, outlines the limitations of the research, and concludes with suggestions for future research.

2. LITERATURE REVIEW

2.1. Introduction

Green hydrogen – an alternative to fossil fuel-based energy carriers – has potentially positioned South Africa as a global green hydrogen player within a dynamic energy market experiencing a systemic transition (IEA, 2024). Nevertheless, it is important to acknowledge that successfully adopting green hydrogen technology within the South African energy industry requires more than mere technological readiness (AbouSeada & Hatem, 2022; Béres et al., 2024).

Recent studies suggest that such an adoption requires a critical consideration of strategic, organisational, and institutional capabilities to enable coordinated industry efforts, robust policy frameworks and strategic investments to navigate the complexities of this transition (Teece, 2018; IEA, 2024; Odenweller & Ueckerdt, 2025). Thus, this study aimed to analyse the impacts of DC on the adoption of green hydrogen technology within the South African energy sector, with an emphasis on the distinct effects of the three attributes of DC: sensing, seizing, and reconfiguring (Hermundsdottir et al., 2024).

This research was expected to generate scientifically grounded insights that would support an informed decision-making process for key stakeholders, including policymakers, energy professionals, industry actors, and academics.

The literature survey served to establish the research context as well as the theoretical and empirical basis to enable critiques and justification of the key constructs (e.g. DC, technology adoption and innovation) that underpinned the research (Docrat, 2024). The chapter was, therefore, designed in such a way that it first provided the context of the research work by elaborating on the global energy landscape, which served as a prerequisite to contextualise the research objectives as well as the business and theoretical implications. The three constructs – DC, technology adoption and innovation theories – were then discussed to ascertain their applicability, relevance and limitations to obtain the relevant basis for the evaluation of the research outcomes (Docrat, 2024; Teece, 2018; Zhang et al.; 2024).

The review of academic articles, industry reports, business intelligence and review of global energy trends, and technological advancement intelligence, alongside with details about country-specific energy opportunities and constraints, enabled the establishment of a robust basis for developing the research question. The research purpose and relevance were therefore reiterated, which led to the concluding remarks.

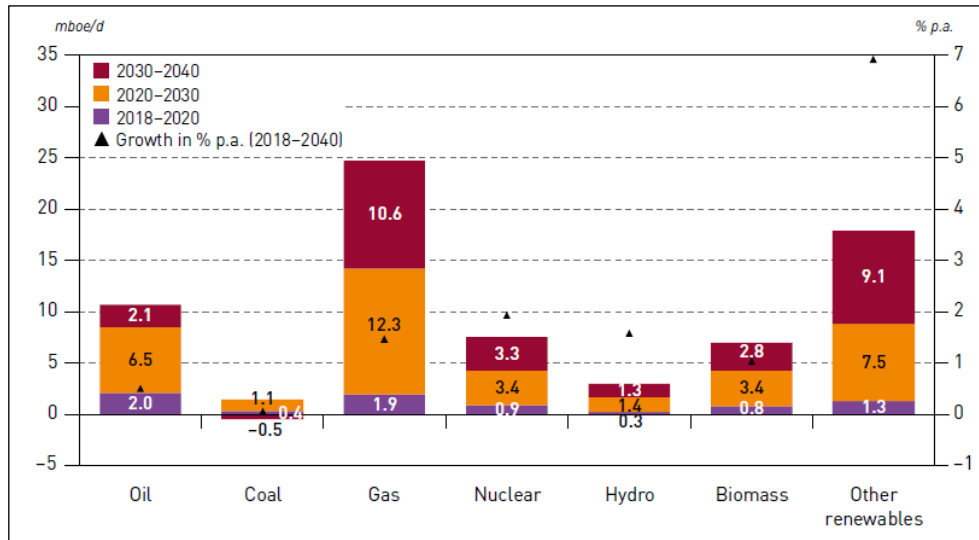
2.2. Global energy landscape

The global energy market heavily relies on fossil fuels – particularly oil, natural gas, and coal – which account for approximately 80% to 82% of the total primary energy supply (IEA, 2024). Statistics have shown that the global energy consumption will continue to rise as a direct consequence of factors such as population growth, industrialisation of the economy and improved living standards, particularly in the emerging economies in Africa and Asia. For example, the global energy consumption in 2023 increased by roughly 2.2%, exceeding the 2019 trend (IEA, 2024; OPEC, 2024).

Furthermore, studies indicated that oil (transport, industry) and coal (electricity, industry), with natural gas on the rise, will still dominate the energy market for decades to come, as illustrated in Figure 1 (IEA, 2024; OPEC, 2024). Figure 1 shows that although coal demand is expected to decrease over the outlook period, natural gas and oil demands are anticipated to increase, with oil expected to remain the fuel with the highest share in the energy mix by 2045. Whereas renewables, including solar, wind, bioenergy and hydroelectricity, show rapid growth albeit from a small base (OPEC, 2024).

Although the increase in global energy demand suggests economic growth, it, however, constitutes one of the main drivers of considerable environmental issues, including the increase in greenhouse gas concentrations (Ishaq et al., 2022; Ahmad & Zhang, 2020; Kovač et al., 2021).

Figure 1: Growth in primary energy demand by fuel type (OPEC, 2024, p.45)



2.2.1. The environmental imperative: Fossil fuels and climate change

As reported by several organisations, including the IEA (2024), fossil fuels are the primary cause of today’s environmental crises, since the combustion of coal, oil, and gas emits substantial amounts of CO₂ into the atmosphere each year, contributing to global warming. For example, the combustion of fossil fuels, including coal, oil and gas, emits an average of 37 – 38 gigatons of CO₂ annually, causing the planet’s temperature to be ~1.1–1.2°C above the pre-industrial temperature. A record of approximately 40.9 CO₂ gigatons was reported in 2023 (International Energy Agency, 2024; IRENA 2023).

Researchers have predicted that the impacts of unabated GHG are likely to be more severe, as they may lead to considerable warming and catastrophic environmental, social and economic impacts (IEA, 2024).

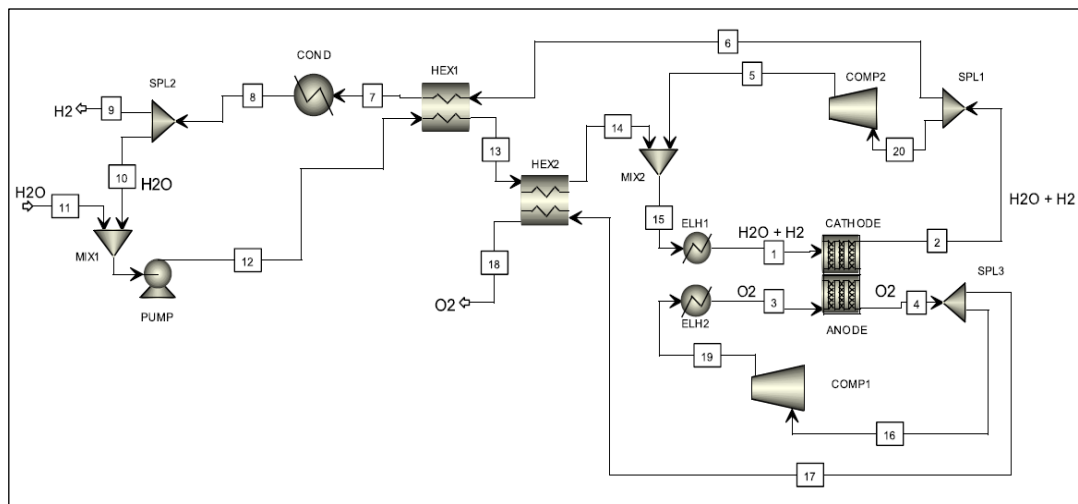
It is therefore a global and collective duty to enforce the integration of clean energy sources into the global energy value chain as alternatives to fossil fuels. And priority shall be given to in hard-to-abate industries such as the cement industry, marine transport and steel industry (Béres et al., 2024).

2.2.2. Green hydrogen: An alternative to fossil fuels

In this project, GH₂ has specified as an energy carrier produced via the electrolysis process utilising PEM electrolysis technology, powered by electricity generated from renewable sources, including wind, solar, or hydropower (IEA, 2024). The PME process consists of splitting water molecules into hydrogen and oxygen molecules using electricity. The electrolysis process, as depicted in Figure 2, does not emit greenhouse gases, making GH₂ a clean energy carrier for decarbonisation (Rena, 2024; Wurbs et al., 2024). Furthermore, the utilisation of green hydrogen does not emit greenhouse gases, unlike other types of combustibles; instead, it mainly produces water as a by-product, though some NO_x can form at high flame temperatures (IEA, 2024; Department of Mineral Resources and Energy, 2021; Rena, 2024).

The PEM technology was the primary focus of this study, as the South African government, through its national hydrogen strategy, has identified GH₂ produced via PEM as a strategically important lever for reducing emissions in hard-to-abate sectors, while also stimulating economic growth through job creation and industrial innovation. Furthermore, the PEM is a well-established technology worldwide, as its technology readiness has reached a high maturity level in South Africa (Department of Science and Innovation, 2021).

Figure 2: Schematic of water electrolysis process (Nami et al., 2022)



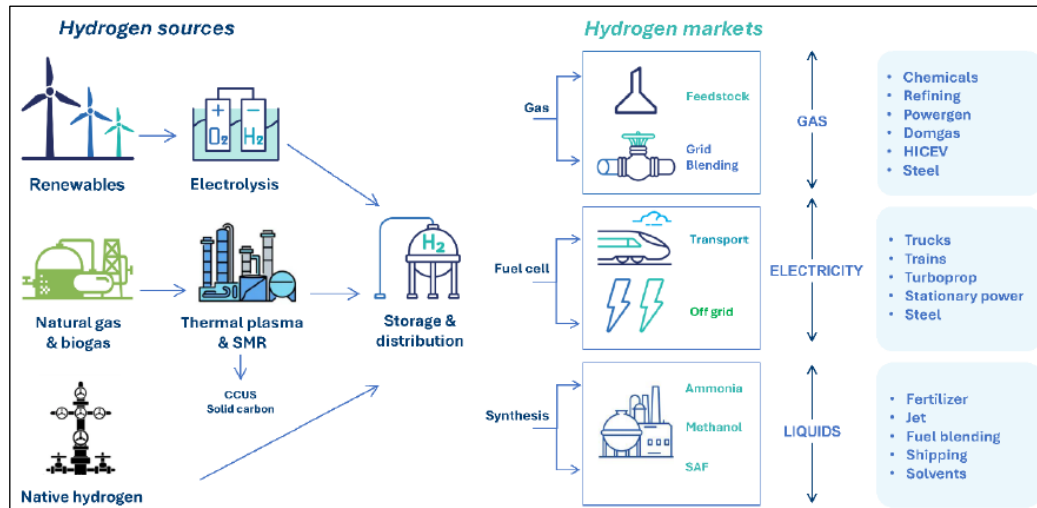
It should be noted that the production processes of other types of hydrogen, including grey hydrogen (produced through the steam reforming process of natural gas and/or gasification of coal), blue hydrogen (produced from natural gas and utilising carbon capture and sequestration) and brown hydrogen (produced from coal gasification), generate multiple by-products, including a substantial quantity of CO₂. As a result, governments, legislators, academics and private energy industries, particularly in developed nations, have recognised GH₂ as a viable alternative energy carrier to fossil fuels that can adequately be used in many applications, including steelmaking, petrochemical and refining, chemical feedstocks for fertiliser production, and mobility (Odenweller & Ueckerdt, 2025; Wurbs et al., 2024; IEA, 2024; IRENA).

Furthermore, GH₂ presents a high level of product versatility when it is utilised as an energy storage. For example, the surplus electricity produced through wind and solar farms can be converted into hydrogen and stored. The stored GH₂ can be used later to generate electricity, therefore providing a means to integrate variable renewables into the grid. Furthermore, when used in a fuel cell, GH₂ will emit only pure water and heat as residues (IRENA, 2023).

These capabilities, including versatility, flexibility, and high energy storage capacity, have conferred a unique advantage to GH₂, in the energy sector. In fact, GH₂ has been gaining more and more credibility in the effort to address key environmental issues, which consists of displacing intense fossil fuel usage in sectors that are difficult to electrify (Buchner et al., 2025; IRENA, 2023). Figure 3 illustrates the green hydrogen value chains and highlights the key components of the clean hydrogen industry. Figure 3 clearly demonstrates the potential of green hydrogen (GH₂) to serve as a pivotal energy carrier across multiple sectors (HydrogenOne Capital LLP, 2025).

The urgent necessity to transition to green energy has been emphasised by several researchers since then. For example, Hermundsdottir et al. (2024) emphasised the urgent need for the European oil and gas companies to accelerate the exploration of greener energy sources (e.g., wind farms) to mitigate the increasing severity of climate extremes – such as heatwaves, droughts, storms, and flooding – given that the global temperatures are already above pre-industrial levels (IEA, 2024; IRENA, 2023).

Figure 3: Clean hydrogen value chain (HydrogenOne Capital LLP, 2025, p.13).



2.2.3. Perspective on the techno-economics of green hydrogen

Production trends of green hydrogen

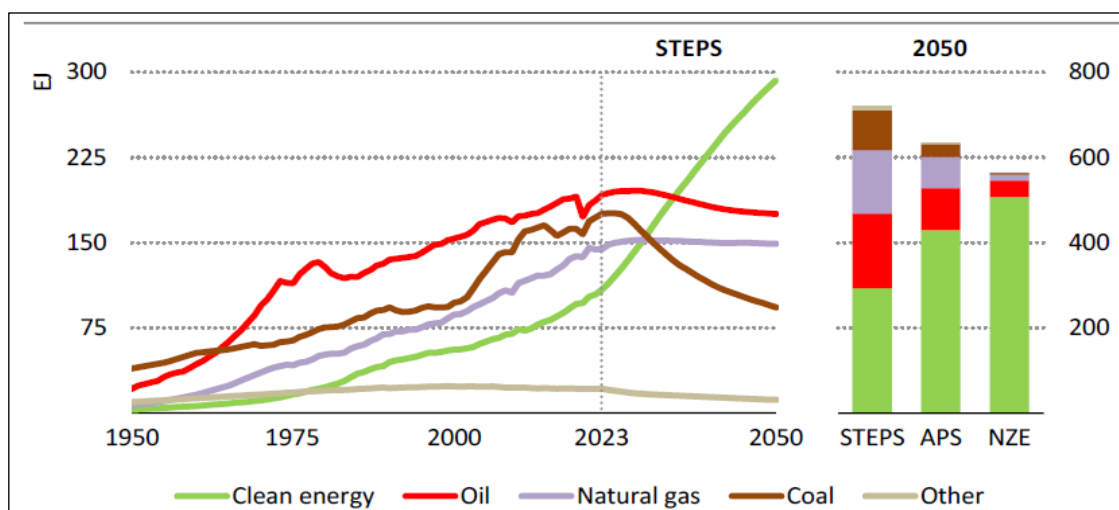
The global production of hydrogen has reached roughly 120 million metric tonnes per annum (MMTpa). However, over 95% of this production remains dominated by fossil-based processes – such as the grey hydrogen, which is produced through the steam reforming process of natural gas or gasification of coal. Less 5% are either blue (fossil fuel-based with carbon capture) or green (IEA, 2024; OPEC, 2024). The global hydrogen demand – approximately 95 million metric tonnes per annum (MMTpa) as of 2022 – is mainly used in the petrochemical and fertiliser processing industries. For example, 75% of the combined pure and mixed hydrogen demand is primarily used for the crude oil refining and for ammonia and methanol synthesis (IRENA, 2023).

Market intelligence has revealed that the global demand for green hydrogen, primarily driven by industrialised nations, is influenced by several factors, including reduced production costs, policy support, and climate commitments. As such, it is expected to reach approximately 500 million MMTpa by 2050, with the European Union (11-15 MMTpa) and Japan (5-10 MMTpa) being among the largest importers (IEA, 2024; IRENA, 2023; Harichandan & Kar, 2023; DNV, 2023). In contrast, developing countries, particularly in Africa, consume very little hydrogen annually, estimated at approximately

three million tonnes (around 3% of global use), which is primarily produced in South Africa, Nigeria, and Egypt chemical plants as grey hydrogen through the chemical processing of natural gas or coal (IEA, 2024; Hassan et al., 2024; AbouSeada & Hatem, 2022; Ayodele & Munda, 2019; Imasiku et al., 2021).

Figure 4 depicts the trend of the global energy mix by scenario up until 2050, based on the stated policies scenario (IEA, 2024). The data show that clean energy deployment, including wind, solar, and green hydrogen, is expected to expand rapidly as the pace of overall energy demand growth slows, leading to a peak for all three fossil fuels before 2030. Notably, between 2023 and 2035, clean energy is expected to grow at a faster rate than total energy demand. Beyond 2030, the share of fossil fuels in the global energy mix is projected to decline from 80% in 2023 to 58% by 2025, signalling potential progress toward meeting the goals of the Paris Agreement (IEA, 2024; IRENA, 2023).

Figure 4: Global energy mix by scenario to 2050 (IEA, 2024, p. 24)



Techno-economics of GH₂

Governments around the world, particularly those of industrialised nations (e.g., European Union countries, Australia, Japan, etc.), are actively working toward the development and implementation of policies to support and promote the utilisation of GH₂ across a wide range of industries (ThyssenGas, 2025). For example, TotalEnergies – the French multinational oil and gas energy company – in its effort to expand the

utilisation of green hydrogen in its refineries for hydrocracking and desulphurisation processes in compliance with the environmental regulatory duty, has agreed to procure 30,000 tonnes of green hydrogen annually on a long-term basis starting in 2030 from Germany's top utility, RWE.

This agreement was materialised thanks to the political drive and support of the European Green Deal (2019), the European Union Hydrogen Strategy (2020), and the Fit-for-55 package (2021), which collectively promote an accelerated decarbonisation of Europe and position green hydrogen as a cornerstone of the energy transition (IRENA, 2023). This project seems to be the largest contract for carbon-neutral hydrogen ever awarded to a German electrolysis facility, and it is expected to run until 2044 (Reuters, 2025). Such positive development is cementing the energy industry's commitment to integrate GH₂ into diverse industrial processes, signalling the potential for increasing market penetration of the green hydrogen technology (GH₂T).

The success story of the world's largest green hydrogen and ammonia plant - currently the largest in the world by installed electrolyser capacity - operated by Envision Energy is a clear indication of integrated stakeholder engagement and collaborative integration. The plant was officially commissioned in early 2024 with a nameplate of 320,000 tonnes a year. The 500 MW first phase of its 2.5 GW green hydrogen and ammonia plant located in Chifeng, China, has produced its first molecules in early 2024 from electrolysers made in-house by Envision (ThyssenGas, 2025).

Following this line of reasoning, the adoption of GH₂ is anticipated to grow as large-scale investments continue to materialise over the next decade (IRENA, 2023). This implies that South Africa's energy sector should explore GH₂ as a business opportunity, given the prospect of sustained market demand. Table 1 below lists key industry sectors with significant potential for green hydrogen utilisation (IEA, 2024; Wurbs et al., 2024).

Table 1: Key industry sectors with significant potential for green hydrogen utilisation (IEA, 2024; Wurbs et al., 2024)

Industry sectors	Utilisation
Energy and Power Generation	Grid balancing and storage: GH ₂ is used as a mid- to long-term energy storage solution for excess renewable energy. Fuel for power plants: GH ₂ is used for fuel cells and as an alternative to natural gas in turbines.
Mobility and transportation systems	Heavy-duty transportation system: GH ₂ is used in fuel cells to power trucks, buses, and trains. Shipping: GH ₂ is utilised to produce clean synthetic fuels.
Chemicals and petrochemical industries	As a feedstock: GH ₂ is used as the main ingredient in the production of methanol, ammonia, and other chemicals. Refineries: GH ₂ is used for hydrocracking and desulphurisation processes of fuels such as petrol and diesel.
Industrial Manufacturing	In the steel production: GH ₂ is generally utilised as substitute for coal in the reduction process to lower emissions. In the cement and glass production processing: GH ₂ is used as a heat source to achieve a high temperature.
Residential and Commercial Heating	In the domestic energy sector: When blended with natural gas GH ₂ is used as an energy carrier for domestic use (cooking and heating).

Table 2 presents the main hydrogen production methods that are commonly used in the industry, including their environmental impact, cost implications, and level of technological maturity. It can be seen that blue and grey hydrogen stand as the most mature from a technological perspective and have the lowest production cost and highest CO₂ emission. GH₂ has the highest production costs (Mukelabai et al., 2022).

Table 2: Different types of hydrogen production in terms of their environmental impact, cost, and maturity (Mukelabai et al., 2022)

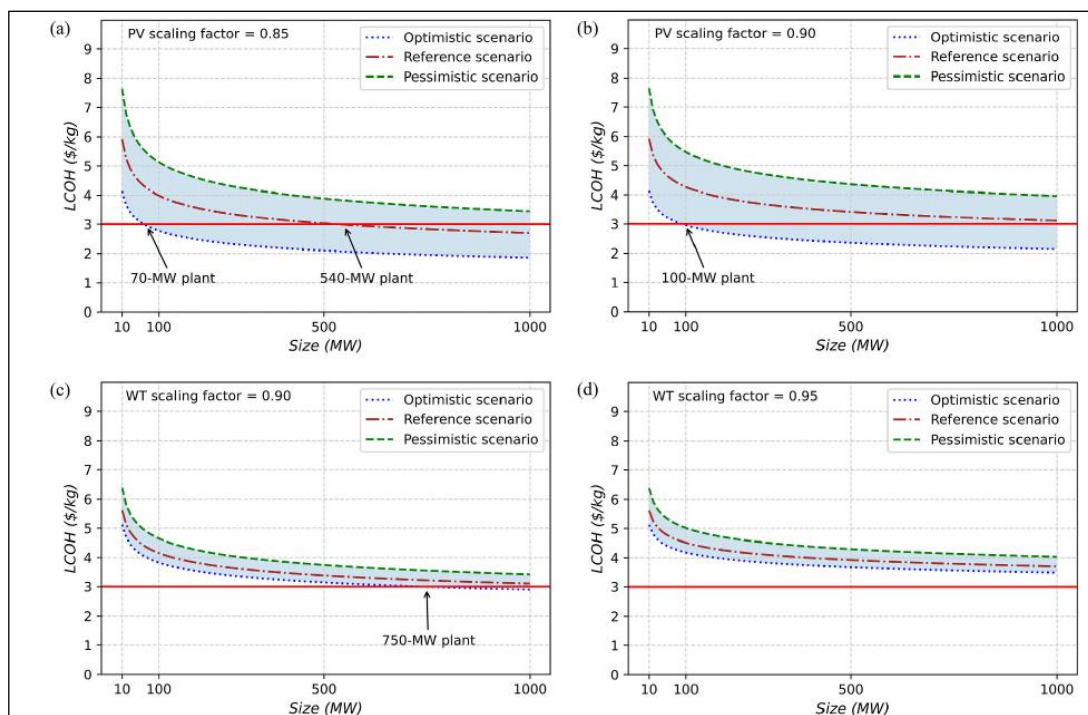
Type of hydrogen	Environmental impact	Raw material	Cost of H ₂ production	Maturity
Blue H ₂	Low-carbon (1.5-6.3 kg CO ₂ eq)	Coal or Natural Gas / with CCS	\$1.69 - \$12.55/kg	Commercially available
Red H ₂	Carbon-free (0.1-0.3 kg CO ₂ eq)	water / Nuclear energy	\$4.77 ± \$1.36/ kg	Under development
Turquoise H ₂	Carbon-free (2-16 kg CO ₂ eq)	Natural Gas / Methane Pyrolysis	\$1.5/kg to \$2/kg	Under development
Grey H ₂	High-carbon (9.5-13.5kg CO ₂ eq)	Natural gas	\$1.5/kg to \$2/kg	Commercially available
Green H₂	Zero-carbon (0 kg CO₂ eq)	Wind and Solar energy	\$4.5 - \$12/kg	Under development

This evidence supports the premise stating that the viability of GH₂ largely depends on the availability of affordable renewable electricity. The cheaper the electricity produced through renewable resources is utilised to generate green hydrogen, the more viable the deployment and expansion of the production chain will be (RENA, 2023).

Despite its current high production cost, green hydrogen, due to its potential and attributes (e.g., energy storage capacity, zero CO₂ emissions, versatility, and flexibility), it still has the potential to offer a path to sustainability through cost reduction facilitated by factors such as government subsidies and technological innovation. Several studies conducted by previous researchers provide further validation of the importance of green hydrogen in the energy transition, as well as the need to incentivise large-scale renewable hydrogen projects (Hermundsdottir et al., 2024; Dagnachew et al., 2024;

Council for Scientific and Industrial Research, n.d.). For example, Rezaei et al., (2024) analysed low-carbon hydrogen production under three distinct scenarios: optimistic, reference, and pessimistic. The study aimed to address uncertainty in cost predictions and to determine whether the target farm-gate cost of \$2 USD/kg could be met, which is below the target farm-gate cost of AUD 3/kg. The findings led the researchers to claim that the cost of the GH₂ is likely to drop below 3 USD/kg by 2030. Provided that appropriate policy measures (e.g., low-risk guarantees) and fiscal measures (e.g., low interest rates) are implemented. See Figure 5.

Figure 5: LCOH as a function of size for various scaling factors (Rezaei et al., 2024)



2.2.4. Challenges in deploying the green Hydrogen technology

Efforts are continuously made to optimise the average cost of producing hydrogen over the lifetime of a production facility. However, the expected GH₂ revolution in these nations, especially in Europe and Japan, encounters significant challenges to materialise to its full potential (Odenweller & Ueckerdt, 2025). Tracking 190 projects worldwide over three years, Odenweller and Ueckerdt (2025) identified a significant gap

in project completion rates. Only 7% of global capacity projects planned for completion in 2023 were on schedule. Odenweller and Ueckerdt (2025) argued that meeting the green hydrogen demand in most European nations will remain challenging, despite the development of ambitious projects.

Recent studies suggest that the low-carbon hydrogen trade landscape is undergoing rapid change, generating opportunities alongside constraints that impede large-scale deployment (IEA, 2024; IRENA, 2023; Harichandan & Kar, 2023). Some of these challenges are discussed below.

Lack of a coherent standardisation and certification schemes across regions and commodity sectors

It is important to ensure that hydrogen certification schemes are transparent, comparable and harmonised to avoid market confusion among various stakeholders, as this could create friction for international trade and domestic uptake. Various schemes – based on different criteria – have emerged to define what qualifies as “green hydrogen” (e.g., the European Union’s CertifHy, national certificates of origin, and industry standards).

However, recent studies (IRENA, 2023) suggest there is currently no globally harmonised standard to certify “green hydrogen”. The research outcomes suggested that the criteria for product specification differ, causing misalignment between international traders (IEA, 2024; IRENA, 2023; Harichandan & Kar, 2023). For example, studies conducted by Odenweller & Ueckerdt (2025) suggested that limited policy supporting the implementation and regulatory uncertainty surrounding GH₂ certification standards in the European Union and the United States are causing high business risk, hampering the growth of the green energy industry.

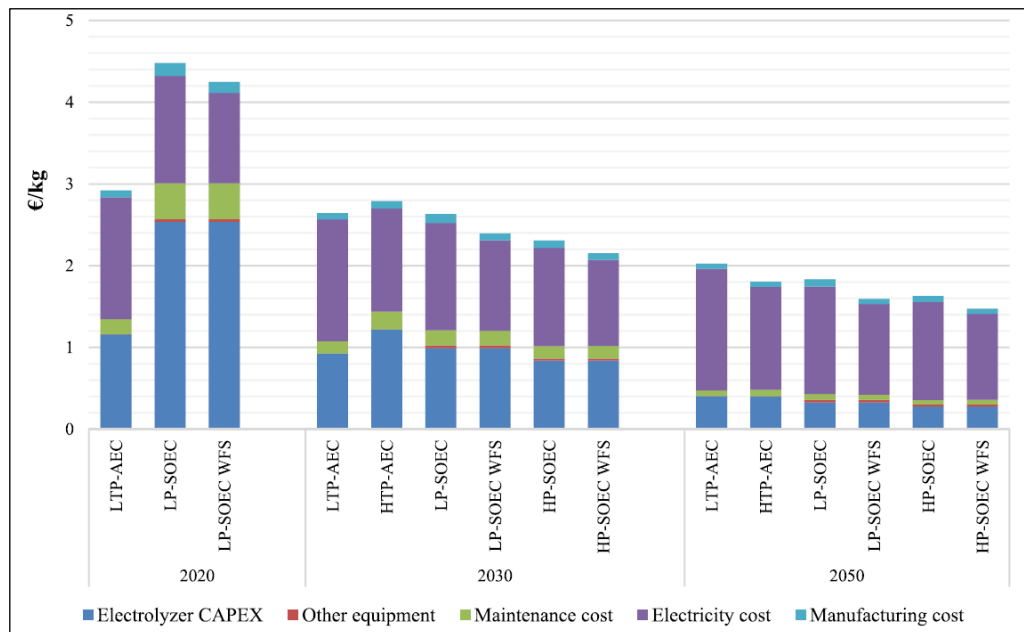
Therefore, one can postulate that unclear rules to define and certify the final product (green hydrogen) create an uneasy business environment for international trade and domestic uptake.

High production cost

Surveys conducted on the green hydrogen commercialisation projects developed over the past decades suggested that the costs of major components, including electrolyzers, storage facilities, and distribution systems, were the main drivers of high project costs, particularly where hydrogen is produced through the electrolysis process (Rezaei et al., 2024; Odenweller & Ueckerdt, 2025; IEA, 2024). A techno-economic analysis of renewables-based hydrogen production conducted by Rezaei et al. (2024) on behalf of the Australian green energy market revealed that the cost of the electrolyser was the dominant factor that defined the levelised cost of green hydrogen (LCOH).

Nami et al. (2022) also highlighted the impact of the electrolyser costs on the overall project cost. Figure 6 presents the cost breakdown of green hydrogen at a constant production rate for different variations of the production technology (e.g., AEC, SOEC and SOEC-WFS) for a period ranging between 2020 and 2050 (Nami et al., 2022). The results show that the electrolyser capital expenditure (CAPEX) – regardless of the type of technology being used – drives the total project cost. This causes the cost of hydrogen to become sensitive to CAPEX, especially at low current densities.

Figure 6: Cost breakdown of hydrogen production via different electrolysis technologies (Nami et al., 2022, p.11)



However, Nami et al. (2022) argued that the CAPEX influence diminishes over time as the technology matures and the economy of scale is materialised. This strengthens the argument that the costs of major components (e.g. electrolysers) are the main drivers of high project costs and are critical for final investment decision (FID) step (Rezaei et al., 2024; Odenweller & Ueckerdt, 2025; IEA, 2024).

Policy and regulatory frameworks

Regulatory frameworks, such as legal and statutory requirements for the production, storage, transportation and utilisation of GH₂, are still embryonic and vary widely by jurisdiction. This is because these safety standards and codes have only recently been developed and adopted, causing uncertainty for international trade. Hence, the absence of a defined common ground for standardisation and certification schemes across regions and commodity sectors (e.g., misalignment in infrastructure regulations, environmental impact assessment rules, emission intensity and safety standards) increases the project risk.

For example, the recent British and European CO₂ emission regulatory regimes – issued unilaterally – that enforce the carbon border mechanism (IEA, 2024) have demonstrated the absence of a consistent hydrogen policy, increased the project risk level and subsequently led to divestment. For example, the recent British and European CO₂ emission regulatory regimes – issued unilaterally – that enforce the carbon border mechanism (IEA, 2024) have demonstrated the absence of a consistent hydrogen policy, increased the project risk level and subsequently led to divestment.

It is therefore essential to establish a defined common ground for regulatory frameworks encompassing uniform and consistent standardisation and certification schemes across regions and commodity sectors to support sustainable deployment of the green hydrogen technology production. (McGregor et al., 2025; International Energy Agency, 2024; Hassan, Genovese, & Herdem, 2024).

Uncertain long-term purchase agreements

Financing large green-hydrogen projects is constrained by uncertainty around long-term offtake and by frequent misalignment between FID timing and sales contracts (IEA,

2024; IRENA, 2023; Harichandan & Kar, 2023). Odenweller and Ueckerdt (2025) further note that weak offtake – driven by limited willingness to pay green premiums – explains the gap between planned and realised GH₂ capacity.

Political and security uncertainty

Political risks represent a major challenge for the green hydrogen projects for both industrial and developing countries. For example, the signing, on January 20, 2025, of the executive order initiating the United States' withdrawal from the Paris Climate Agreement by President Donald Trump is expected to considerably affect the business landscape. This evidence suggests that unless political and security concerns are mitigated, they will continue to slow the hydrogen economy.

It also underscores the dynamic nature of the business environment of low-carbon hydrogen and highlights once more the necessity for nations aiming to establish a foothold in the green hydrogen market to adopt the dynamic capabilities approach (DC) to adapt and continually innovate (Smith and Doe, 2006).

2.2.5. Green hydrogen in South Africa

South Africa has reiterated its commitment to the Paris Agreement (IRENA, 2024; Department of Science and Innovation, 2021). Thanks to its abundant renewable resources, including solar and wind energy, as well as direct access to seawater, the country has an estimated potential for GH₂ production with a capacity ranging between 1.9 and 8.0 MMTpa. These resources have the potential to position South Africa in the global market as a key player of green hydrogen (Béres et al., 2024; Kweinor Tetteh et al., 2024; Council for Scientific and Industrial Research, n.d.)

And for the past five years, South Africa has started to leverage these advantages by formulating and implementing policies that support the integration of GH₂ within its energy sectors and to foster strategic partnerships with potential international investors to secure direct foreign investments for sustainable development (Department of Mineral Resources and Energy, 2021). The announcement of the European Union's 4.7 billion euro investment in South Africa's green hydrogen production, made at the 8th South Africa-European Union Summit in early March 2025, is not only an obvious

evidence of the country's significant potential in renewable energy but also constitutes a strong indication of the nation's prospect as a key global producer and exporter of green hydrogen (The Presidency of South Africa, n.d.).

Furthermore, South Africa possesses unique advantages such as abundant reserves of minerals (e.g., platinum), which are essential for the GH_2 production via the electrolysis process (Department of Mineral Resources and Energy, 2021). Its geographical position – on the Atlantic and Indian shipping routes – can yield 8% to 10% of the global market share of the green ammonia market for shipping, potentially leading to an additional 0.8 to 1.0 MMTpa of green hydrogen (IRENA, 2024). However, the South African energy industry has been slow in translating these benefits into tangible value propositions and economic benefits in comparison to other sub-Saharan African countries, such as Namibia (Lahnaoui et al., 2024).

Various initiatives that support the adoption of green hydrogen technology (GHT) at a national level are being initiated at local and national levels through the national hydrogen strategy (Béres et al., 2024; Kweinor Tetteh et al., 2024). Although they are gaining significant momentum, progress is still lagging in achieving the goal – such as the implementation of the electrolysis project with a capacity of 10 gigawatts by 2030 (Department of Science and Innovation, 2021; McGregor et al., 2025).

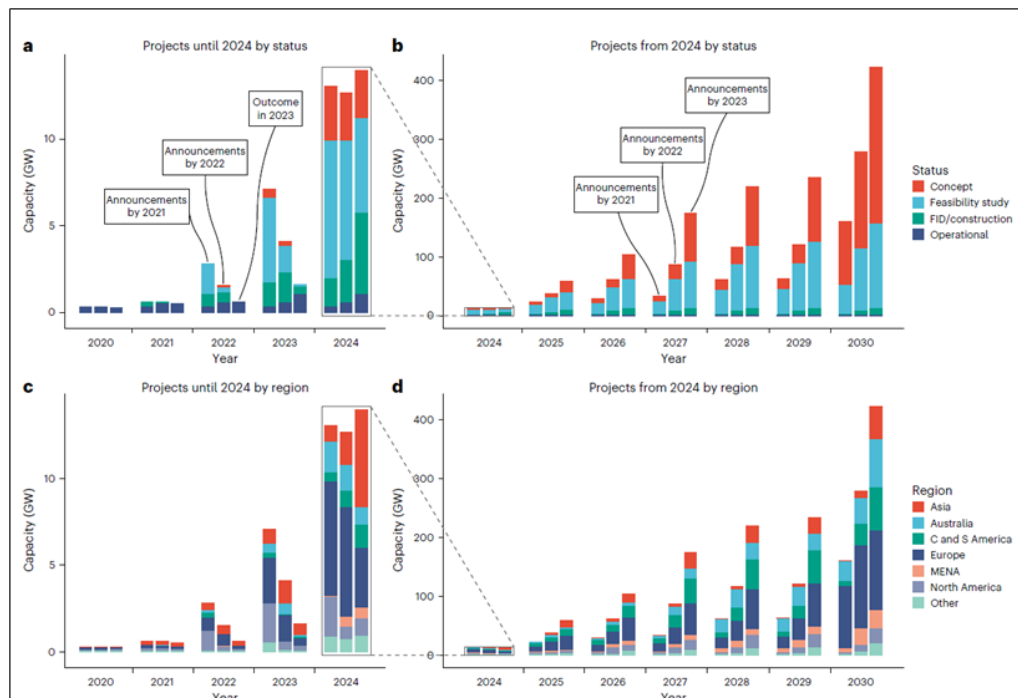
Hence, a critical question has emerged in order to understand why most African countries – endowed with abundant renewable resources – are still unable to play a leading role as exporters in the global green energy market. Mukelabai et al. (2022) concluded that strategic cooperation between African countries and hydrogen technology developers was the determining factor in addressing this dilemma. They substantiated their argument by illustrating the milestones achieved in the Namibian green hydrogen project, which was made possible by a dynamic approach and strong policies, particularly subsidies which reduced investment risk.

In contrast, Bandiri et al. (2024) proposed a different approach to address this predicament. They argued that African countries should, instead, build adequate energy infrastructure (e.g., transmission pipeline system, storage facilities, etc.) and initiate a political drive that will attract foreign investment. In fact, the authors are arguing that

African countries should focus on the decision-and-deployment engine that turns opportunities sensed by the firm into realised competitive advantage. This includes coherent business model choices tied to the opportunity thesis, clear, timely investment decisions (low time-to-commit) and resource mobilisation speed (capital, talent, partners). This study once again highlights the complex nature of the business environment of low-carbon hydrogen, requiring a dynamic response (Teece, 2018).

Odenweller and Ueckerdt (2025) conducted studies which revealed that GH₂ electrolyser capacity is projected to climb from about 1 GW in 2020 to roughly 400 GW by 2030, while most announced projects remain at early stages - concept (~55%) or feasibility (~42%) - as depicted in Figure 7 (a - b). Furthermore, Figure 7 (c - d) reveals that the bulk of these concept projects are concentrated in Europe and Asia. These observations once again justify the purpose and relevance of this research work, as they underscore a clear business opportunity for Africa - and especially South Africa, which combines strong solar and wind resources and abundant seawater for electrolysis - to seize a larger role in the emerging green H₂ value chain.

Figure 7: Green hydrogen implementation gap (Odenweller & Ueckerdt, 2025, p.113)



2.2.6. Conclusion

The global shift towards green energy highlights the critical role of green hydrogen in the decarbonisation of the global ecosystem. South Africa possesses significant natural renewable resources, such as wind, solar, and seawater (Béres et al., 2024; Kweinor Tetteh et al., 2024). This suggests that South Africa should adopt a dynamic approach to adapt and materialise its full potential as a key player in the global green energy market (IEA, 2024; Odenweller & Ueckerdt, 2025).

2.3. The Dynamic Capabilities Framework

2.3.1. Theory of the Dynamic Capabilities (DC)

Teece et al. (1997) examined the adaptability of organisations in rapidly evolving market environments characterised by factors such as shifts in market supply and demand trends. The researchers posited that organisations need to adjust their business models and develop strategies that are essential to sense new opportunities, seize them, and transform their operations to navigate through such uncertainties while maintaining their competitiveness.

Consequently, Teece et al. (1997) introduced the DC theory, defined as an organisation's ability to sense opportunities, seize them through strategic action, and transform internal and external assets and resources. Teece et al. (1997) suggested that the implementation of this theory is an essential organisational driver that capacitates for designing, refining, and pivoting business models in response to a rapidly evolving business environment.

Furthermore, Teece (2018) expanded the scope of the DC. He analysed the interactions between a firm's business models and its DC, and he concluded that implementing strong DC could enable the creation and implementation of effective business models.

Analysing these findings from an organisational strategy development perspective, one could postulate that strong DC can capacitate the management team with greater latitude to contemplate innovative business models, provided that the appropriate leadership is in place. These findings had demonstrated that there is a relationship

between DC and organisational structure concepts, emphasising the broader scope of the scope and applicability of the DCs' framework.

As a result, several other scholars have extensively employed this framework to examine the adaptability of firms and organisations, particularly those evolving within the energy sectors, to navigate uncertainty in a dynamic market (Docrat, 2024; Hermundsdottir et al., 2024; Čirjevskis, 2019).

2.3.2. Dynamic capabilities theory in the green energy sectors

The transition from fossil fuels to green energy is characterised by various uncertainties. Including regulatory shifts, scarcity of renewable resources, technological intricacies, and elevated production costs. Drawing from this viewpoint, prior researchers have posited that the DC could effectively support the advancement of the green technology as it enables firms and organisations to penetrate new markets by cultivating new capabilities while maintaining responsiveness and resilience to the market dynamics (Hermundsdottir et al., 2024; Bandiri et al., 2024; Nawab & Shafiq, 2024). They further asserted that implementation of the DC theory could help energy companies and organisations to address environmental challenges and promote economic growth by mitigating ecological impacts while enhancing social welfare (Hermundsdottir et al. 2024).

Hermundsdottir et al. (2024) have conducted an exploratory study – employing a quantitative methodology – to investigate the abilities of the Norwegian oil and gas companies to adopt the DC to transition to green energy sustainably. Hermundsdottir et al. (2024) reported that these companies were able to identify new business opportunities within renewables (sensing) through two methods. These included broadening the search window and engaging in exploratory initiatives. These companies had to seize the identified opportunities by assessing their existing knowledge and resources and establishing new collaborations with counterparts before reconfiguring. For example, these organisations had to redeploy existing knowledge and resources and establish new organisational forms.

Moreover, experts, such as Bandiri et al. (2024), have identified the African continent as a potential hub for large-scale hydrogen production, which could serve both local and

international markets. Bandiri et al. (2024) strongly contended that the DC framework was crucial for African energy companies to tackle challenges such as the lack of formal regulatory standards and elevated hydrogen prices, which were identified as significant obstacles.

These findings underscore the significance of employing dynamic capabilities – particularly sensing (market and technological trends), seizing (strategic action), and transforming (resource reconfiguration) – to facilitate the green energy transition.

While the literature review indicated that numerous research works were conducted to investigate the transition to green energy through the adoption of the DC framework, critics, however, noted that the majority have focused solely on quantitative analysis. Limited studies have focused on the quantitative analysis (Bandiri et al., 2024). Therefore, this study aimed to investigate – using statistical quantitative analysis – the influence of the DC on the adoption of green technology, with a particular focus on the distinct effects on the three dimensions of dynamic capacities: sensing, seizing, and reconfiguring.

2.3.3. Limitations of the Dynamic Capabilities Theory

Effective implementation of the DC requires active participation and inclusion of all stakeholders at both the company and organisational levels. Buchner et al. (2025) have asserted that the efficacy of the process required the identification and mitigation of any possible social, environmental, economic and technical barriers through collective and collaborative efforts, thereby underscoring the imperative of robust leadership as emphasised by various researchers (Teece, 2018; Buchner et al., 2025; Parente et al., 2024).

Teece (2018) further argues that effective, robust leadership is essential for promoting agility and cross-functional collaboration throughout the organisation.

Furthermore, Teece (2018) argued that it was imperative for leaders to continuously assess and adjust the business models of the organisation and leverage the DC to mitigate risks, such as market inertia. Teece (2018) advanced the DC literature by exploring the linkage between corporate leadership and dynamic capabilities. The

researchers, Teece (2018), concluded that the integration of robust dynamic capabilities with strong leadership can support the creation and implementation of effective business models.

Analysing these findings from an organisational strategic perspective, one may assert that robust DC' skills empower the management team with greater latitude to adopt adaptive business strategy, provided that the appropriate leadership is in place.

The DC theory has been established as a fundamental scientific and practical tool for enabling firms to navigate transitions through sensing, strategic seizing, and organisational transformation. However, it is essential to acknowledge that contextual challenges – such as political sanctions – might not necessitate a conventional approach but rather customised adaptations of the theory (Arifin & Frmanzah, 2015). For example, Zhang et al. (2024) conducted studies with the objective of comprehending the interaction between internal capabilities and external regulatory forces in support of sustainable practices. The authors suggested that organisations with robust leadership with the ability to integrate eco-friendly technologies and lead the organisation to adapt to the environmental changes have a higher probability of developing effective green business strategies.

Collectively, these insights underscore the imperative for robust leadership to capacitate a practical implementation of the DC, as well as the inability of solutions that derive from the DC theory to maintain their relevance over time, particularly in a continuously evolving green energy business environment shaped by new regulations (Arifin & Frmanzah, 2015; Čirjevskis, 2019).

2.3.4. Challenges in implementing the Dynamic Capabilities concept

This section examines the practical challenges and contextual factors that impact the applicability of the DC theory. It expands the applicability of the theory to encompass broader organisational and industry contexts, while acknowledging the evolving complexities of the business environment.

Teece et al., (1997) defined the DC as a framework for firms navigating rapid market shifts. As such, the theory is rooted in resource-based theory, which emphasises the

relevance of internal organisational agility, such as sensing opportunities, seizing and reconfiguring resources, and transforming, to adapt to evolving market conditions. Therefore, it can be contended that market factors are more influential than non-market factors, as the framework postulates that the uniqueness of an organisation's resources and capabilities will likely constitute the source of its competitive advantage (Teece et al., 1997, 2016, 2018). This is not always valid, as the applicability of the theory in wider business environments, particularly at the industry level, could be influenced by external factors (The White House, 2025), such as geopolitical realignments that the world is currently experiencing, and regulatory regime volatility remains (IRENA, 2023; Harichandan & Kar, 2023).

Li et al., (2022) conducted a study to evaluate the feasibility of applying the DC concept in examining the impact of subsidy policies on the Chinese green hydrogen industry. They contended that the DC framework could be successfully utilised to enable firms operating within the sector to collectively and adequately respond to and adapt to external changes, justifying the applicability of the DC framework at the industry level. In the context of the South African energy sector, the concept of dynamic capacities is pertinent because local energy firms are facing mounting pressure to decarbonise by adopting greener technologies, such as green hydrogen.

Hence, it can be argued that the DC theory is particularly suitable for this study because factors such as industry-wide collaboration, institutional support mechanisms (e.g., public-private partnerships, regulatory frameworks), and shared strategic responses are required. These are essential for the collective coordinated sensing of opportunities, the seizing of green investment, and the reconfiguration of operational models, rather than focusing on individual firms (Department of Mineral Resources and Energy, 2021).

Considering the preceding discussion, it is prudent to assert that the DC theory is particularly relevant to industries experiencing substantial transformations. This is especially true for the energy sector's shift toward a green energy transition. Thus, one can assert that "Industries that adjust their business strategy in response to both internal and external factors via the DC approach can more effectively traverse the changing energy landscape" (Teece, 2018). This underscores the need for the South African energy sector to consider a tailored version of the DC concept to achieve sustainability

in a dynamic market. It also positions the theory as a robust tool and critical lens for analysing South Africa's adoption of green hydrogen (Teece et al., 2016; Teece, 2018).

In conclusion, the literature review suggests that, through its three pillars, sensing, seizing, and transforming, the DC framework provides a valuable strategic lens through which the energy industry can penetrate new markets by cultivating new capabilities while maintaining responsiveness and resilience to the market dynamics (Hermundsdottir et al., 2024; Bandiri et al., 2024). Thus, it can be asserted that the framework supports the advancement of green technology, as it enables firms and organisations to navigate and adapt to an evolving energy market landscape (Nawab & Shafiq, 2024).

2.4. Technology Adoption

The South African green energy sector is experiencing a situation characterised by the inability of the production of green hydrogen to match the government's targets, although significant initiatives are being implemented at a national level to fast-track the production of green hydrogen (Department of Mineral Resources and Energy, 2021).

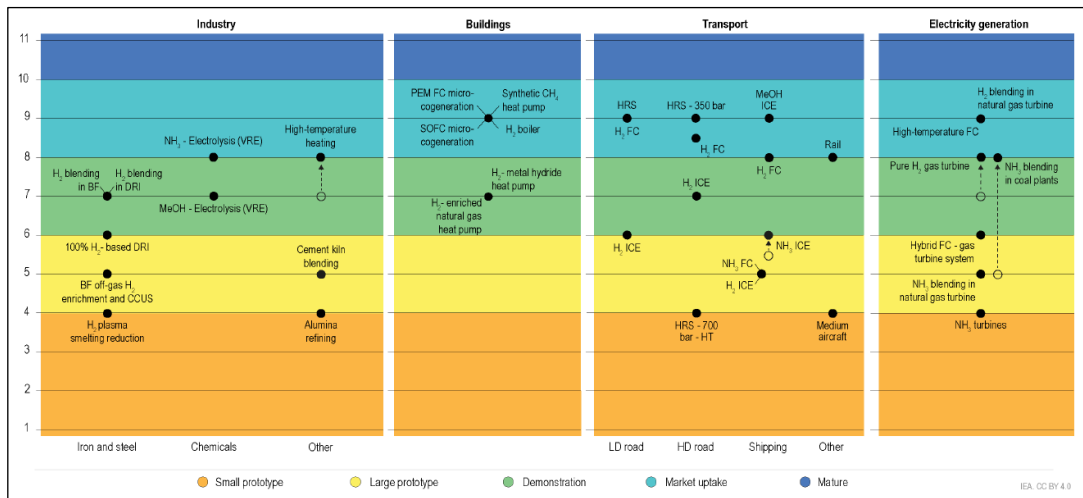
The critical role of DC to facilitate technology adoption at the industry level was reported by other scholars (Buchner et al., 2025; McGregor et al., 2025; Mukelabai et al., 2022). Buchner et al. (2025) found that the successful integration of green hydrogen into the German energy value chain could only successfully be achieved through market acceptance, which they referred to as the market adoption process of an innovation. Additionally, such an achievement would necessitate an adaptive and dynamic approach to ensure adequate public engagement.

However, it is essential to emphasise that the market adoption process of new technology is generally complex and requires the existence of a need (e.g., market demands) and the involvement of various stakeholders as well as their engagement at different levels of the industry or society (Sharma & Mishra, 2014). This also underscores the relevance of stakeholder theory, which suggests that an organisation should consider the interests of all parties affected by its actions. This includes customers, suppliers, policymakers, and communities (Friedman & Miles, 2002; Valentinov, 2023).

Studies conducted by Sharma and Mishra (2014) further highlight the complexity of the technology adoption implementation – defined by Carr (1999) as the “stage of selecting a technology for use by an individual or an organisation” – in a broader and dynamic environment. Sharma and Mishra (2014) reported that investments made for introducing a new technology may fail to yield the expected results if the intended users do not adopt that technology. To substantiate their argument, Sharma and Mishra (2014) referred to the initial failure of the implementation of the electronic health record systems that occurred in the United States of America in 2000. It was found that the failure was not due to the programme's inadequacy or lack of funding but rather due to the slow adoption of the technology, caused by the resistance of the public to change to another physician.

In addition to that, evidence shows that the diffusion of new technologies is strongly correlated with their maturity. Hence, IEA (2024) anticipates faster GH₂ adoption as its production technology (PEM) has a high level of maturity. The level of readiness of various technologies to produce low-emissions hydrogen is depicted in Figure 8 (IEA, 2024). It can be observed that the GH₂ has reached a readiness level of 9.

Figure 8: Green hydrogen technology readiness (IEA, 2024, p.159)



This complexity underscores the necessity of integrating the DC theory – as a critical determinant – into the technology adoption process for industries undergoing systemic transitions, specifically the South African energy sector’s shift towards a green energy

transition. Hence, one can conclude that the DC theory is an essential tool to mitigate resistance to change by enhancing industry flexibility, thereby accelerating the adoption of the technology (Sharma & Mishra, 2014). This clearly suggests that there exists a relationship between the DC and technology adoption (D. Teece et al., 2016; D. J. Teece, 2018).

Note that this study has focused on technology adoption at the industry level, which aligns with an industry-level approach (Sharma & Mishra, 2014). The term diffusion - a subsequent phenomenon of adoption - refers to "the stage in which the technology that has been adopted spreads to general use" (Rogers, 2003); and from that perspective, this study – while looking into the green hydrogen technology adoption – also elaborated on its diffusion through the end user.

The nature and magnitude of the relationship between the DC and the technology adoption have been studied by Arifin and Frmanzah (2015). Arifin and Frmanzah (2015) argued that technological adoption serves as a functional competence that mediates the relationship between DC and firm performance, which has been acquired through innovation. However, the authors highlighted the need for further empirical research to validate these findings and to explore the productivity paradox associated with technology adoption – as the construct of adoption can only be measured through performance. In contrast to earlier findings, Nawab and Shafiq (2024) confirmed that a green competitive advantage achieved through technological innovation significantly moderates the relationship between DC and green technology adoption, demonstrating also an indirect relationship as well.

It is, therefore, evident that a relationship exists between DC and technology adoption, which may occur either directly or indirectly through innovation.

This present study has a significant particularity, as it aims to evaluate the direct moderating effects of innovation on the relationship between DC and green technology adoption, while also focusing on the effects on the three attributes of DC: sensing, seizing, and reconfiguring as well.

2.5. Innovation in the green hydrogen industry

The energy industry is experiencing an unprecedented and continuous shift, particularly the adoption of low-carbon hydrogen as an energy carrier to address environmental challenges resulting from the use of fossil fuels (IEA, 2024). However, this shift brings both new opportunities and challenges for energy producers, such as technological advancements (e.g., new green hydrogen synthesis processes), the lack of common standardisation and certification schemes across regions and commodity sectors, and ongoing shifts in customer value proposition perceptions, among others. Additionally, uncertainties caused by climate policy significantly influence the business strategy implementations within the energy industry. All these, once again, highlight the need for innovation (Ayodele & Munda, 2019; IRENA, 2023).

Hence, such an environment has compelled most energy producers, if not all of them, to make a continuous and deliberate effort to become more innovative in leveraging their abilities to constantly monitor new trends in the market and identify new business threats and opportunities (sense). Additionally, to mobilise their resources to leverage the identified opportunities (seize) and to reconfigure their organisational structure (transform) to maintain relevance (Teece et al., 2016, 2018; Nielsen, 2006).

It is reasonable to assert that, at the industry level, innovation can only be achieved effectively if firms innovate individually within the sector and then engage in a collective innovation effort. Rogers (1960), the precursor of the diffusion of innovation theory, also argued that an effective adoption of new technology is achieved through its widespread diffusion across different layers of society. This aligns with the sectoral systems of innovation (SSI) framework, which also stipulates that innovation is not an isolated activity but rather a dynamic and integrated process involving interactions among various actors, including firms, universities, research and development organisations, and government agencies (Malerba, 2002).

Innovation in green hydrogen technology

Market analysis reports have revealed that the high cost of GH₂ production is a significant constraint to adopting green hydrogen, which can be addressed through increased market uptake (IEA, 2024). Through innovation, reduced production costs can be achieved by improving efficiency and reducing equipment costs, for example, by

increasing the stack lifetime, improving the manufacturing process, and reducing reliance on critical materials (IEA, 2024; Ayodele & Munda, 2019; IRENA, 2023).

From a technological standpoint, alkaline and PEM electrolysis processes are recognised as the most cost-effective and mature technologies available on the market. They are commercially available, with ongoing innovation efforts aimed at reducing production costs through design optimisation (IEA, 2024). Hence, for the past few decades, most Research and Technology organisations (R&T) have been working towards the optimisation of PEM technology design by focusing on finding ways to lower production and fabrication costs of electrolyzers by minimising the utilisation of expensive platinum group metal components in catalysts. For example, in September 2023, H2U Technologies – a private clean-energy company headquartered in Chatsworth, California, USA – achieved a 25000-hour durability test with an iridium-free catalyst, which outperformed other iridium-free catalysts (IEA, 2024). The performance test lasted up to 1,400 hours, which corresponds to a 7% improvement in efficiency (i.e., above industry norms by approximately 9%).

The importance and necessity of adopting an innovative approach to support the transition were also demonstrated by Rezaei et al. (2024) through their study, which aimed to determine whether green hydrogen could be produced sustainably at \$2 USD/kg. As depicted in Figure 5, their results revealed that it is technically possible to achieve a cost of \$3 USD/kg when the optimal electrolyser production capacity is selected and the economies of scale are applied to optimise the capital costs of electrolyzers.

Together, these R&D efforts demonstrate progress in clean-energy innovation and suggest that continued performance improvements will lower costs in the years ahead (IEA, 2024).

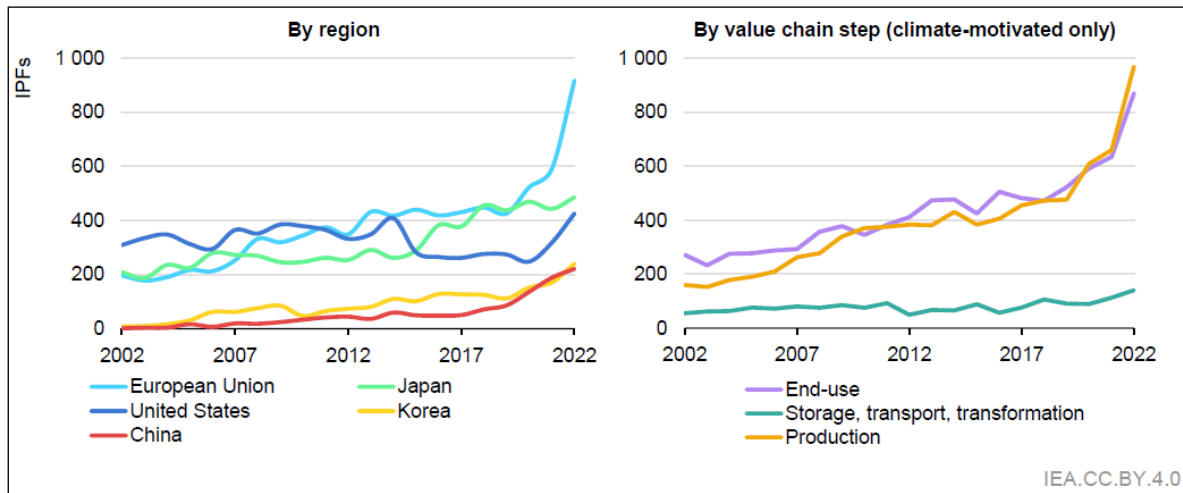
Market analysis reports have revealed that the high cost of GH₂ production is a significant constraint to adopting green hydrogen, which can be addressed through increased market uptake (IEA, 2024). Through innovation, reduced production costs can be achieved by improving efficiency and reducing equipment costs, for example, by increasing the stack lifetime, improving the manufacturing process, and reducing reliance on critical materials (IEA, 2024; Ayodele & Munda, 2019; IRENA, 2023).

From a technological standpoint, alkaline and PEM electrolysis processes are recognised as the most long-term cost-effective and mature technologies available on the market. They are commercially available, with ongoing innovation efforts to reduce the short-term production costs through design optimisation (IEA, 2024). Hence, for the past few decades, most research and technology organisations (R&T) have been working towards the optimisation of PEM technology design by focusing on finding ways to lower production and fabrication costs of electrolyzers by minimising the utilisation of expensive platinum group metal components in catalysts. For example, in September 2023, H2U Technologies – a private clean-energy company headquartered in Chatsworth, California, USA – achieved a 25000-hour durability test with an iridium-free catalyst, which outperformed other iridium-free catalysts (IEA, 2024). The performance test lasted up to 1,400 hours, which corresponds to a 7% improvement in efficiency (i.e., above industry norms by approximately 9%).

Disparity in the adoption of the green hydrogen technology

Furthermore, the literature review revealed that the adoption of GH₂ technologies varies across regions of the world. Figure 9 demonstrates that growth in 2022 emanated from all major regions, with the European Union leading the way, followed by Japan. Other nations such as the United States (34% year-on-year growth), Korea (40% growth), and China (18% growth) also demonstrate a high level of adoption of the technology. However, Africa shows a minimal level of adoption. This situation, once again, should be seen as an opportunity for the African nations endowed with abundant renewable natural resources to adopt the GH₂ technology and play a major role in the global green energy market (IEA, 2024).

Figure 9: Hydrogen technology patenting trends by main regions, 2002-2022 (IEA, 2024, p.161)



2.6. Conclusion

The global shift towards green energy highlights the critical role of GH₂ in accelerating the decarbonisation of global energy systems and meeting the "Paris Agreement." South Africa possesses abundant natural renewable resources, such as wind, solar, and seawater, to produce GH₂ at lower LCOH (Béres et al., 2024; Kweiner Tetteh et al., 2024). However, the adoption of green hydrogen technology and its conversion into observable value propositions and financial gains has not yet materialised as expected (Dagnachew et al., 2024). The dynamic capabilities framework – through its three pillars, sensing, seizing, and transforming – offers a valuable tool for the energy industry that can enable them to penetrate new markets by cultivating new capabilities while maintaining responsiveness to the market dynamics and market competitiveness (Hermundsdottir et al., 2024; Bandiri et al., 2024).

This study aimed to fill a critical gap in the existing literature by conducting a quantitative study to explore the impact of dynamic capabilities on the adoption of the green hydrogen technology with due consideration of South Africa's energy sector. Hence, the research question was formulated.

3. RESEARCH QUESTIONS AND CONCEPTUAL MODEL

3.1. Research Questions and Hypotheses

The disconnect between South Africa's considerable technical potential and its existing green hydrogen production capacity and integration within the energy value chain has prompted essential discussions and evaluations among government, industry, and academia (Mukelabai et al., 2022; Lahnaoui et al., 2024). Nevertheless, most of these discussions predominantly emphasise the economic and technical showcasing of the challenges and potential that South Africa possesses (e.g. abundant renewable natural resources) to produce low-cost green hydrogen (AbouSeada & Hatem, 2022; Ayodele & Munda, 2019; Imasiku et al., 2021; Li et al., 2022).

Research studies examining the need for the South African energy industry to adopt the DC approach to address this disconnect are minimal and, in some instances, non-existent. This study sought to assess the impacts of the DC on the adoption of green hydrogen technology (GHT), to enable South Africa to equip itself with the essential tools to become a prominent net exporter of GH₂ in the global market. Consequently, the following research question was posed.

Primary Question

What is the impact of dynamic capabilities on the adoption of green hydrogen technology moderated by innovation?

To answer the main research question, in line with the research problem statement and purpose, the following secondary questions were formulated.

Secondary Questions

Sub-question 1: What are the distinct impacts of the three attributes of the dynamic capabilities (sensing, seizing, and reconfiguring) on green hydrogen technology adoption moderated by innovation?

The DC framework is based on three dimensions, namely, sense, seize, and transform (Teece, 2018). This concept implies that its impacts on the adoption of green hydrogen

technology will occur through these three pillars. Furthermore, the distinct impacts of these three attributes (e.g., sensing, seizing, and reconfiguring) could differ in their effect on the adoption of green hydrogen technology. Teece (2018) argued that although the terminology “strong dynamic capabilities” generally suggests being strong in all three attributes (e.g., sensing, seizing, and reconfiguring), it is imperative to acknowledge that in real life, an organisation might outperform at sensing new business opportunities but also fall behind at developing a suitable business strategy to exploit these opportunities. Additionally, the organisation may be capable of developing a suitable business strategy, yet it may be relatively weak at executing it. This conclusion gave rise to Sub-question One.

Hypotheses

Based on the first secondary question, the following hypotheses were formulated:

- H1: Dynamic capabilities (sensing, seizing, and reconfiguring) positively influence the adoption of green hydrogen technology.
- H2: The three attributes of the dynamic capabilities (Sensing - H2a, Seizing – H2b, and Reconfiguring - H2c) have distinct impacts on green hydrogen technology adoption.

Sub-question 2: To what extent does innovation uniquely moderate the three attributes of dynamic capabilities: sensing, seizing, and reconfiguring, and thereof the relationship between dynamic capabilities and green hydrogen technology adoption?

This study has evaluated the direct impact of innovation – identified as a moderator – and to what extent it would separately impact the three attributes of DC (sensing, seizing, and reconfiguring) and subsequently the overall relationship between DC and green hydrogen technology adoption (Teece, 2018; Nawab and Shafiq, 2024). This led to the formulation of Sub-question 2. Consequently, the following hypothesis was formulated:

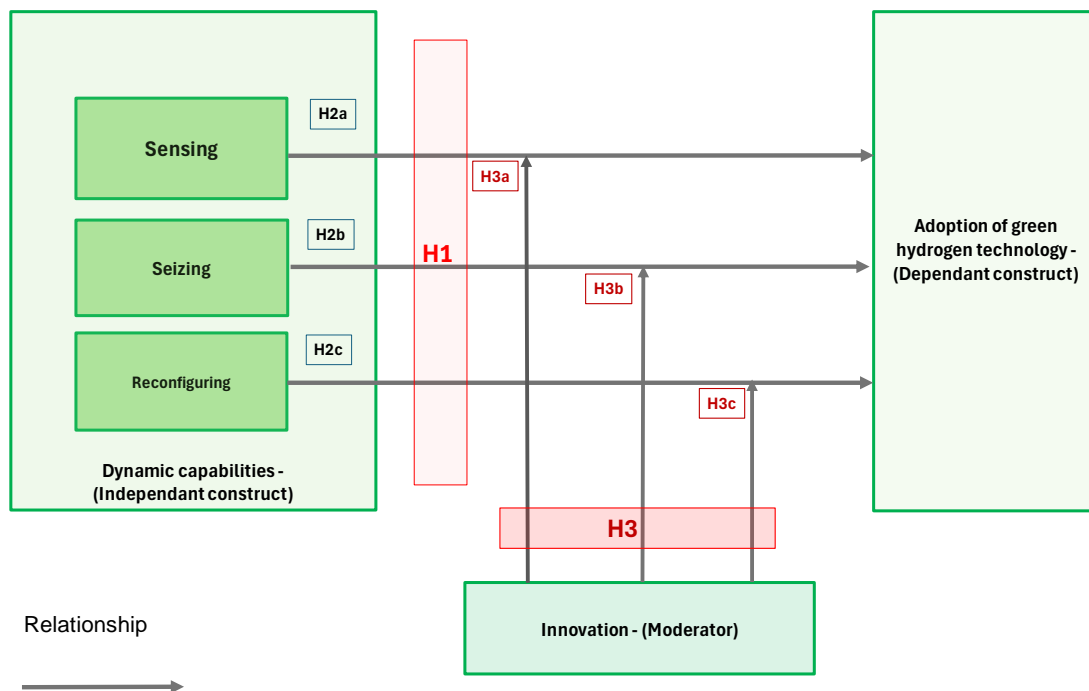
- H3: Innovation moderates the relationship between dynamic capabilities and green hydrogen technology adoption, such that the relationship is robust at a higher level of innovation.

In essence, this implies that a significant interaction effect in H3 would indicate that the influence of dynamic capabilities on green hydrogen technology adoption varies depending on the level of innovation within the organisation.

3.2. Proposed theoretical model

The proposed generic conceptual framework, which maps the flow to solve the research problem, is presented below in Figure 10. The conceptual framework accounts for the distinct impacts of the three attributes of the DC (sensing, seizing, and reconfiguring) on technology adoption. Similarly, innovation functions as a moderator of the DC-Adoption relationship.

Figure 10: Proposed conceptual model of the study



4. RESEARCH DESIGN AND METHODOLOGY

4.1. Introduction

Studies that explore the need for the South African energy industry to adopt the concept of dynamic capabilities while considering the distinct roles of sensing, seizing, and transforming are limited in the literature (Sijadu & Rathilal, 2024; Teece et al., 2016; Teece, 2018; Sharma & Mishra, 2014). This explanatory research work aimed to address this gap by assessing the impact of the dynamic capabilities on the adoption of green hydrogen technology within the South African energy sector, utilising a quantitative methodology.

This chapter also expands on the design approach and the methodology used to ensure that the objectives of the present study, as articulated in Chapters 1 and 2, were achieved. The chapter also elaborates on the statistical analysis approach, research ethics, quality control, and limitations.

4.2. Research design

4.2.1. Purpose of research design

Within the context of a quantitative study, an explanatory research approach aims to establish and understand the cause-and-effect relationships between two or more variables (e.g., independent and dependent variables) that are not clearly defined. It seeks to explain how and why certain events occur and correlate through a statistical analysis of data (Saunders & Lewis, 2018). The proposed conceptual model is presented in Chapter 3 (Figure 10). Considering the research question, which entails evaluating the impact of adopting a dynamic capabilities approach on the sustainability of the low-carbon hydrogen industry in South Africa – particularly GH₂, the use of an explanatory research approach could be justified. It is worthwhile noting that since this study aimed to replicate similarities and differences throughout the survey to uncover the nature of the relationship between the independent (dynamic capabilities) and dependent (technology adoption) variables, its whole design concept should be explanatory by nature (Pallant, 2020; Saunders & Lewis, 2017; Wegner, 2020).

4.2.2. Research philosophy

Conducting such research work required that the researcher remain neutral and passionately separated from the analysis to prevent biased findings. On the other hand, positivism refers to the philosophical stance of the neutral researcher and assumes that the reality being analysed is objective and can be observed, measured, and quantified (Saunders & Lewis, 2018). Hence, one can argue that positivism would be the most appropriate research philosophy since it aligns with the study's goal, which consisted of collecting survey objectives and observable data to analyse them and test hypotheses about cause-and-effect relationships— hence determining the impact of the dynamic capabilities approach (Saunders & Lewis, 2017; Wegner, 2020).

4.2.3. Selected approach

According to Saunders & Lewis (2018), deduction is an approach to theory development that entails formulating hypotheses derived from well-established theoretical principles and testing these through data collection and analysis. The main characteristic of this approach is to explain the causal relationship between variables and then operationalise the questions as testable propositions. Therefore, it is logical and practical for this research study to employ a deductive approach, as the aim is to test the well-established Dynamic Capabilities Theory within a specific context using data analysis collected from a survey (Saunders & Lewis, 2017; Wegner, 2020).

4.2.4. Methodological choices

The mono-method quantitative approach, unlike other approaches, focuses specifically on numerical data collection (e.g., through a quantitative method) and analysis. Since the current study focused on quantifiable impacts and relationships of well-defined constructs (e.g., the dynamic capabilities approach and GH2 technology adoption) – which were expected to be operationalised using surveys and guided by the selected research philosophy, positivism, the mono-method quantitative approach was found to be the appropriate methodology of choice for this study (Saunders & Lewis, 2017; Wegner, 2020).

The mono-method quantitative approach focuses solely on statistical relationships, thereby neglecting to some extent the broader social and cultural contexts that could influence the respondents' behaviour towards the adoption of a new technology study (Saunders & Lewis, 2017; Wegner, 2020). To mitigate such limitations, the research methodology was therefore designed to minimise the influence of external factors, particularly during the early stages of the data collection process. In fact, respondents were invited to participate in the survey as professionals in their personal capacities rather than as employees of a specific firm or members of an organisation, for example, an environmental organisation. Adopting this approach reduced any potential biases that could influence their perceptions of the current study and, by extension, their responses (Saunders & Lewis, 2017). Furthermore, the survey questionnaire was designed in a way that minimises bias, as respondents were not compelled to disclose opinions that could potentially affect their employee-employer relationships (e.g., by elaborating on political and societal factors in relation to their professions).

4.2.5. Strategy

A survey entails a systematic collection of data from a substantial cohort of respondents. This technique, a practical and cost-effective research tool, is generally used in quantitative studies because it allows the analyst to conduct a statistical analysis capable of testing the relationships between variables (Saunders & Lewis, 2018). On the other hand, the primary focus of this research work was to quantify the impact of the dynamic capabilities approach (e.g., sensing, seizing, and transforming) on the adoption of low-carbon hydrogen in South Africa. It was expected that this would involve multiple stakeholders from the local and internal energy and petrochemical industry, policymakers, South African statutory regulatory bodies (e.g., the Engineering Council of South Africa), and government agencies (e.g., the South African National Energy Development Institute); supply chain partners and industrial offtakers; academics; R&D institutions; and industry experts.

An online survey was found to be the most appropriate research strategy for this quantitative study, specifically a structured survey questionnaire using the 7-point Likert scale. It was expected that the majority of the targeted participants would have access to the internet and smartphones or computers. This made the process more practical

and cost-effective. The choice of this strategy was also guided by the selected research philosophy, positivism, and factors such as project time and resource constraints. (Saunders & Lewis, 2017; Wegner, 2020).

4.2.6. Time Horizon

The cross-sectional approach intends to study a particular subject by collecting data at a particular time (Saunders & Lewis, 2018). Although the primary goal of this research work was to evaluate the impact of the dynamic capabilities approach on sustainability in a dynamic market, it did not intend to track these impacts over some time but rather assess the current impacts within a defined period and context.

Hence, the cross-sectional time horizon would be the appropriate approach to use. This is because the study focuses on the analysis of the relationships and impacts at a limited time, which aligns with the research question. However, it is worthwhile to acknowledge that a cross-sectional design has the potential to limit the ability to observe long-term trends in technology adoption. Positivism, the guiding research philosophy, also informed this selection (Saunders & Lewis, 2017; Wegner, 2020).

4.3. Research Methodology

Research methodology choice

Research into dynamic capabilities and technology adoption has previously been conducted through qualitative and quantitative as well as mixed methodologies. And each of these methodologies offers its own benefits and limitations (Chen, 2024; Easterby-Smith, Lyles, & Peteraf, 2009; Harichandan & Kar, 2023).

This present work aimed to assess the impact of the dynamic capabilities on the adoption of green hydrogen technology within the South African energy sector. Hence, the quantitative methodology was found to be the appropriate approach since it aligned with the primary intent of this research study, which was to assess the relationship between measurable constructs, namely the dynamic capabilities and green hydrogen technology. (Harichandan & Kar, 2023).

Furthermore, the selection of the quantitative approach was justified by the fact that the methodology enabled the analysis of numerical data to identify patterns, test the postulated hypotheses, and ascertain correlations between variables (Teece et al., 1997; Mikalef and Pateli, 2017).

4.4. Population

The research strategy for this quantitative study was a survey, which targeted multiple stakeholders involved in the green energy sector with adequate knowledge, expertise and understanding, such as:

- Senior managers from various energy industries and/or involved in organisational strategy development for green and renewable energy adoption.
- Policymakers and stakeholders working on renewable and green energy policies.
- Industry experts and engineers (including project managers) engaged in the green energy project cycle (e.g., from concept development to deployment of hydrogen technologies).
- Local and international researchers from academia, R&D communities and national energy agencies.
- International regulatory institutions (e.g., EU Green Hydrogen Research Hub).
- Energy business practitioners.
- Green energy supply chain partners and industrial offtakers.

This range of population was selected because it enabled the researcher to collect information from a wide range of respondents with various backgrounds in the hydrogen field. Also, it was assumed that respondents possessed relevant and adequate know-how, understanding and influence in the adoption of GH₂ technologies and the industry's dynamic capabilities as well as its chain value. Furthermore, this selection range was expected to ensure consistency of data that were comparable (Pallant, 2020; Saunders & Lewis, 2017; Wegner, 2020).

4.5. Unit of analysis

The unit of analysis was the South African energy industry stakeholders at the institutional and organisational level (e.g., both local and international energy professionals). This unit of analysis was selected because the study intended to **evaluate** how the dynamic capabilities impact the green hydrogen technology adoption across the energy industry, rather than within a specific organisation level (Wegner, 2020).

4.6. Sampling method and size

A purposive, non-probability sampling technique was employed in a way that ensured a balanced representation across diverse industry stakeholders. To support this, strata were defined based on the professional role of participants (e.g., senior managers, policymakers, engineers, etc.), their functions and seniorities, the primary organisation's sector, etc. Adequate sampling size as suggested by Saunders & Lewis (2017) was specified based on power analysis to achieve satisfactory statistical significance (e.g., a minimum of 120 respondents). It was envisaged that this sampling size would be sufficient to run a multiple linear regression approach (Pallant, 2020; Saunders & Lewis, 2017; Wegner, 2020). This approach had demonstrated significant benefits, as bias risks were minimised.

A snowball method was also considered as a secondary sampling method. Sampling technique, supported by social media such as LinkedIn, was used to identify and select the most suitable participants, thereby meeting the goal of the research work.

Relevant and adequate technical knowledge (e.g., academic or professional training in GH₂ technology, GH₂ value chain, and the financial green hydrogen market), seniority in the green energy field, field of expertise (type of industry), and financial and project execution (e.g., understanding of possible economic impacts of the adoption of GH₂ technologies in the energy and global markets) were used as criteria to support the equitable sampling. Expanding upon this argument, previous researchers reported that including respondents with less experience within the green technology led to significant deviation (Taghizadeh et al., 2023).

4.7. Measurement instrument

A structured questionnaire using validated scales for the three constructs and a 7-point Likert scale was developed and used as the primary data collection instrument to measure each construct, including dynamic capabilities (independent construct) and green hydrogen technology adoption (dependent construct), as well as a moderator (innovation). The proposed scale is presented in Table 3. To understand the mechanisms and nature of the relationship between dynamic capabilities and green hydrogen technology adoption, innovation was assessed as a moderating factor for this relationship. Selecting the 7-point Likert scale permitted capturing perceptions and attitudes, which were essential for understanding the relevancies of the constructs (Pallant, 2020; Saunders & Lewis, 2017; Wegner, 2020).

4.7.1. Construct operationalisation

Independent construct - Dynamic capabilities (DC)

Measured on the attributes (sensing, seizing, reconfiguring) with 4 - 6 items per dimension using a scale adapted from Teece et al. (1997), Mikalef and Pateli (2017), Nawab and Shafiq (2024) and Makkonen et al. (2014).

Dependent construct - green hydrogen technology adoption

Measured through investment, operational integration, and stakeholder acceptance (3–6 items per dimension). Metrics included the number of green hydrogen projects implemented, the scale of investment made in green hydrogen projects, etc. The scales developed by Nawab and Shafiq (2024) and Buchner et al. (2025) while evaluating the extent of adopting and integrating green GH₂ technologies were used.

Moderator - Innovation

Measured through the number of new products or processes introduced - the overall innovation culture within the industry and the level of investment in R&D (4 - 6 items each).

4.7.2. Survey questionnaire design

This study used metrics derived from prior research works (Rocha et al., 2023; de Souza Bermejo et al., 2016). However, minor adjustments were made to ensure alignment with the specific objectives and context of the present investigation.

The research questionnaire was designed to gather information from each respondent on the defined variables, including dynamic capabilities (sensing, seizing and reconfiguring), green technology adoption, and innovation, to support the research objectives. The consistency matrix is presented in Appendix 3.

Questions were arranged in a way that ensured a logical flow of thought while minimising confusion and misinterpretation (Saunders & Lewis, 2014). Appendix 5 provides the survey questionnaires.

Table 3: The 7-point Likert scale

1	Strongly Disagree
2	Disagree
3	Somewhat Disagree
4	Neutral
5	Somewhat Agree
6	Agree
7	Strongly Agree

4.7.2.1. Control variables

Section 2 in Appendix 5 contains six questions related to various characteristics of the participants, including academic level, professional experience, type of industry, and geographical region of professional activity. The objective of developing this set of questions was, firstly, to determine the suitability of the respondents for the research, and secondly, to serve as control variables (Makkonen et al., 2014; Nawab and Shafiq, 2024).

Existent literature suggests that the lack of governmental green energy policy and the lack of aligned standardisation and certification schemes have significant impact on the level of adoption of GH₂ across various regions and commodity sectors (Odenweller & Ueckerdt, 2025). Accordingly, an additional set of questions relative to governmental green energy policy on green hydrogen, which served as control variables, was introduced. Refer to item “Control variable” in Table 2 in Appendix 5.

4.8. Data gathering process

Various means of communication (e.g., personalised email invitations, LinkedIn, industry associations, South African energy regulatory bodies, university conferences, etc.) were used to identify and reach out to a wider audience. A set of questionnaires, as outlined in Appendix 5 (structured survey), was developed and used for data collection via a survey. Note that a pilot interview was conducted to ensure clarity and reliability of the questionnaires. A questionnaire was sent to a maximum of 10% of the proposed sample size (e.g., 140 respondents) to gauge the level of clarity and appropriateness of the questions. Note that green energy is a nascent and, to some extent, controversial topic characterised by less objective, rational opinions, even from industry professionals, who generally tend to demonstrate a supportive attitude towards the South African industry's commitment to the "Paris Accord". This is a reality that several African nations are experiencing (Ayodele & Munda, 2019; AbouSeada & Hatem, 2022).

An online survey using Microsoft Forms platform was conducted to reach a wider range of respondents, and this facilitated easy reminders to maximise response rates. Also, most respondents had access to smartphones and computers. The reason for selecting an online survey was that it is cost-effective, has fewer resources and enabled timely data collection from geographically dispersed respondents (Wegner, 2020; Saunders & Lewis, 2017).

As previously indicated, the structured questionnaire using validated scales for key constructs, informed by similar previous works, was utilised (Teece et al., 1997; Nawab and Shafiq, 2024; Rocha et al., 2023; de Souza Bermejo et al., 2016).

To alleviate the risk of a low response rate, early engagement with identified respondents was conducted. This entailed contacting potential respondents via social media, particularly LinkedIn, and introducing them to the scope of research work, its objective and its relevancy. And conveying a clear message regarding the confidentiality and anonymity requirements.

Previous researchers such as Buchner et al. (2025) have successfully used this approach, so we anticipated positive results. Buchner et al. (2025) contended that early public engagement was a pivotal factor in achieving a higher response rate in the adoption process of green hydrogen while examining the public acceptance of green hydrogen production in Germany.

Potential participants were requested to refer other professionals that meet the population criteria (Buchner et al., 2025; Wegner, 2020; Saunders & Lewis, 2017).

4.9. Data analysis approach

The Statistical Package for the Social Sciences software (SPSS) was used. The use of this software enabled testing the constructs, mediation and moderation relationships, as well as their direct effects. The software R version 4.3.1 was used for graphical display (e.g., generating the charts of composite score distributions of constructs).

Linear regression was used because such a technique supported the intent of the research work, which consisted of assessing the impact of the DC on the adoption of green hydrogen technology. In fact, adopting the linear regression permitted examining the relationship between the two constructs, namely the dynamic capabilities (independent variable) and the technology adoption (dependent variable). Furthermore, because the hypotheses had to be tested, adopting the linear regression approach was imperative and relevant, as it enabled the quantification of the strength and direction of the relationship of two constructs (Buchner et al., 2025; Wegner, 2020; Saunders & Lewis, 2017).

After data collection through the structured questionnaire that was developed using validated scales for key constructs, the data analysis was then conducted (Wegner, 2020).

4.9.1. Research ethics

The GIBS ethics protocol, as stipulated in the Applied Business Analysis and Research Report Regulations – 2025 (University of Pretoria, 2025), was strictly followed. For example, all the information collected were confidential and anonymous. And data were handled in accordance with the University of Pretoria's confidentiality policies. Appropriate methods were used to ensure that data are safely stored (for example, in a cloud system) in an accessible format for a minimum period of 10 years.

Furthermore, participants were requested to complete the survey in their personal capacity as professionals to minimise potential conflict of interest with their employers that could influence their responsiveness towards the interview.

To assure the confidentiality and anonymity of the respondents and their data, the researcher, as a minimum, abided by the following:

- No names were requested, and no identifier was allocated to any collected data.
- Only aggregated information was captured and reported.
- No names of the individuals and/or organisations were reported or divulged.

Respondents were engaged via social media platforms such as LinkedIn. However, the researcher fully complied with the Protection of Personal Information Act, 2013 (POPIA), which regulates the collection, storage, use, and sharing of personal information by both public and private entities. Note that all collected data were stored on a password-protected cloud drive. The ethical clearance certificate is presented in Appendix 4.

4.9.2. Quality Controls

One of the most critical steps in a statistical analysis is quality control, as it helps identify and correct errors in data collection and entry at the early stage of the analysis. Quality control ensures accuracy, reliability, and trustworthiness as well as scientifically sound conclusions of research findings - repeatable results (Wegner, 2020; Saunders & Lewis, 2017). Hence, the following tests were conducted.

Pilot Testing

This analysis was achieved as follows: First, response time per question was analysed to detect items that may require excessive cognitive effort. Questions that exhibited evident high average response times was flagged for potential rewording. Consequently, the survey protocol was designed in a way that respondent had to each question before moving to the next question. This approach allowed the researcher to ensure there were no skipped question.

Note that respondents were asked to rate the perceived clarity of each question on a 5-point Likert scale (e.g. 1 = Not clear at all, 5 = Very clear). And where a mean clarity scores below 4 was achieved, further evaluation and revision of the relevant items were conducted (Arifin and Frmanzah, 2015).

4.9.3. Data cleaning and screening

In statistical studies, this step is always required to ensure that adequate validity of constructs and reliability of the measuring instruments were adequately achieved. (Wegner, 2020; Saunders & Lewis, 2017). For the purpose of this work, the survey protocol required respondents to answer each question before moving on. This strategy allowed to prevent missing data.

4.9.4. Validity testing of constructs

High validity research suggests that findings correlate to genuine features and variances in either the physical or social reality (Smith & Doe, 2006). Hence, to achieve a minimum variation in data collection, the scope of the work across the professional value chain of green energy was limited to professionals who have sufficient and practical experience in project implementation and execution, as this would enable an acceptable level of homogeneity within the population group - in fact, respondents were able to provide consistent, reliable, comparable, and real-world answers, hence limiting the potentially reduced validity of the findings. This strategy enabled better quality control by making minor discrepancies in results apparent (Wegner, 2020; Saunders & Lewis, 2017).

Prior to conducting the exploratory factor analysis the suitability of the data was assessed by means of the Kaiser-Meyer-Olkin (KMO) measure and Bartlett's test of

sphericity. This enabled the researcher to determine whether variables were sufficiently correlated to justify using factor analysis. Note that KMO and Bartlett test results (planned) were strictly used for factorability.

For the purposes of this study, A KMO index value closer to 1 (e.g., ranging between 0.79 and 1.00) was deemed acceptable. Statistical works conducted by Odenweller & Ueckerdt (2025) reported a value of 0.86, suggesting that there are significant correlations among variables - factor analysis is appropriate. The scale reported by Smith and Doe (2023), as depicted in Table 4, was used as a guideline for the validity test (Kaiser, 1974).

Table 4: KMO Index

KMO Index	Interpretation
0.90 to 1.00	Marvelous – Excellent suitability
0.80 to 0.89	Meritorious – Very good
0.70 to 0.79	Middling – Acceptable
0.60 to 0.69	Mediocre – Adequate
0.50 to 0.59	Miserable – Poor
Below 0.50	Unacceptable – Do not proceed

For the Bartlett’s Test of sphericity, it was expected that a p -value smaller than 0.05 ($p < 0.05$) would be achieved, suggesting that there were significant correlations among variables - factor analysis was appropriate (Wegner, 2020; Saunders & Lewis, 2017; Kaiser, 1974). Exploratory factor analysis was conducted to determine if the observable questions for each construct together did in fact measure the associated constructs.

4.9.5. Exploratory factor analysis

Exploratory factor analysis (EFA) was conducted to understand the factor structure of the sample, identify the weak items and remove them from the scales through statistical reasoning.

4.9.6. Reliability testing of the instrument

It was crucial that the reliability – which relates to the consistency of a measure - of questionnaires and scales used in quantitative research be established prior to conducting the analysis (Wegner, 2020; Saunders & Lewis, 2017). Therefore, the Cronbach's Alpha tests were conducted to ensure internal consistency.

Cronbach's Alpha values greater than or equal to 0.70 were considered desirable in reliability analysis. However, if the Alpha value was found to be less than 0.7, the result could be acknowledged as one of the limitations of the study (Wegner, 2020; Saunders & Lewis, 2017). The scale of the Alpha value depicted in Table 5 was used as a guideline to test the reliability (Cronbach & Dennick, 2011; Smith & Doe, 2006).

Table 5: Cronbach's Alpha

Alpha Value	Interpretation
≥ 0.90	Excellent (but could indicate redundancy)
0.80 – 0.89	Good
0.70 – 0.79	Acceptable
0.60 – 0.69	Questionable
0.50 – 0.59	Poor
< 0.50	Unacceptable

4.9.7. Inferential statistical analysis

Inferential analyses were conducted to test three hypotheses: (i) whether stronger dynamic capabilities (DC) are associated with higher levels of green-hydrogen technology (GHT) adoption; (ii) the distinct impacts of the three attributes of the dynamic capabilities (sensing, seizing, and reconfiguring) on green hydrogen technology adoption; and (iii) the extent to which innovation moderates the relationship between DC and GHT adoption. The procedures followed established guidance (Saunders & Lewis, 2017; Wegner, 2020). Detailed inferential tests for each hypothesis are reported in Chapter 5.

4.9.8. Limitations

Statistical analysis is a useful tool for finding patterns and testing hypotheses, however, it may have several limitations that can impact the validity and reliability of the results (Saunders & Lewis, 2017; Wegner, 2020). These include:

The mono-method quantitative approach focused solely on statistical relationships, thereby neglecting to some extent the broader social and cultural contexts that could influence the respondents' behaviour (Saunders & Lewis, 2017; Wegner, 2020). For example, respondents may provide skewed and non-representative responses in an attempt to portray an environmentalist posture of the industry; and present themselves as environmentally conscious.

Large sample sizes are required to achieve statistical significance in quantitative research. Due to the potentially limited number of respondents – since green hydrogen is still a nascent technology – achieving a large sample size within the South African green hydrogen sector was a major challenge, and this could potentially impact the results. For example, the respondent's distribution based on industry sector (Figure 12) suggested that the sample was an energy-centric, private-sector-dominant sample – primarily oil & gas and petrochemicals (>35%) – with limited participation from government and policy actors (<5%). This imbalanced distribution introduced, to some extent, sampling bias and limited the representativeness of the findings (Wegner, 2020).

Certain categories of stakeholders within the energy industry were underrepresented. Particularly in sectors such as policy assurance, government regulatory bodies, supply chain and distribution, business and end-user strata (Figure 12). Under representation of these sectors limited to some degree representativeness and weakens the external validity of inferences to South Africa's wider green-hydrogen landscape (Saunders & Lewis, 2017; Wegner, 2020).

It was found that low response rates, within the sectors such as the government regulatory bodies and consulting & professional services, occurred possibly due to the respondents wanting to demonstrate adherence of the South African industry to the "Paris Accord" or being bound by employer-employee non-disclosure agreements. Such tendency was mainly observed during the trial test.

It is worthwhile noting that these limitations have highlighted the challenge of working in an emerging field where real-world and extensive operational aggregated data (e.g., information on renewable green hydrogen production) are not yet broadly accessible, and the techno-economic bodies of knowledge (e.g., cumulative production capacity of PEM electrolyzers) are limited. Thus, the results were prone to a certain level of approximation (Saunders & Lewis, 2018; Wegner, 2020).

Despite these limitations, the study has provided a scientific tool for engagement between key stakeholders, including South Africa's energy industry, regulatory architecture and civil-society engagement, with the goal of achieving net green energy exports – an essential condition for a just energy transition (Department of Mineral Resources and Energy, 2021).

This research has also provided valuable insights for various stakeholders in academia, policymaking, and business across Africa by emphasising strategic methods essential for the extensive implementation of renewable energy (Bhagwat & Olczak, 2020; Bandiri et al., 2024).

5. RESEARCH RESULTS

5.1. Introduction

Chapter 5 presents and interprets the empirical findings from the online survey undertaken in this study. First, the chapter summarises the survey participation by covering the response rate, then profiles the sample using demographics and descriptive statistics. The chapter further presents the outcomes of data cleaning and screening, as well as the composite score-distribution analysis. Next, the chapter outlines the procedures used to assess the measurement instrument's validity and reliability. Finally, it presents the statistical analyses that test the relationships between the core constructs, including dynamic capabilities, technology adoption, and innovation. The role of innovation as a moderator is also presented.

While evaluating whether innovation moderates the relationship between DC and GHT, the analysis emphasised the distinct effects on the three attributes of dynamic capabilities: sensing, seizing, and reconfiguring. The effect of the South African policy – as a control variable – is also evaluated.

Lastly, the chapter assesses the direct impact of innovation and to what extent it moderates separately the three attributes of DC (sensing, seizing, and reconfiguring).

The results obtained from the statistical analysis are further discussed in Chapter 6.

5.2. Response rates

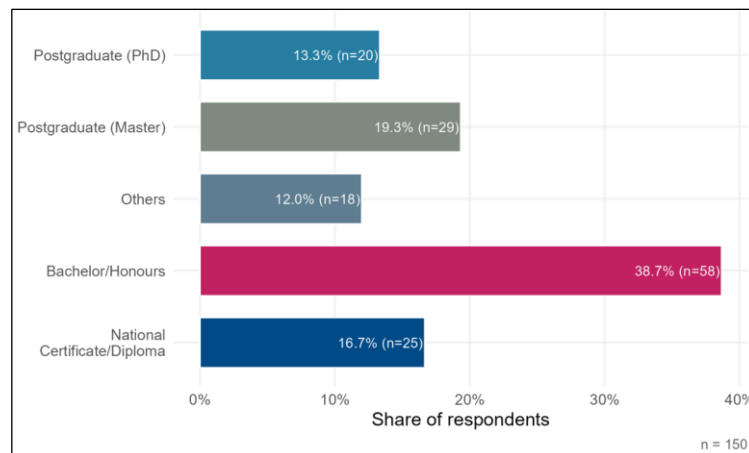
The survey, conducted using Google Forms, was open for five weeks starting on August 13, 2025. Over that period, 329 invitations were distributed, and 150 complete responses were obtained. The achieved response rate was 45.6%, and all completed cases (n = 150) were analysed.

5.3. Response demographic

- **Percentage of respondents based on academic level**

Figure 11 depicts the academic qualification distributions of the 150 people who took part in the survey. The largest group of respondents 38.70% (n=58) had a bachelor's or honours degree; the next largest groups 19.30% (n=29) were those with a master's degree, followed by those with a national certificate or diploma 16.70% (n=25). A smaller group at 13.30% (n=20) held a PhD degree, while the "others" category at 12% (n=18) included other types of degrees, such as professional certificates. These observations suggest that the cohort was highly educated.

Figure 11: Respondents academic levels

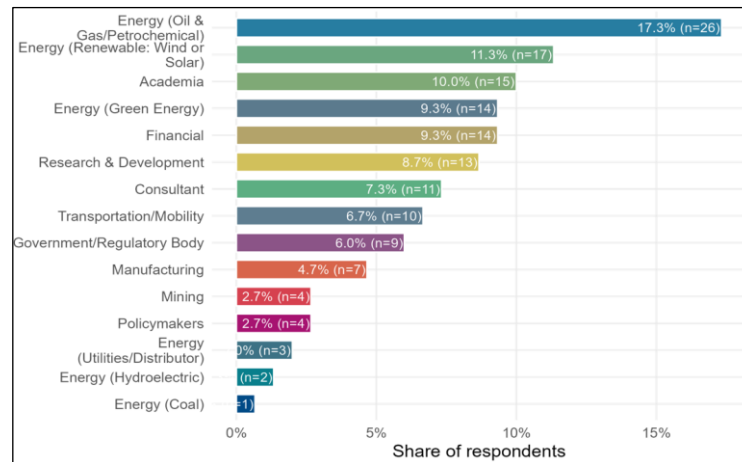


- **Respondent distribution based on industry sector**

Figure 12 shows the sectoral distributions of the 150 respondents. The largest group, 17.30% (n = 26), came from the energy industry, specifically the oil & gas/petrochemical sectors; the next largest, 11.30% (n = 17), were from the renewables & wind/solar sectors, followed by the academia at 10.0% (n = 15). Comparable shares were observed for the green energy sector at 9.30% (n = 14) and financial services at 9.30% (n = 14). Smaller groups were made of the research & development sectors at 8.70% (n = 13), consultants at 7.31% (n = 11), and transportation/mobility at 6.70% (n = 10). Less representation came from the government and regulatory body at 6.0% (n=9), and manufacturing at 4.70% (n = 7), while mining sector at 2.70% (n = 4) and policymakers

at 2.70% (n = 4) were limited. Only marginal participation was recorded from the energy (Utilities) sector at 2.01% (n = 3), hydroelectric at 1.31% (n = 2), and coal at 0.70% (n = 1). In conclusion, the sample was energy-centric and private-sector heavy, mainly led by the oil & gas and petrochemicals, with meaningful renewables, academia, and finance representation. But with limited input from government, utilities, mining, and coal.

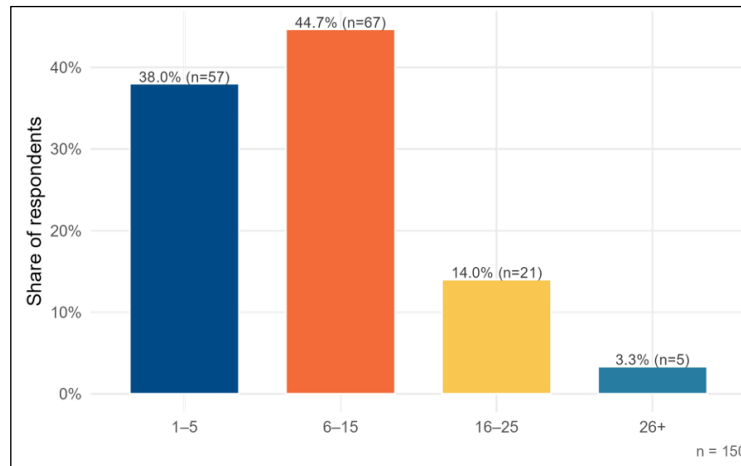
Figure 12: Respondents as per industry sectors



- **Respondent distribution by years of professional experience**

Figure 13 displays respondents based on the range of years of working experience in their specific fields – not necessarily involved in the green hydrogen sector. The largest group consisted of respondents with 6 to 15 years of experience, accounting for 44.71% (n = 67), while the second largest group included those with 1 to 5 years of experience, representing 38% (n = 57). A smaller share, 14.01% (n = 21), had 16-25 years of experience, and only a few respondents, at 3.3% (n=5), have worked in the energy domain for 26 years or more. Overall, the cohort was early- to mid-career. About 83% have 1 to 15 years of working experience in the energy sector; with relatively few long-tenured specialists (+26 years).

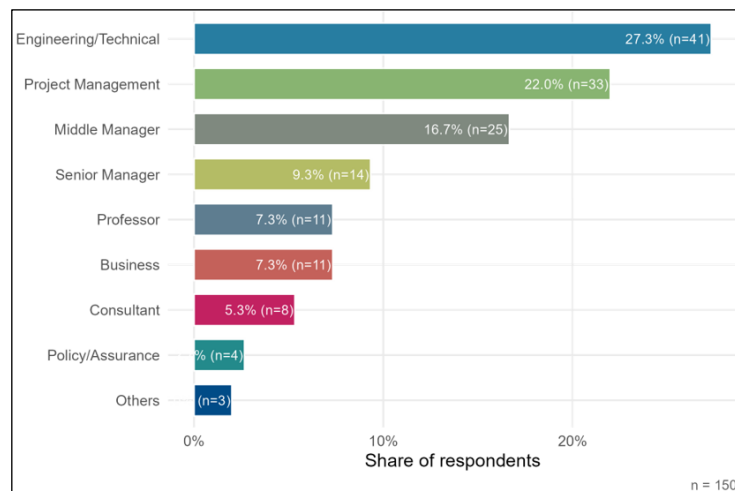
Figure 13: Respondents professional experience levels



- **Respondent’s professional roles**

Figure 14 summarises the respective sectors represented by the 150 respondents. The largest share of respondents worked in engineering and technical roles 27.30% (n = 41), followed by project management (22.01%, n = 33). Middle managers comprised 16.7% (n = 25) and senior managers 9.3% (n = 14); whereas professors accounted for 7.31% (n = 11) and business roles for 7.30%, (n = 11) were equally represented. Consultants accounted for 5.31% (n = 8), while policy/assurance 2.70% (n = 4) and “other” formed the smallest groups (2.01% (n = 3). Overall, the respondent pool was predominantly professional and industry-facing.

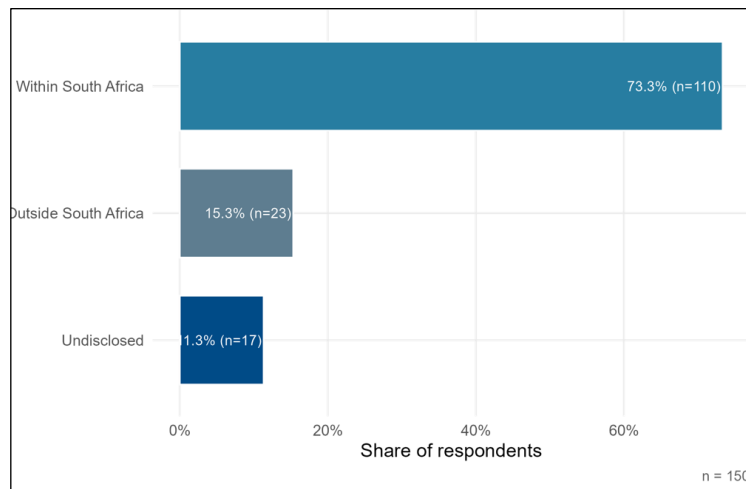
Figure 14: Respondent’s professional roles



- **Respondent’s geographical region of professional activity**

As shown in Figure 15, the majority of respondents were based in South Africa (73.30%, n = 110), while a smaller share worked outside the country (15.31%, n = 23); a further 11.30% (n = 17) did not report their region. Overall, the sample was strongly South Africa–focused. This was consistent with the study’s primary scope, a focus on the South African energy sector, while considering perspectives from other regions as well.

Figure 15: Respondents geographical locations



5.4. Data cleaning & screening

Because the dataset contained no missing values, Little’s MCAR test – used to assess the pattern of missing data – was not applicable and was therefore not performed (Saunders & Lewis, 2017; Doane & Seward, 2024).

5.5. Composite score distributions

The composite score distributions analysis was conducted to evaluate how respondents’ averaged ratings were spread, where they clustered, and whether ceiling or floor effects could affect later inference. The analysis enabled the researcher to summarise the central tendency and dispersion at the construct level, ensure sufficient variance for hypothesis testing, and provide an early reliability and face-validity check

before conducting correlation and regression analyses (Doane & Seward, 2024; Hirschauer et al., 2020).

Results presented in Appendix 7 suggested that across the subscales, sensing scores clustered toward the upper range with modest spread and a slight left skew, indicating broad agreement on strong sensing capability. Seizing was similarly top-heavy above the midpoint – with a mild ceiling effect yet retained variability – suggesting a general endorsement of seizing behaviours. Reconfiguring showed higher values with few low outliers and a gentle left skew, pointing to favourable views of the sector’s reconfiguring capacity.

These patterns indicate consistent positive but not saturated perceptions – adequate dispersion to support subsequent modelling. These observations were therefore used to motivate and interpret the inferential tests reported in the main results, further down in this chapter (Doane & Seward, 2024).

5.6. Validity testing of constructs

Prior to the inferential statistical analysis, the validation of the constructs underpinning the research questions had to be carried out. The suitability of the data for exploratory factor analysis (EFA) was confirmed using the Kaiser–Meyer–Olkin (KMO) measure of sampling adequacy and Bartlett’s test of sphericity (Bartlett, 1950; Kaiser, 1974; Saunders & Lewis, 2017). The resulting metrics are reported in the sub-sections that follow.

5.6.1. Kaiser Meyer Olkin (KMO)

As shown in Table 6 the KMO measures of sampling adequacy, including DC, technology adoption and innovation are greater than the specified lower limit of 0.70 as indicated in Table 4 (Doane & Seward, 2024; Kaiser, 1974). All values are well above 0.80, suggesting that the data were excellent for factor analysis. Table 6 further shows that the KMO measures of sampling adequacy of all the constructs fall within the specified range (e.g. between 0.79 and 1.00) as formulated in Chapter 4, section 4.9.4 (Kaiser, 1974).

Table 6: KMO and Bartlett's Summary by Scale

Scale	KMO	Bartlett_Chi2	Bartlett_df	Bartlett_p
Sensing (DCS)	0.844	271.812	10	.001
Seizing (DCZ)	0.828	282.465	6	.001
Reconfiguring (DCR)	0.855	318.875	10	.001
Tech Adoption (GHTA)	0.870	327.077	10	.001
Innovation (INNOV)	0.860	366.323	10	.001

5.6.2. Bartlett's test for sphericity

The Bartlett's test of sphericity was conducted to tests whether items were sufficiently correlated to form factors. The results of the Bartlett's test of sphericity - as presented in Table 7 - suggested that all scales had large chi-values (≥ 270) with p values smaller than 0.05 ($p < 0.05$), suggesting that there were significant correlations among variables and factor analysis was appropriate for $N = 150$ (Bartlett, 1950).

Table 7: Kaiser-Meyer-Olkin Measure

Kaiser-Meyer-Olkin measure of sampling adequacy.		0.846
Bartlett's Test of Sphericity	Approx. Chi-Square	1853.309
	df	276
	Sig.	<.001

5.7. Exploratory factor analysis results

The exploratory factor analysis (EFA) was conducted with the intent of understanding the factor structure of the sample, identifying the weak items and removing them from the scales through statistical reasoning (Kaiser, 1974; Saunders & Lewis, 2017; Wegner, 2020). The analysis results suggested the following:

- The DC construct breaks into three distinct but related attributes (e.g. sensing, seizing and reconfiguring).
- Green technology adoption and innovation each stand alone as single constructs.
- The factor loadings and variance explained confirm that the survey questions are working well and measuring what they were designed to measure.

Dynamic capabilities (3-factor; ML with oblimin)

Table 8 shows that the items group neatly into three clusters (factors).

- F1: Reconfiguring (DCR1–DCR5) → loadings around 0.683 – 0.777
- F2: Sensing (DCS1–DCS5) → loadings around 0.641–0.787
- F3: Seizing (DCZ1–DCZ4) → loadings around 0.767–0.817

These results indicate that each item had its strongest loading on the expected factor and very low cross-loadings on the others. This pattern suggests that the survey questions clearly captured all three separate related constructs, including sensing, seizing, and reconfiguring.

Table 8: Dynamic capabilities (3-factor; ML with oblimin)

Item	F1	F2	F3	abs	Primary
DCR5	0.777	-0.128	0.032	0.777	F1
DCR4	0.762	0.073	-0.044	0.762	F1
DCR1	0.755	0.003	-0.006	0.755	F1
DCR3	0.735	0.040	0.001	0.735	F1
DCR2	0.683	0.065	0.049	0.683	F1
DCS3	0.000	0.787	-0.034	0.787	F2
DCS2	-0.008	0.760	0.049	0.760	F2
DCS5	-0.014	0.689	-0.066	0.689	F2
DCS1	0.068	0.673	-0.016	0.673	F2
DCS4	0.003	0.641	0.132	0.641	F2

Item	F1	F2	F3	abs	Primary
DCZ4	-0.063	-0.036	0.817	0.817	F3
DCZ2	-0.016	0.075	0.791	0.791	F3
DCZ3	0.035	-0.013	0.781	0.781	F3
DCZ1	0.074	-0.004	0.767	0.767	F3

F1, F2, F3 are Factor 1, Factor 2, Factor 3 extracted with Maximum Likelihood (ML) and rotated with oblimin. Loadings < |.10| shown as 0.00 for brevity.

Variance accounted (Dynamic capabilities)

Table 9 shows how much of the overall variation was explained by the three DC factors: Factor 1 explains 20.10%; Factor 2 explains 18.61% and Factor 3 explains 18.2%.

All three factors, put together, explain about 57% of the total variance before rotation, and the rotated solution showed that each factor contributes evenly. In conclusion, the three DC dimensions together explained more than half of the differences in responses, which is a strong result for social science data (Wegner, 2020; Saunders & Lewis, 2017; Kaiser, 1974).

Table 9: Variance accounted (Dynamic capabilities)

Metric	ML1	ML2	ML3
SS loadings	2.813	2.609	2.552
Proportion Var	0.201	0.186	0.182
Cumulative Var	0.201	0.387	0.570
Proportion Explained	0.353	0.327	0.320
Cumulative Proportion	0.353	0.680	1.000

ML1, ML2, ML3 are the first, second, and third factors extracted using Maximum Likelihood EFA.

Green hydrogen tech adoption (1-factor)

Table 10 shows that all five items (GHTA1–GHTA5) loaded strongly on a single factor. The loadings are noticeable high (0.674 – 0.806) suggesting that all items align well with the idea of green technology adoption – the items measure one clear construct (Hirschauer et al., 2020).

Table 10: Green tech adoption (1-factor)

Item	Loading
GHTA1	0.763
GHTA2	0.674
GHTA3	0.806
GHTA4	0.760
GHTA5	0.766

Innovation (1-factor)

Table 11 shows that all five items (INNOV1–INNOV5) also load strongly on a single factor, and the loadings are consistently high (0.712 - 0.833). Similarly to GHTA, innovation is also a single, coherent construct.

Table 11: Innovation (1-factor)

Item	Loading
INNOV1	0.712
INNOV2	0.822
INNOV3	0.732
INNOV4	0.749
INNOV5	0.833

In conclusion, the following can be stated:

- Dynamic capabilities break into three distinct but related attributes (e.g., sensing, seizing, reconfiguring).

- The green hydrogen technology adoption and innovation each stand alone as single constructs.
- The factor loadings and variance explained confirm that the survey questions are working well and measuring what they were designed to measure.

5.8. Reliability of the instrument (Cronbach’s alpha)

The study’s methodology, as stipulated in Chapter 4, section 4.9.5, evaluated the reliability of the instrument using the Cronbach’s alpha for each construct (Cronbach, 1951). All construct coefficients - with the lowest value being 0.841 - were found to be greater than 0.80, suggesting good internal consistency for the scales employed. The scale of the Alpha value used as a guideline to test the reliability is depicted in Table 5, in Chapter 4 (Cronbach, 1951; Tavakol & Dennick, 2011). This trend suggests that the questions designed to measure the same idea (e.g., sensing, seizing, innovation, etc.) enabled the researcher to achieve consistent results across all respondents.

The reliability analysis indicated that the study’s measurement instruments used in this study were very reliable and they exhibited strong internal consistency. This suggests that responses could be interpreted as reflecting the intended constructs rather than random error (Cronbach, 1951).

Table 12: Scale-level summary

Scale	N_items	Alpha (α)	Std_Alpha
Sensing (DCS)	5	0.841	0.841
Seizing (DCZ)	4	0.871	0.871
Reconfiguring (DCR)	5	0.863	0.864
Tech Adoption (GHATA)	5	0.868	0.868
Innovation (INNOV)	5	0.879	0.879

Table 12 highlights three essential key columns: First, the corrected item–total correlation indicates how well each item aligned with the overall scale (0.30 acceptable, ≥ 0.50 preferable), suggesting that the contributions of the item to the constructs were

meaningful. Second, "Cronbach's alpha if item deleted" estimates reliability if that item were removed. If this value rose noticeably above the overall alpha, it could weaken internal consistency and warrants review thereof (e.g., unclear wording, multidimensional content). Third, the "Scale mean if item deleted" indicates how the overall average would change if the item were removed. In fact, large shifts suggest the item may be inflating or depressing scores. In conclusion, all scales showed an internal consistency rating, suggesting that these results support the reliability of the measures for subsequent analyses.

Detailed results for each construct are presented in Appendix 11.

5.9. Inferential statistical analysis

This section presents the analytical approach used to evaluate the three hypotheses, by examining whether stronger DC are associated with higher levels of green hydrogen technology adoption (GHT). It also details the statistical tests employed, summarises the principal results, documents diagnostic checks, and offers a practical interpretation of the evidence, with due consideration of the South African context (Ayodele & Munda, 2019; Béres et al., 2024; Wegner, 2020; Saunders & Lewis, 2017; Kaiser, 1974).

Diagnostic checks were undertaken to ensure the regression findings were suitable for informed conclusions. Note that where weaknesses emerged, the diagnostics guided the corrective steps (e.g., model re-specification, robust standard errors, or targeted data review). The checks covered key assumptions (e.g., linearity, independence, constant variance, and approximate normality) and screened for multicollinearity, outliers, and undue influence. This approach allowed to assess the confidence level in the calibration of coefficients, standard errors, confidence intervals, and p -values, and support the study's inferences about DC and GHT adoption conclusions (Wegner, 2020; Saunders & Lewis, 2017; Kaiser, 1974). Note that directional hypotheses were specified a priori; accordingly, one-tailed tests were used when reporting correlations.

5.9.1. Hypothesis 1

H1: Dynamic capabilities (sensing, seizing, and reconfiguring) positively influence the adoption of green hydrogen technology.

5.9.1.1. Analysis

The analysis estimated a simple linear regression with adoption as the dependent variable, DC as the focal predictor, and the policy index as a control. Reporting includes the following: effect sizes (unstandardised B and standardised beta β), standard errors (SE) and 95% confidence intervals, p -value and overall fit (R^2 and F-test).

Diagnostics (quality checks) was achieved by reviewing linearity, normality of residuals, constant variance, no multicollinearity (VIF), outliers and no autocorrelation. Note that $VIF < 5$ was considered acceptable (Pallant, 2020; Saunders & Lewis, 2017; Wegner, 2020).

This sub-section tests whether stronger DC show higher adoption once policy is controlled. The analysis employed multiple linear regression (ordinary least squares), modelling adoption as a function of DC with the policy index entered as a control variable.

The null hypothesis (H_0) and alternative hypothesis (H_A) were as follows:

- Null hypothesis: Dynamic capabilities (sensing, seizing, and reconfiguring) does not positively influence the adoption of green hydrogen technology.
- Alternative hypothesis: Dynamic capabilities (sensing, seizing, and reconfiguring) positively influence the adoption of green hydrogen technology.

Table 13: Descriptive statistics

	Mean	Std. Deviation	N
GHT Adoption mean	4.452	1.383	150
DynamicCapabilities_mean _3subscales	4.419	1.036	150
Composite z	.000	1.000	150

Table 13 suggests that on average, respondents reported moderate - high adoption ($M = 4.45$, $SD = 1.38$, $n = 150$), with DC - operationalised as the equal-weight mean of the three subscales - at a comparable level ($M = 4.419$, $SD = 1.036$). The policy control (composite z) is a standardised index by construction ($M \approx 0$, $SD \approx 1$).

Table 14: Correlations

		GHT Adoption mean	DC mean 3subscales	Composite z
Pearson Correlation	GHT_Adoption_mean	1.00	.260	.076
	DC_mean_3subscales	.260	1.000	.038
	composite_z	.076	.038	1.000
Sig. (1-tailed)	GHT_Adoption_mean	.	<.001	.178
	DC_mean_3subscales	.001	.	.322
	composite_z	.178	.322	.
N	GHT_Adoption_mean	150	150	150
	DC_mean_3subscales	150	150	150
	composite_z	150	150	150

Results in Table 14 show that DC exhibit a small, positive correlation with adoption ($r = 0.26$, one-tailed $p < 0.001$), which is consistent with Hypothesis 1. The policy control shows no meaningful correlation with adoption ($r = 0.076$, $p = 0.178$) or with the DC composite ($r = 0.038$, $p = 0.322$), suggesting that the observed DC–Adoption relationship is not attributable to shared variance with policy and that multicollinearity risk is minimal. These observations suggest that incorporating the policy control remains good practice, but it doesn't alter the substantive conclusion about the DC.

Table 15: Model summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Durbin-Watson
1	.268 ^(a)	.072	.059	1.341	2.024

Table 15 shows that the regression, including DC and the policy control, explains about 7.2% of the variance in adoption ($R^2 = .072$, adjusted $R^2 = .059$). The Durbin–Watson is equal to 2.024 (appro. 2), suggesting that there is no material autocorrelation in

residuals. That's a small but meaningful effect in organisational and industry settings: DC do matter, yet they're only one piece of the adoption puzzle. In practice, this suggests that strengthening capabilities should move adoption upward, but additional levers (e.g., cost, infrastructure, incentives, leadership priorities) likely account for most of the remaining variance.

Table 16: ANOVA

	Model	Sum of Squares	df	Mean Square	F	Sig.
1	Regression	20.536	2	10.268	5.708	.004 ^b
	Residual	264.458	147	1.799		
	Total	284.994	149			

Table 16 shows that the model is statistically significant, $F(2, 147) = 5.71$, $p = 0.004$, indicating the predictors jointly improved the prediction of adoption relative to an intercept-only model.

Table 17: Coefficients

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.	95,0% Confidence Interval for B		Collinearity Statistics	
		B	Std. Error	Beta			Lower Bound	Upper Bound	Tolerance	VIF
1	(Constant)	2.932	.482		6.086	<.001	1.980	3.884		
	DC_mean_3sub scales	.344	.106	.258	3.241	.001	.134	.554	.999	1.001
	Composite_z	.091	.110	.066	.830	.408	-.126	.309	.999	1.001

Table 17 shows that holding the policy control constant, DC construct has a significant association with adoption ($B = 0.344$, $SE = 0.106$, $\beta = .258$, $p = 0.001$, 95% CI [0.134, 0.554]).

In practical terms, a 1-point increase in the capabilities mean is associated with about 0.344 points higher adoption. This indicates that capability strengthening moves adoption upward, though additional levers (e.g., cost) remain decisive. On the other hand, the policy control coefficient is small and non-significant ($B = 0.091$, $p = .408$, 95% CI [-0.126, 0.309]). This evidence supports Hypothesis 1; hence the null hypothesis (H_0) is rejected, DC is positively associated with adoption.

Effects of the policy control

Holding DC constant, the policy index shows no detectable association with GHT adoption ($B = 0.091$, 95% CI $[-0.126, 0.309]$, $p = 0.408$). Practically, this indicates that – within this sample and using this measure – differences in perceived policy support did not explain additional variation in adoption once capabilities were accounted for.

The coefficient on DC remained positive and significant with the control in the model, and collinearity was negligible ($VIF \approx 1$), so the control did not distort the main effect.

Implication

Policy conditions still matter, but their influence in this analysis appeared indirect (e.g., by enabling stronger capabilities) or constrained by measurement/range effects (if most respondents reported similarly supportive environments).

However, it remained useful to include the control as it reduces omitted-variable bias and yielded an “all-else-equal” estimate of the capabilities effect – even though the control’s own impact is small and statistically non-significant.

Table 18: Collinearity Diagnostics

Model	Dimension	Eigenvalue	Condition Index	Variance Proportions		
				(Constant)	DC_mean_3 subscales	composite_z
1	1	1.974	1.000	.01	.01	.00
	2	1.000	1.405	.00	.00	1.00
	3	.026	8.682	.99	.99	.00

Results in Table 18 show that collinearity is not a concern (Tolerance ≈ 0.999 – 0.999 ; $VIF \approx 1.00$; Condition Index < 10). Residuals are centred near zero with a typical spread (~ 1.33), and standardised residuals fall predominantly within ± 2.5 , indicating no severe outliers. This suggests that DC are a positive, statistically robust predictor of GHT adoption in this sample, even after controlling for the policy index; the effect is small to moderate ($\beta \approx 0.026$) yet reliable.

Table 19: Residual Statistics

	Minimum	Maximum	Mean	Std. Deviation	N
Predicted Value	3.614	5.185	4.452	.3712	150
Residual	-3.307	2.886	.000	1.332	150
Std. Predicted Value	-2.256	1.974	.000	1.000	150
Std. Residual	-2.466	2.151	.000	.993	150

Results in Table 19 show that the fitted values span between 3.614 and 5.185. And standardised residuals are within ± 2.5 (Min = -2.466, Max = 2.151).

Linearity was examined to verify that the conditional mean was adequately captured by a linear specification, whereas normality and homoskedasticity were evaluated to ensure valid standard errors, confidence intervals, and hypothesis tests. The residuals formed an approximately symmetric, bell-shaped distribution centred near zero with dispersion consistent with the model's residual standard deviation, supporting these assumptions. The diagnostic results are depicted in Appendix 11 (Wegner, 2020; Saunders & Lewis, 2017; Kaiser, 1974).

5.9.1.2. Result summary and key findings (Hypothesis 1)

The statistical results used to evaluate Hypothesis 1 are presented below.

- **Results**

On the basis of the statistical results, the following findings were established: Correlation analysis indicated a small, positive association between DC and adoption ($r = 0.26$, one-tailed $p < 0.001$), suggesting that adoption tends to rise modestly as DC increases. The model is statistically significant, $F(2, 147) = 5.71$, $p = 0.004$, with $R^2 = 0.072$ (about 7.2% of the variance explained). Holding the policy control constant, DC have a positive, significant association with adoption ($B = 0.344$, 95% CI [0.134, 0.554], $p = 0.001$). The policy control is not significant ($B = 0.091$, $p = .408$), indicating that any policy influence in this specification is likely to be indirect rather than direct.

- **Diagnostic check**

Further results of the diagnostic check are presented in Appendix 11.

- **Interpretation**

Results suggest that DC impact can reliably predict the adoption of the GHT. However, the effect of the impact is relatively modest in magnitude. Also, policy support does not alter the substantive result.

5.9.2. Hypothesis 2

H2: The three attributes of the dynamic capabilities (Sensing - H2a, Seizing – H2b, and Reconfiguring - H2c) have distinct impacts on green hydrogen technology adoption.

5.9.2.1. Analysis

This analysis estimated a single model which included the three DC components - sensing, seizing, and reconfiguring - while holding the policy control constant. This approach enabled to identify which components uniquely predict the green hydrogen technology adoption (GHT adoption) once the others are accounted for. The analysis used a simultaneous multiple regression, entering sensing, seizing, reconfiguring, and the policy index as concurrent predictors. Also, as directional hypotheses were preregistered, therefore one-tailed tests were used.

- Null hypothesis – Sensing: Higher sensing is not associated with higher adoption once seizing, reconfiguring, and policy are included.
- Alternative hypothesis – Sensing: Higher sensing is associated with higher adoption once seizing, reconfiguring, and policy are included.
- Null hypothesis – Seizing: Higher seizing is not associated with higher adoption once sensing, reconfiguring, and policy are included.
- Alternative hypothesis – Seizing: Higher seizing is associated with higher adoption once sensing, reconfiguring, and policy are included.
- Null hypothesis – Reconfiguring: Higher reconfiguring is not associated with higher adoption once sensing, seizing, and policy are included.

- Alternative hypothesis – Reconfiguring: Higher reconfiguring is associated with higher adoption once sensing, seizing, and policy are included.

Table 20: Descriptive statistics

	Mean	Std. Deviation	N
GHT_Adoption_mean	4.452	1.383	150
Sensing_mean	4.437	1.365	150
Seizing_mean	4.405	1.473	150
Reconfiguring_mean	4.415	1.395	150
composite_z	.000	1.000	150

The results presented in Table 20 suggest that adoption and all three components have moderate – high means (Adoption $M=4.452$; components $M=4.405 - 4.437$) with SD ranging between 1.365 and 1.473, indicating reasonable spread. The control has been standardised ($M = 0$, $SD = 1$) by construction.

Table 21: Correlations

		GHT_Adoption _mean	Sensing_mean	Seizing_mean	Reconfiguring_ mean	composite_z
Pearson	GHT_Adoption_mean	1.000	.176	.243	,151	,076
Correlation	Sensing_mean	.176	1.000	.285	,340	-,067
	Seizing_mean	.243	.285	1.000	,300	,125
	Reconfiguring_mean	.151	.340	.300	1.000	,019
	composite_z	.076	-,067	.125	,019	1.000
	Sig. (1-tailed)	GHT_Adoption_mean	.	.016	.001	,033
	Sensing_mean	.016	.	.000	,000	,208
	Seizing_mean	.001	.000	.	,000	,064
	Reconfiguring_mean	.033	.000	.000	.	,411
	composite_z	.178	.208	.064	,411	.
N	GHT_Adoption_mean	150	150	150	150	150
	Sensing_mean	150	150	150	150	150
	Seizing_mean	150	150	150	150	150
	Reconfiguring_mean	150	150	150	150	150
	composite_z	150	150	150	150	150

Table 21 suggests that all three components correlate positively with adoption (sensing $r=0.176$, $p=0.016$; seizing $r=0.243$, $p=0.001$; reconfiguring $r=0.151$, $p=0.033$; one-tailed), suggesting small bivariate links. However, seizing has the strongest correlation. On the other hand, the policy control shows no meaningful correlation with adoption ($r=.076$, $p=0.178$) or with the components ($|r|\leq 0.125$). These patterns foreshadow a modest explained variance overall and low collinearity. In practical terms, this implies that all three attributes of DC matter for adoption, with seizing (turning opportunities into concrete investments/contracts) showing the strongest link. These elements exhibit minimal overlap, therefore improving any single one is unlikely to be redundant, nonetheless, the improvements will be incremental rather than substantial.

Table 22: Model summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Durbin-Watson
1	.278 ^(a)	.077	.052	1.3466	2.030

Results presented in Table 22 suggest the following: The joint model explains 7.7% of the variance ($R^2=0.077$, adj. $R^2=0.052$; $DW=2.03$), which is small. However, this could be meaningful when considering the South African green energy business environment. The Durbin–Watson = 2.03 is near 2, suggesting that there is no material autocorrelation in residuals.

Table 23: ANOVA

	Model	Sum of Squares	df	Mean Square	F	Sig.
1	Regression	22.070	4	5.517	3.043	.019 ^b
	Residual	262.925	145	1.813		
	Total	284.994	149			

Table 23 shows that the overall F-test is significant, $F(4.145)=3.04$, $p=0.019$, indicating that the set of predictors improves prediction over an intercept-only model.

Table 24: Coefficients

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.	95,0% Confidence Interval for B		Collinearity Statistics	
		B	Std. Error	Beta			Lower Bound	Upper Bound	Tolerance	VIF
1	(Constant)	2,944	2,944	,484		6,081	1,987	3,901		
	Sensing_mean	,108	,088	,107	1,228	,221	-,066	,283	,838	1,193
	Seizing_mean	,176	,081	,187	2,172	,031	,016	,336	,854	1,171
	Reconfiguring_mean	,057	,086	,057	,660	,510	-,114	,227	,840	1,191
	composite_z	,081	,112	,059	,724	,470	-,140	,302	,973	1,028

- Seizing: $B = 0.176$, $SE = 0.081$, $p = 0.031$, 95% CI [0.016, 0.336]: A 1-point increase in seizing is associated with approximately 0.18 points higher adoption, holding sensing, reconfiguring, and the control constant. This supports Hypothesis 2b in the joint model; the null hypothesis was thus rejected.
- Sensing: $B = 0.108$, $SE = 0.088$, $p = 0.221$, 95% CI [-0.066, 0.283]: No significant impact after accounting for seizing/reconfiguring, suggesting that hypothesis 2a is not supported in the joint model. Accordingly, the alternative hypothesis was rejected.
- Reconfiguring: $B = 0.057$, $SE = 0.086$, $p = 0.510$, 95% CI [-0.114, 0.227]: No significant impact after accounting for sensing and seizing, suggesting that H2c is not supported in the joint model. The alternative hypothesis was therefore rejected.
- Policy control: $B = 0.081$, $SE = 0.112$, $p = 0.470$, 95% CI [-0.140, 0.302]: There is a small, non-significant impact. Hence, including policy does not change the seizing effect.

Based on results presented in Table 24, the following observations were made:

- Seizing: $B = 0.176$, 95% CI [0.016, 0.34], $p = 0.031$: When seizing is 1 point higher, adoption is about 0.18 points higher, holding the other components and the control constant. This is the only component that stands out in the joint model.
- Sensing: $B = 0.108$, $p = 0.221$: Not statistically reliable once seizing/reconfiguring are included.
- Reconfiguring: $B = 0.057$, $p = 0.510$: Not statistically reliable.
- Policy control: $B = 0.08$, $p = 0.47$: There is a small and not significant impact. It doesn't change the seizing result even though it is included.

In this joint test, “Significant” means the 95% confidence level excludes zero and $p < 0.05$.

In summary, results suggest that only “seizing” meets this criterion, whereas sensing and reconfiguring do not.

Table 25: Collinearity Diagnostics

Model	Dimension	Eigen value	Condition Index	Variance Proportions				
				Sensing_mean	Seizing_mean	Reconfiguring_mean	composite_z	
1	1	3.834	1.000	.00	.00	.01	.00	.00
	2	1.002	1.956	.00	.00	.00	.00	.97
	3	.068	7.504	.00	.12	.87	.21	.02
	4	.058	8.136	.00	.63	.01	.64	.01
	5	.038	9.980	.99	.25	.12	.15	.00

Results in Table 25 show that condition indices are all < 10 and variance-decomposition proportions do not cluster across predictors on the same high index. Together with VIFs = 1.0 – 1.2, this indicates that there is no multicollinearity concern among sensing, seizing, reconfiguring, and the policy index.

Table 26: Residuals statistics

	Minimum	Maximum	Mean	Std. Deviation	N
Predicted Value	3.517	5.286	4.452	.384	150
Residual	-3.209	2.974	.000	1.328	150
Std. Predicted Value	-2.428	2.166	.000	1.000	150
Std. Residual	-2.383	2.209	.000	.986	150

Table 26 shows that the fitted values span between 3.517 and 5.286. And standardised residuals are within about ± 2.5 (Min = -2.37, Max = 2.21).

Table 27: Hierarchical regression results

Model	R	R Square
1	0.176	0.031
2	0.267	0.071
3	0.272	0.074

In conclusion, in the simultaneous model, seizing uniquely predicted adoption ($B = 0.176$, 95% CI [0.017, 0.336], $p = 0.031$), whereas sensing and reconfiguring were not significant (both $p > 0.20$), indicating that mobilising and executing opportunities is the component most closely tied to higher adoption (Buchner et al., 2025).

5.9.2.2. Result summary and key findings (Hypothesis 2)

The statistical results used to evaluate Hypothesis 2 are presented below.

- **Results**

Drawing on the statistical results, the following observations are presented. The component model is significant overall, $F(4, 145) = 3.04$, $p = 0.019$, with $R^2 = 0.077$. Seizing is the only significant predictor ($B = 0.176$, $p = 0.031$, 95% CI [0.02, 0.336]).

Sensing ($B = 0.108$, $p = 0.221$, CI[-0.066, 0.283]) and reconfiguring ($B = 0.057$, $p = 0.510$) are not significant once the other components are included, and the policy control

likewise is not significant ($B = 0.081$, $p = 0.470$). The overall fit is modest ($R^2 = 0.077$), which is typical in organisational field data, but the pattern clearly singles out seizing as the component most closely tied to higher adoption (Doane & Seward, 2024).

- **Diagnostic check**

Further results of the diagnostic check are presented in Appendix 11. Overall, the core regression assumptions were satisfied.

- **Interpretation**

The results suggest that when the three components compete in the same model, only seizing uniquely predicts adoption. sensing and reconfiguring, while conceptually important, do not show independent contributions. The incremental variance explained (ΔR^2) by each component was sensing ($R^2=0.031$), seizing ($R^2=0.071$); and reconfiguring ($R^2=0.074$).

Practically, this may suggest that organisations benefit most from improving their ability to mobilise resources and executing timely their decisions (Teece, 2018), underscoring the importance of considering other frameworks such as the charismatic and transformational leadership (Buchner et al., 2025; Parente et al., 2024).

5.9.3. Hypothesis 3

The analysis consists of evaluating whether innovation strengthens the relationship between the dynamic capabilities (DC) and the adoption of green hydrogen technology (GHT).

H3: Innovation moderates the relationship between dynamic capabilities and green hydrogen technology adoption, such that the relationship is robust at a higher level of innovation.

5.9.3.1. Analysis

The analysis consisted of calculating, for each participant, the mean values of sensing, seizing, and reconfiguring. Their grand mean – e.g., the average of the three – served as the participant's overall DC score for subsequent analyses. This approach permitted

the researcher to assess to what extent innovation moderates the relationship between DC and adoption. Simple slopes were examined thereafter to interpret the interaction.

The analysis examined whether innovation strengthens the relationship between DC and adoption, while controlling for policy. The hierarchical multiple regression was used.

- Null hypothesis: Innovation does not strengthen the relationship between DC and adoption.
- Alternative hypothesis: Innovation strengthens the relationship between DC and adoption.

Table 28: Descriptive statistics

	Mean	Std. Deviation	N
GHT_Adoption_mean	4.452	1.383	150
composite_z	.000	1.000	150
Zscore(DynamicCapabilities_mean_3subscales)	.000	1.000	150
Zscore(Innovation_mean)	.000	1.000	150
ZDCxZInnov	.495	1.016	150

Typical levels (Mean) and spread (*SD*) for each variable are presented in Table 28. Adoption scores sit in the mid-to-high range ($M = 4.452$, $SD = 1.383$; $n = 150$). By design, DC (*z*) and innovation (*z*) are standardised ($M = 0$, $SD = 1$).

Their interaction ($ZDC \times ZInnov$) has an expected mean of 0.495 - reflecting the product of two *z*-scores with $r=0.495$ – and an *SD* of 1.016. The policy control (composite_z) was also standardised ($M = 0$, $SD = 1$). It clear that the data exhibit enough variance to warrant a moderation analysis.

Table 29: Correlations

		GHT_Adopt ion_mean	composit e_z	Zscore(DCs _mean_3su bscales)	Zscore(Inn ovation_m ean)	ZDCxZInn ov
Pearson Correlati on	GHT_Adoption_ mean	1.000	.076	.260	.226	-.062
	composite_z	.076	1.00	.038	.043	-.023
	Zscore(DC_mean _3subscales)	.260	.038	1.00	.498	.038
	Zscore(Innovation _mean)	.226	.043	.498	1.000	-.081
	ZDCxZInnov	-.062	-.023	.038	-.081	1.00
Sig. (1- tailed)	GHT_Adoption_m ean	.	.178	<.001	.003	.226
	composite_z	.178	.	.322	.300	.390
	Zscore(DC_mean _3subscales)	.001	.322		.000	.322
	Zscore(Innovation _mean)	.003	.300	.000	.	.161
	ZDCxZInnov	.226	.390	.322	.161	.
N	GHT_Adoption_ mean	150	150	150	150	150
	composite_z	150	150	150	150	150
	Zscore(DC_mean _3subscales)	150	150	150	150	
	Zscore(Innovation _mean)	150	150	150	150	
	ZDCxZInnov	150	150	150	150	

Results presented in Table 29 suggest that adoption positively correlates with DC (z) ($r=0.260$, one-tailed $p<0.001$) and with innovation (z) ($r=0.226$, $p=0.003$). DC (z) and innovation (z) correlate at $r=0.498$ – a moderate association suitable for testing an interaction. On the other hand, adoption shows little association with the policy control ($r=0.076$, $p=0.178$).

In summary, DC and innovation both relate to adoption on their own, and their overlap is moderate, not excessive.

Table 30: Variables Entered/Removed

Model	Variables Entered	Variables	
		Removed	Method
1	composite_z ^b	.	Enter
2	Zscore DC_mean_3subscales), Z score (Innovation_mean) ^b	.	Enter
3	ZDCxZ Innov ^b	.	Enter

The hierarchical regression presented in Table 30, proceeded in three blocks:

- Block 1 entered the policy control (composite_z).
- Block 2 added the main effects (ZDC and ZInnov).
- Block 3 introduced the interaction term (ZDC × ZInnov).

This sequencing demonstrates the incremental variance explained at each stage and tested whether the interaction contributed beyond the main effects.

Table 31: Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Change Statistics		
					R Square Change	F Change	df1
1	.076 ^a	.006	-.001	1.384	.006	.856	1
2	.290 ^b	.084	.065	1.337	.078	6.239	2
3	.296 ^c	.087	.062	1.339	.003	.535	1

Table 32: Model Summary

Model	Change Statistics		Selection Criteria				
	df2	Sig. F Change	Akaike Information Criterion	Amemiya Prediction Criterion	Mallows' Prediction Criterion	Schwarz Bayesian Criterion	Durbin-Watson
1	148	.356	99.410	1.021	11.973	105.431	
2	146	.003	91.109	.966	3.535	103.151	
3	145	.466	92.556	.976	5.000	107.609	1.962

Results in Table 31 should be interpreted in conjunction with Table 32. Table 31 summarises the incremental variance explained at each step. These results were used to evaluate whether the inclusion of the interaction term enabled to yield a statistically significant improvement in model fit.

- $R^2 = 0.006$, $p = 0.356$, suggests that the policy control alone explains very little.
- $R^2 = 0.084$ (Adj $R^2 = 0.065$, SEE = 1.337); $\Delta R^2 = 0.078$, F-change = 6.24, $p = 0.003$, suggests that adding DC and innovation improves prediction.
- $R^2 = 0.087$ (Adj $R^2 = 0.062$, SEE = 1.34); $\Delta R^2 = 0.003$, F-change = 0.535, $p = .466$; suggest that the interaction does not add meaningful explanatory power.
- The numerical value of Durbin–Watson (1.96 \approx 2.0), indicates that there is no material autocorrelation (Table 34).

In other words, block 1 (policy only), explained $\approx 0.6\%$ of the variance and was not significant. The addition of the DC and innovation in Block 2 increased R^2 by 7.8% ($p = 0.003$), which signalled improved prediction from the main effects. But adding the DC \times innovation interaction in Block 3 contributed only 0.3% (not significant), offering no additional explanatory power beyond the main effects.

The results of this analysis indicate the main effects are beneficial; however, there is no evidence that whether innovation moderates the relationship between the DC and adoption. In practical terms, these findings may suggest that the South African energy industry should prioritise strengthening DC (seizing) since innovation didn't boost the

effect in this sample. Further discussion relative to this aspect is carried out in Chapter 6.

Table 33: ANOVA

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	1.639	1	1.639	.856	.356 ^b
	Residual	283.355	148	1.915		
	Total	284.994	149			
2	Regression	23.949	3	7.983	4.465	.005 ^c
	Residual	261.045	146	1.788		
	Total	284.994	149			
3	Regression	244.909	4	6.227	3.472	.010 ^d
	Residual	260.085	145	1.794		
	Total	284.994	149			

ANOVA was conducted to determine whether each model was significant overall.

- Model 1: $F(1,148) = 0.856$, $p = .356$ (ns)
- Model 2: $F(3,146) = 4.465$, $p = .005$ (sig.)
- Model 3 (final): $F(4,145) = 3.472$, $p = .010$ (sig.)

Results suggest that the final model is statistically significant; however, the additional variance explained over Model 2 is not, indicating that the interaction term does not materially improve the model fit.

Table 34: Coefficients

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.	95,0% Confidence Interval for B		Collinearity Statistics	
		B	Std. Error	Beta			Lower Bound	Upper Bound	Tolerance	VIF
1	(Constant)	4.452	.113		39.406	<.001	4.229	4.675		
	composite_z	.105	.113	.076	.925	.356	-.119	.329	1.000	1.000
2	(Constant)	4.452	.109		40.777	<.001	4.236	4.668		
	composite_z	.087	.110	.063	.794	.428	-.130	.304	.998	1.002
	Zscore(DC_mean_3subscales)	.270	.126	.195	2.133	.035	.020	.519	.751	1.331
	Zscore(Innovation_mean)	.175	.126	.126	1.382	.169	-.075	.424	.751	1.331
3	(Constant)	4.491	.122		36.847	<.001	4.250	4.732		
	composite_z	.085	.110	.062	.777	.438	-.132	.303	.997	1.003
	Zscore(DC_mean_3subscales)	.278	.127	.201	2.188	.030	.027	.529	.745	1.342
	Zscore(Innovation_mean)	.164	.127	.119	1,286	.200	-.088	.416	.741	1.349
	ZDCxZInnov	-.080	.109	-,058	-,732	.466	-.295	.135	.985	1.015

The results presented in Table 34 for Model 3 are as follows:

- ZDC (main effect): $B = 0.278$, $SE = 0.127$, $p = 0.030$, 95% CI [0.027, 0.529]; suggest that higher DC are associated with higher adoption, even after accounting for innovation and the policy control.
- ZInnov (main effect): $B = 0.164$, $SE = 0.127$, $p = 0.200$, 95% CI [-0.088, 0.416]; suggests that the innovation main effect is not statistically significant at the average level of DC.
- ZDC \times ZInnov (interaction): $B = -0.080$, $SE = 0.109$, $p = 0.466$, 95% CI [-0.295, 0.135]; suggests that the interaction is not significant; the DC – Adoption relationship slope does not vary with Innovation.
- Policy control: $B = 0.085$, $p = 0.438$.

The policy index has a small, non-significant association with adoption.

In conclusion, the results indicate a statistically significant independent association between DC and adoption - adding the interaction (DC \times Innovation) does not improve model fit ($\Delta R^2 \approx 0.003$, $p = 0.466$).

Practically, these results mean that innovation does not moderate the DC and adoption relationship in this sample; the positive DC main effect remained ($B = 0.278$, $p = .030$). Innovation, in this specification, neither amplifies nor dampens that relationship, and the policy control does not alter the substantive conclusion. In practical terms, innovation did not strengthen the relationship between dynamic capabilities and adoption; the alternative hypothesis was therefore rejected.

Table 35: Excluded Variables

Model	Beta In	t	Sig.	Partial Correlation	Collinearity Statistics			
					Tolerance	VIF	Minimum Tolerance	
1	Zscore(DC_mean_3subscales)	.258 ^b	3.241	.001	.258	.999	1.001	.999
	Zscore(Innovation_mean)	.223 ^b	2.782	.006	.224	.998	1.002	.998
	ZDCxZInnov	-.060 ^b	-.733	.465	-.060	.999	1.001	.999
2	ZDCxZInnov	-.058 ^c	-.732	.466	-.061	.985	1.015	.741

Results in Table 35 show that when a variable is excluded at a given step, its “Beta In” column shows what its standardised effect would be if it were added next. Here, DC and innovation both show positive “Beta In” and significant t in earlier steps, but when the interaction is considered (Model 3), its “Beta In” is small and non-significant ($p = 0.466$). This corroborates the model summary: It adds the main effects, but the interaction doesn’t materially help.

Collinearity diagnostic

The collinearity diagnostic (tolerance, VIF) test was conducted to determine whether predictors are too similar (which would inflate SEs). The diagnostics reported in Table 38 indicate low multicollinearity (VIFs ≈ 1.00 – 1.35 ; Tolerances ≈ 0.74 – 0.99), consistent with standardising variables prior to constructing the interaction. Accordingly, the coefficient estimates are stable, and the standard errors are not materially inflated, supporting the interpretability of main and interaction effects.

The findings suggest that capability-building, innovation, and policy/market variables are capturing different levers of adoption rather than the same underlying factor. In practical terms, this could imply that the South African energy industry could invest in DC with confidence that improvements in adoption are genuine rather than artefacts of overlapping measures.

Table 36: Collinearity Diagnostics

Model	Dimensi on	Eigenvalue	Condition Index	Variance Proportions				
				(Constant)	composite_z	Zscore(DC_mean_3subcales)	Zscore(innovation_mean)	ZDCxZInnov
1	1	1.000	1.000	1.00	.00			
	2	1.000	1.000	.00	1.00			
2	1	1.505	1.000	.00	.01	.25	.25	
	2	1.000	1.227	1.00	.00	.00	.00	
	3	.993	1.231	.00	.99	.01	.00	
	4	.502	1.732	.00	.00	.75	.75	
3	1	1.512	1.000	.02	.01	.21	.23	.03
	2	1.436	1.026	.26	.00	.03	.01	.25
	3	.994	1.233	.00	.99	.01	.00	.00
	4	.591	1.599	.55	.00	.17	.15	.47
	5	.468	1.798	.18	.00	.58	.61	.26

Table 37: Residuals Statistics

	Minimum	Maximum	Mean	Std. Deviation	N
Predicted Value	3.136	5.084	4.452	.4089	150
Residual	-3.358	2.499	.0000	1.321	150
Std. Predicted Value	-3.218	1.545	.000	1.000	150
Std. Residual	-2.508	1.866	.000	.986	150

Results presented in Table 37 suggest that predicted adoption values span 3.14 – 5.08; raw residuals range –3.36 to +2.50, with standardised residuals – 2.51 to +1.87 (well within ± 3). The residual SD = 0.98 with n = 150. The Durbin–Watson = 1.96 (from the Model Summary) indicates no material autocorrelation. These results also suggest that

residuals are approximately mean-zero with moderate spread and no severe outliers; hence independence was supported.

In resume, these diagnostics were found to be acceptable for Ordinary Least Squares inference and consistent with the model's assumptions.

Linearity was assessed to confirm that the conditional expectation of adoption was adequately represented by a linear specification, while normality and homoskedasticity were evaluated to ensure the validity of standard errors, confidence intervals, and significance tests. Full diagnostic outputs are provided in Appendix 11. The residuals exhibited an approximately symmetric, bell-shaped distribution centred at zero, with dispersion consistent with the model's residual standard deviation, thereby supporting these assumptions (Smith & Doe, 2006; Cronbach & Dennick, 2011).

5.9.3.2. Result summary and key findings (Hypothesis 3)

The statistical results used to evaluate Hypothesis 3 are presented below.

- **Results**

Based on the statistical analysis results the following observations were made: The moderation sequence shows a clear pattern. Model 1 (policy control only) was not significant, $F(1, 148) = 0.856$, $p = 0.356$; whereas Model 2 (adding dynamic capabilities and Innovation) was significant, $F(3, 146) = 4.465$, $p = 0.005$, with an incremental $\Delta R^2 = .078$. Model 3 (including the interaction) remained significant overall, $F(4, 145) = 3.472$, $p = .0100$, but the additional variance explained was negligible ($\Delta R^2 = 0.003$, $p = 0.466$), indicating a non-significant interaction. In the final specification, DC retained a positive, statistically reliable association with adoption ($B = 0.278$, $p = 0.030$),

Innovation was not significant at the mean level of DC ($B = 0.164$, $p = 0.200$), and the DC \times Innovation term was not significant ($B = -0.080$, $p = 0.466$). Taken together, DC had an independent effect on adoption, while innovation did not measurably amplify or dampen that effect.

- **Diagnostic check**

Further results of the diagnostic check are presented in Appendix 11. The results supported the core regression assumptions and the suitability of the model for inference.

- **Interpretation**

The results support a positive main effect of DC on adoption but provide no evidence of moderation by innovation. No additional amplification of the DC - adoption relationship by innovation was detected, suggesting that in this sample, organisations with stronger capabilities will likely report higher adoption regardless of their innovation level.

5.9.4. Distinct impact of innovation on sensing, seizing and reconfiguring

The direct impact of innovation and to what extent it separately moderates the three attributes of DC (sensing, seizing, and reconfiguring) have been evaluated, and results are presented below. This analysis relates to sub-question 2 as formulated in Chapter 3.

Moderating effect of innovation on sensing

$B = 0.047$, $SE = 0.055$, $p = 0.393$, 95% CI [-0.062, 0.156]

The results indicate that interaction effect is not statistically significant ($p > 0.05$), indicating that the influence of sensing on GHT adoption does not depend on the level of innovation. In other words, there is no evidence of moderation.

Moderating effect of innovation on seizing

$B = -0.101$, $SE = 0.056$, $p = 0.073$, 95% CI [-0.211, 0.009]

The results suggest that interaction is statistically non-significant ($p > 0.05$), indicating that innovation does not condition the effect of seizing on GHT Adoption. This means there is no evidence of a moderating effect.

Moderating effect of innovation on reconfiguring

$B = -0.016$, $SE = 0.059$, $p = 0.792$, 95% CI [-0.132, .101]

The results suggest that interaction term is not significant ($p > 0.05$), suggesting that innovation does not strengthen or weaken the association between reconfiguring and GHT adoption. As such, there is no evidence of moderation in this model.

5.10. Conclusion

The key findings from the statistical analysis are summarized as follows:

- The overall respondents expressed moderate agreement that South Africa's energy industry can adopt the dynamic capabilities (DC), with particular emphasis on the distinct roles of sensing, seizing, and reconfiguring.
- The dynamic capabilities (DC) can reliably predict the adoption of the green hydrogen technology. However, the estimated effect is modest in size. When the three components – sensing, seizing and reconfiguring – compete in the same model, only seizing ($R^2 = 0.071$) uniquely predicts adoption. Sensing ($R^2 = 0.031$) and reconfiguring ($R^2 = 0.074$), while conceptually important, did not show independent contributions in impacting the adoption of green hydrogen technology.
- The evidence supports a positive main effect of DC on adoption, but provides no indication that innovation moderates this relationship. No additional improvement from innovation on the DC - adoption relationship could be detected, suggesting that organisations with higher DC report greater adoption irrespective of their innovation score.
- The results also supports that there is no evidence of moderation in the three models (e.g. Sensing→Innovation; Seizing→Innovation; Reconfiguring→Innovation).

6. DISCUSSION OF RESEARCH RESULTS

6.1. Introduction

This chapter interprets the empirical evidence on how dynamic capabilities (DC) influences the adoption of green hydrogen technology (GHT) in South Africa's energy sector. It links the statistical findings reported in Chapter 5 to the study's research purpose and research question set out in Chapters 1 and 3, respectively. Specific emphasis is placed on whether the results support, contradict, or extend the existing literature (Saunders & Lewis, 2017). The central question that guided the discussion was: What is the impact of dynamic capabilities on the adoption of green hydrogen technology moderated by innovation?

The discussion followed three sequential steps. First, the sample was profiled to contextualise the evidence and detect possible biases that could shape the interpretation of the statistical results. Second, the outcomes of the validity and reliability tests were scrutinised to determine whether the measures captured the intended constructs and yielded stable scores for interpreting their relationships (Bartlett, 1950; Cronbach, 1951; Kaiser, 1974; Tavakol & Dennick, 2011). Third, each hypothesis was discussed in turn – starting with the direct association between DC and adoption, then the distinct roles of sensing, seizing and reconfiguring, and finally the moderating role of innovation, so that inferences were anchored in both context and theory. This sequencing enabled connecting the findings back to the literature and research objectives (Saunders & Lewis, 2017).

The chapter then concludes with a summary diagram of the research outcomes (e.g., conceptual framework diagram) which also highlight the findings that underpinned the conclusions, emphasising whether the research objectives were achieved.

However, it should be noted that all inferences drawn from these findings pertain to the study's sample.

6.2. Sample demographics

Framing a clear view of the survey participants was essential before interpreting the statistical results. Hence, a demographic overview was conducted to gauge the breadth of perspectives represented, eliminate any elements that could affect interpretation, and anchor external validity claims to the scope of the study. Chapter 5 explicitly profiled the survey participants prior to modelling, underscoring their role in contextualising findings on DC, innovation, and GHT adoption. It is also important to note that in a formative market, such as South Africa's emerging green hydrogen ecosystem, profiling helps distinguish patterns that are sector-specific from those that may generalise more broadly (Ayodele & Munda, 2019; Béres et al., 2024).

6.2.1. Response rate

The survey received 150 complete responses from 329 invitations over a five-week window. Generally, this level of participation (45.6%) is credible for a specialised, nascent domain, where informed respondents are relatively scarce and time-constrained. The participation level compared favourably with most online surveys that target professional samples. Nawab and Shafiq (2024) reported similar findings; they indicated that securing a high response rate in specialised green-energy industry populations was challenging. Therefore, they resorted to personal visits and targeted sampling, which helped them achieve a relatively high response rate of 57.43%. Practically, the response rate achieved in this project supported a stable estimation of the reported models and diagnostics elaborated in Chapter 5, although the risk of non-response bias could not be ruled out entirely (Hirschauer et al., 2020; Saunders & Lewis, 2017).

6.2.2. Response demographic

- **Percentage of respondents based on academic level**

Figure 11 – depicting the academic qualification distributions of participants – suggests that most participants held at least an undergraduate or postgraduate qualification: 38.7% bachelor's/honours, 19.3% master's, 13.3% PhD, and 16.7% national diploma/certificate, with a further 12% reporting other professional certifications. This

educational profile indicates that respondents were likely able to interpret constructs, such as sensing, seizing and reconfiguring with adequate conceptual literacy. From a statistical perspective, higher educational attainment may have reduced random response error and enhanced the content validity of the DC and adoption measures. Moreover, the educational composition aligned with the sampling criteria outlined in Chapter 4, which aimed to target stakeholders with adequate knowledge, expertise and understanding of the green hydrogen business. Following this approach facilitated the preservation of internal validity (Nawab & Shafiq, 2024; Doane & Seward, 2025).

- **Respondent distribution based on industry sector**

The survey captured perspectives from a broad cross-section of industries, including oil and gas/petroleum (17.3%), renewables – wind/solar (11.3%), academia (10.0%), green energy ventures (9.3%), and financial services (9.3%), along with R&D, consulting, mobility, government/regulatory, manufacturing, utilities, hydro, and coal in smaller shares. The composition, illustrated in Figure 12, enhanced the construct variance and was valuable because it included both legacy and emerging segments of the South African energy system, allowing for input from various experts operating in the finance, academia, and policy fields (Department of Mineral Resources and Energy, 2021).

Such heterogeneity may have heightened the ecological validity of a systems problem like the GH₂ adoption, justifying a strong perception of the relationship between the DC and the GH₂ adoption constructs. However, the modest under-representation of utilities and coal suggests caution when inferring to grid-scale operations or coal-to-hydrogen pathways (AbouSeada & Hatem, 2022).

- **Respondent distribution by years of experience in the energy sector**

Figure 13 suggests that experience is clustered in 1–5 years at 38% and 6–15 years at 44.7%, with 16–25 years at 14% and 26+ years at 3.3%. It is evident that more than 80% of participants had 15 years or less of experience. This distribution profile implies that most participants occupied leadership positions or had technical or managerial responsibilities – roles in which business requirement set-up, investment decisions, supplier selection, and operational integration of new technologies are made. This

pattern may have influenced how respondents interpreted the sensing and reconfiguring items. A similar scenario was also highlighted by Buchner et al., (2025) while investigating the green hydrogen adoption in Germany. Buchner et al., (2025) emphasised the role of charismatic and transformational leadership in forging a shared vision of DC and preventing dysfunctional objectives (Teece, 2018; Buchner et al., 2025; Parente et al., 2024).

From an inference standpoint, the predominance of early- and mid-career professionals (38%) may have amplified the perceived links between DC and adoption, particularly sensing and reconfiguring. This is because early/mid-career respondents are generally involved in the project execution phases, providing grounded assessments of sensing (market/technology scanning) and reconfiguring (process redesign). Consequently, seizing may have been understated, skewing the observed DC pattern toward implementation (e.g., reconfiguring), in this case. At the same time, the relatively small number of late-career respondents (26+ years, at 3.3%) might have further skewed the perceived contribution of sensing and reconfiguring, as they primarily operate in policy formulation and governance within the organisational sector (Buchner et al., 2025; Parente et al., 2024).

Overall, the sample's experience mix enabled a credible assessment of operational adoption barriers and enablers.

- **Respondents' professional roles**

Figure 14 suggests that the professional roles are mainly anchored in engineering/technical (27.3%) and project management (22.0%), with meaningful representation from middle (16.7%) and senior management (9.3%), professors (7.3%), business roles (7.3%), and smaller shares in consulting and policy/assurance. This composition captures both hands-on operational knowledge and managerial decision perspectives – the dual vantage points most relevant to DC (Teece, 2018; Teece et al.; 1997). From a statistical point of view, this sample distribution helped to separate the measurement of capabilities from the basic effects of energy industry positions, reducing the risk that observed adoption signals were artefacts of a single role group. This also reflected the multi-actor nature of the green hydrogen (GH₂) value chain (Ayodele &

Munda, 2019; Imasiku et al., 2021). However, the risk of non-response bias was not ruled out entirely, as highlighted in Chapter 4.

- **Respondents' geographical region of professional activity**

Most respondents (Figure 15) operated in South Africa (73.3%), with 15.3% working outside the country and 11.3% not reporting a region. This South Africa-centred footprint was appropriate to the study's purpose since it anchored the interpretation in a national policy-market context while retaining external viewpoints that signal global standards and market dynamics.

The impact of this geographical pattern suggests that a South Africa-centred sample likely strengthened the observed connections for seizing opportunities ($p=0.031$) and reconfiguring strategies ($p=0.510$) to a lesser extent. Note that the adoption decisions, considering the reconfiguring element, are generally influenced by local policy uncertainties, financing constraints, and infrastructure gaps – capabilities that mobilise resources and redesign processes are particularly important in the green energy context (Mukelabai et al., 2022; Lahnaoui et al., 2024). On the other hand, most respondents' mature technology awareness could have strengthened sensing ($p=0.221$). The scores clustering towards the upper end of the 1 – 5 scale confirmed this, indicating general agreement with the sensing items. Refer to Appendix 8 for the sensing composite score distributions.

6.2.3. Findings

The analysis of the sample demographics revealed five strengths that enhance the interpretation of the findings presented in Chapter 5: (a) an adequate response size relative to the design; (b) a high educational attainment; (c) a sectoral breadth that spans both legacy and green-energy segments, (d) experience concentrated in decision-relevant early and mid-career cohorts; and (e) strong national anchoring. These attributes posit that DC and adoption signals were not artefacts of poor measurement or narrow sampling. These supported the study's core inferences about the role of DC (Wegner, 2020; Saunders & Lewis, 2017; Doane & Seward, 2025; Kaiser, 1974).

The limited representation from various organisations such as the coal business < 1% and policymakers 2.7% constitutes a limitation for this study (Wegner, 2020; Saunders & Lewis, 2017).

6.3. Validity testing of constructs and reliability testing of the instrument

Validity and reliability tests were conducted to confirm that the study's measures had accurately captured the constructs and produced dependable scores for interpreting construct relationships (Kaiser, 1974; Bartlett, 1950). Evidence included sampling adequacy and correlation structure (KMO and Bartlett's test), exploratory factor analysis (maximum likelihood, oblimin rotation) and internal consistency (Cronbach's alpha).

Sampling adequacy and factorability

The results presented in Table 6 suggest that all scales achieved KMO values above 0.80 (sensing 0.844; seizing 0.828; reconfiguring 0.855; adoption 0.870; innovation 0.860), placing them in the "meritorious" range. Furthermore, all Bartlett's tests were substantial and significant ($p < .001$), hence rejecting identity correlation matrices and endorsing component extraction at $N = 150$. These results suggest that the item sets shared enough common variance to justify the exploratory factor analysis (Bartlett, 1950; Cronbach, 1951; Kaiser, 1974; Tavakol & Dennick, 2011).

Exploratory factor analysis (structure and variance)

The results presented in Table 8 (3-factor; ML with oblimin) suggest that the measurement overlap among sensing, seizing, and reconfiguring did not confound the component-wise regressions. The fairly even variance across the three capability factors reduced the likelihood that any "winner" in the regressions simply reflected an oversized item set rather than a genuine link to adoption. The unidimensional adoption and innovation scales also simplified the interpretation of the main and moderating effects, lowering the risk that null or small findings were artefacts of hidden multidimensionality.

Reliability of the instrument (Cronbach's alpha)

The results presented in Table 12 (Scale-level summary) suggest that the values of the scale-level alphas exceeded 0.70 for all constructs – sensing (0.841), seizing (0.871), reconfiguring (0.863), adoption (0.868), and innovation (0.879), which indicate good internal consistency for correlational and regression analysis (Cronbach & Dennick, 2011; Smith & Doe, 2006). With alpha values (α) ranging between 0.841 and 0.879, attenuation of effect sizes due to random error was likely modest thus, standard errors and confidence intervals reported in the Chapter 5 models were less prone to instability from noisy composites. Accordingly, this reliability profile supported the use of composite means and z-scores in the hypothesis tests.

What do these results mean for the quality of the statistical findings?

Considering the construct validity and specification risk aspects, the above observations posit that the findings of the statistical analysis were construct-consistent instead of artefacts of item intermingling. By identifying seizing as the sole DC predictor of adoption, while sensing and reconfiguring were not significant at conventional levels, one could argue that the measurement evidence shifted the interpretation toward a substantive explanation. This suggests that the binding constraint of the adoption of the GH₂ technology was not the lack of finding opportunities as reported by some contemporary researchers (Béres et al., 2024; Kweinor Tetteh et al., 2024), but rather turning those identified opportunities into action, for example getting decisions made and correctly allocating resource (e.g. resource requirements/people and equipment).

This aligns with Bandiri et al.'s (2024) findings, which advocate for a complementary approach to address limitations in South Africa's energy sector. The authors argued that South Africa should, instead, build adequate energy infrastructure (e.g., conveyance and storage facilities, etc.) and initiate a political drive focusing on the decision-and-deployment engine that transforms the identified opportunities into realised competitive advantage. This argument was also strengthened by the seizing composite score distributions, which suggest that respondents somewhat agree that South Africa engages in seizing behaviours. The sensing, seizing reconfiguring composite score distributions are depicted in Appendix 7.

Considering the assumptions and downstream inference, the factor structures and the composites were reliable, which complemented the regression diagnostics (e.g., linearity, approximate residual normality and homoskedasticity, and low multicollinearity). Together, these checks strengthened the confidence level in coefficient calibration, p -values, and confidence intervals. The measurement layer, therefore, did not raise red flags that would have weakened the inferential validity of the results of the analysis presented in Chapter 5 (Kaiser, 1974; Saunders & Lewis, 2017; Wegner, 2020).

In summation, the outcomes of the validity testing of constructs and reliability testing of the instrument indicate the following: (i) item sets were factorable and structurally valid; (ii) DC decomposed into three empirically separable, balanced dimensions; (iii) adoption and innovation were coherent single-factor constructs; and (iv) internal consistency was strong across all scales.

6.4. Conclusion and practical meaning

The results of the statistical analysis reported in Chapter 5 confirmed that the latent variables used in this study, including the DC (sensing, seizing, and reconfiguring), GH₂ technology adoption, and innovation, were suitable for factor analysis, exhibited the expected structure, and showed strong internal consistency (Bartlett, 1950; Kaiser, 1974). These findings also underpinned the robustness of the reported results. They justified a focused discussion on execution-centric capability building (seizing) as a near-term lever, while acknowledging that sensing and reconfiguring may matter indirectly.

The subsequent section 6.5 discusses the research findings in relation to the research hypotheses that were formulated in Chapter 3.

6.5. The impact of DC on the adoption of green hydrogen technology

This study aimed to assess the impact DC on the adoption of green hydrogen technology, by answering the main question: “What is the impact of dynamic capabilities on the adoption of green hydrogen technology moderated by innovation?”. Therefore, Hypothesis 1 was formulated:

H1: Dynamic capabilities (sensing, seizing, and reconfiguring) positively influence the adoption of green hydrogen technology.

The hypothesis tests identified GHT adoption as the dependent variable, with the composite DC index (calculated as the equal-weight mean of sensing, seizing, and reconfiguring) serving as the main predictor. A policy index was included as a control variable.

Statistical results in Chapter 5, section 5.9, suggest that stronger DC is associated with a higher degree of GH₂ adoption. This was evidenced by the positive association of the correlation matrix between the DC and adoption ($r = 0.26$, one-tailed $p < 0.001$), consistent with Hypothesis 1. However, the DC–adoption relationship was modest in magnitude but statistically robust after accounting for perceived policy.

Furthermore, results presented in Table 14 suggest that any policy influence in this specification was likely indirect rather than direct since no meaningful correlation was observed between the policy control and adoption nor with the dynamic-capabilities composite.

In practical terms, these observations posit that since there is a positive DC-adoption relationship, strengthening DC should promote higher adoption. However, additional levers, generally found in green energy project implementation, such as high initial capital intensity, infrastructure availability, high investment risks and leadership priorities, may have accounted for much of the residual variance (Department of Science and Innovation, 2021; McGregor et al., 2025).

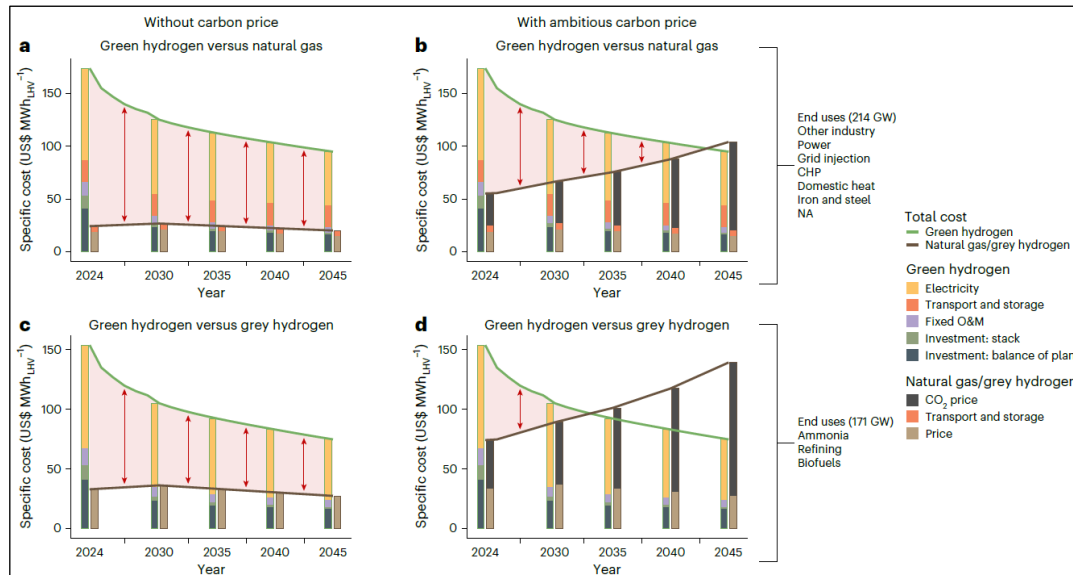
The modest effect, in magnitude, of DC on the adoption of GH₂ could be explained by several sectoral realities, particularly within the South African context. These include low business appetite, generally justified by high capital intensity and cost exposure; and lack of established legal and statutory requirements (e.g., codes and standards). These, in turn, are mainly caused by the high levelised cost (\$4.5 - \$12/kg) of GH₂ (Mukelabai et al., 2022), lack of secured long-term offtake agreements leading to high investment risks, as well as shifts in the international regulatory regimes (IEA, 2024). Following this line of reasoning, Mukelabai et al. (2022) contended that strategic collaboration and partnerships between the African governments and hydrogen

technology developers were the decisive lever that could be used to accelerate the adoption of GH₂. The authors substantiated their argument by citing milestones in Namibia's green-hydrogen (GH₂) programme, demonstrating that an adaptive strategy and robust policy – particularly de-risking subsidies – can unlock investment and accelerate adoption.

Challenges relative to production cost were evidenced by studies carried out by previous researchers (Ayodele & Munda, 2019; McGregor et al., 2025; Nami et al., 2022; Rezaei et al., 2024). The techno-economic studies conducted by Nami et al. (2022) and Odenweller and Ueckerdt (2025) have identified the high financing terms and the electrolyser capital expenditure (CAPEX) – which represents more than 30% of the initial capital investment in most cases – as the dominant drivers of the GH₂ levelised cost (LCOH). As a result, GH₂ adoption has become highly sensitive to organisations' ability to leverage internal resources and capabilities to design bankable projects and structure capital at acceptable risk levels.

Expanding upon this argument, a review of the feasibility study conducted by Odenweller and Ueckerdt (2025) to forecast the green hydrogen and natural gas production costs in a continuously evolving green energy business environment shaped by new and stringent environmental regulations has demonstrated how strengthening the DC could positively promote higher GH₂ adoption at a national level. These findings suggest that leveraging seizing (e.g., subsidising the production cost of GH₂) could potentially contribute to the success of the project by lowering the LCOH. For example, Figure 16 (a, c) reveals that without incentive measures such as carbon pricing, the GH₂ in 2024 is more than seven times as expensive as natural gas. Contrarily, when the carbon price pathway aligns with the European climate policy targets, the GH₂ achieves cost parity with natural gas, strengthening its market competitiveness. See Figure 16 (b, d).

Figure 16: Project implementation gaps (Odenweller & Ueckerdt, 2025, p.115)



Nonetheless, one should acknowledge that driving incentivised initiatives for emerging technologies – aimed at lowering the production costs – calls for a strong and purposeful leadership style. Further underscoring this idea, Teece (2018) through his study where he analysed the interactions between the firm's business leadership and its DC, argued that robust DC, when coupled with strong leadership, enables organisations to adapt to shifting market conditions (e.g., geopolitical dynamics). In fact, this simply means that without strong leadership, DC remain latent. Sensing can enable the organisation to identify suitable business options, however without the authority to commit resources and align incentives, seizing will probably stall. Reconfiguring likewise needs mandate, coordination, and political drive (Teece, 2018; ThyssenGas, 2025).

Putting this into perspective, in green energy project development, financing, stakeholder mobilisation, and risk sharing are leadership tasks; when they are weak, DC routines fragment and misalign, undermining implementation (Buchner et al., 2025; Parente et al., 2024). The recent Australian government's 6.7 billion US dollar hydrogen production tax incentive to support the clean energy initiatives to unlock further investment opportunities across Australia (Pinsent Masons, 2025) provides further

validation of the critical role of purposefully leadership style in the green energy business.

In conclusion, one can postulate that DC create capacity, while leadership converts that capacity into adoption.

Conclusion

Hypothesis 1 is supported. DC has a positive influence on the adoption of green hydrogen technology in the South African energy sector. The impact of the DC on adoption is statistically reliable yet modest, reflecting external constraints – such as high financing terms and CAPEX and market dynamics – that, if adequately leveraged, can enhance adoption (ThyssenGas, 2025).

South Africa should prioritise adopting the DC framework as a practical management tool, as it provides a valid pathway to accelerate GHT adoption in the country's energy sector.

6.6. The distinct impacts of the three attributes of the DC on the adoption of green hydrogen technology

Section 6.5 examined the impact of DC on the adoption of GHT. This section aims to evaluate whether the three dimensions of DC (sensing, seizing, and reconfiguring) have distinct, direct effects on GHT adoption. Accordingly, H2a tested the effect of sensing, H2b tested the effect of seizing, and H2c tested the effect of reconfiguring on GHT adoption. Hence, Hypothesis 2 was formulated:

H2: The three attributes of the dynamic capabilities (sensing – H2a, seizing – H2b, and reconfiguring – H2c) have distinct impacts on green hydrogen technology adoption.

The outcomes of the statistical analysis (Table 25) indicate that seizing stood out as the primary driver of adoption, since it is the only component that uniquely predicts adoption when all three are entered together ($B = 0.176$, 95% CI = [0.016, 0.336], $p = 0.031$). Sensing and reconfiguring did not demonstrate independent effects when the impacts of all three components were analysed simultaneously. Sensing showed a small positive simple correlation with adoption; however, its coefficient was not significant once seizing

and reconfiguring were included (e.g., $B = 0.108$, $p = 0.221$). This is despite the fact that the composite score distribution suggested a broad agreement on strong sensing capability. The coefficient for reconfiguring was found to be small and non-significant (e.g., $B = 0.057$, $p = 0.510$) after including the other components, indicating that any simple association likely represented shared variance with seizing/sensing rather than a distinct contribution. Still, the composite score distribution indicated a broad agreement on strong sensing capability.

In practical terms, these results suggest that improving how the organisation mobilises resources and makes timely decisions (seizing) is associated with higher adoption, even after accounting for the other capability facets and the policy controls (Teece, 2018). Research findings reported by Taghizadeh et al. (2023) support this argument. The researchers contended that executional orchestration (seizing) had a greater impact on delivering sustainability-orientated innovation in small and medium enterprises (SME) as compared to opportunity sensing because, in the SME context, firms often lacked the tools, awareness, and human capital depth to turn identified market ideas into actionable innovation. Hence, the authors posited that the bottleneck to adoption is not the identification of opportunities but a firm's ability to commit and mobilise resources to capture value from them.

In the context of the South African GH₂ industry, this trend aligns with the setting where latent and inherent endowments (e.g., abundant renewable resources) and business opportunities (e.g., high demand for green energy, etc.) are available but remain unexploited (Ayodele & Munda, 2019; AbouSeada & Hatem, 2022). The subsequent paragraph articulates the rationale underpinning respondents' perception that seizing predominates over sensing and reconfiguring within South Africa's energy sector.

Teece et al., (1997) posit that DC are heterogeneous and multi-faceted; therefore, organisations in the pursuit of implementing a suitable business strategy to adapt may not necessarily focus on all CD attributes (e.g., sensing, seizing and reconfiguring) at once and to the same degree of engagement. The organisational strategy often depends on the business environment and its dynamics, which implies that perceived capabilities for sensing, seizing, or reconfiguring may vary unevenly. Putting this approach into perspective, Ayodele and Munda (2019) posit that in the South African

GH₂ context, the hurdle is not about spotting opportunities but turning them into bankable business – securing offtake, finance, and compliance amid high CAPEX and evolving international market requirements.

Since these tasks sit squarely in seizing, the South African energy sector should focus on the seizing aspect in order to adapt. This situation aligns with the stage-of-market effect reported by Zhang (2020) while investigating the green DC of construction enterprises. The authors argued that in an early/mid-transition market, scanning (sensing) and internal restructuring (reconfiguring) add limited adoption lift unless paired with credible contracts and funding. Furthermore, the chart of composite score distributions (Appendix 7) suggested that respondents somewhat agreed that South Africa engages in seizing behaviours.

Based on the above discussion, it is worthwhile to argue that the recent announcement by the European Union at the 8th South Africa-EU Summit in early March 2025, regarding an investment of 4.7 billion euros in South Africa's green hydrogen production sector (The Presidency of South Africa, n.d.), should not only be viewed as clear evidence of the country's significant potential in renewable energy, and its abilities to sense business opportunities but also as a crucial necessity for the South African energy sector to enhance its capabilities – specifically seizing – to seize and convert identified GH₂ opportunities into executable commercial arrangements (Ayodele & Munda, 2019; IRENA, 2023; Teece, 2018).

The paragraph below aims to elucidate why sensing and reconfiguring exerted less impact on green-hydrogen adoption than seizing. The green energy market is complex and dynamic, characterised by frequent policy shifts and political pressures that generate conflicting signals for firms and organisations. The recent British and European CO₂ unilateral emission regulatory regimes that enforce the carbon border mechanism clearly illustrate such dynamic (IEA, 2024).

Market intelligence (e.g., IRENA, 2023) indicated that firms are generally able to identify opportunities (sensing). However, translating these opportunities into concrete adoption decisions is often driven by bankability, credible offtake pathways, and de-risked financing structures that must be secured through seizing. Extending this view, Agyekum (2024) argued that Africa's binding constraints are not opportunity discovery,

since these opportunities already exist and are visible in the global energy market (e.g. the European GH₂ master plan). Rather, the constraints are high LCOH, gaps in regulatory and legal frameworks, and limited financing – again pointing to seizing rather than sensing, as the decisive capability. Following this line of reasoning, reconfiguring (e.g., asset realignment and redeployment of existing knowledge and resources) remains salient, yet its impact is frequently contingent on prior commercial closure; in export-oriented plays, it may be sequenced after offtake and certification clarity.

In practice, this means that organisations typically prioritise reconfiguring (e.g., redeployment of existing resources) only after an offtake contract has been signed and the governing GH₂ certification has been understood. Once these requirements are materialised, only then can reconfiguring proceed. For example, the German green hydrogen utility company RWE could only initiate the reconfiguration of its production facility after seizing – once TotalEnergies' offtake contract had been secured through a long-term agreement to procure 30,000 tonnes annually from 2030 (ThyssenGas, 2025). While conducting empirical studies to assess the transition from fossil fuels to renewable energy (GH₂), Hermundsdottir et al. (2024) also claimed that reconfiguring was not a constraint in the adoption of the GH₂ because the organisation could easily reconfigure by redeploying existing knowledge and resources, such as directly transferring expertise in engineering disciplines and safety to green energy development.

Bringing these observations into perspective, the researcher believes that most respondents also had a similar view, where sensing and reconfiguring do not play a critical role as seizing in the adoption of the GHT within the South African context. The sensing composite score distribution patterns, which suggested a strong sensing capability across the sample, evidenced this conclusion (Appendix 7). And the reconfiguring composite score distributions suggested that most respondents view reconfiguring favourably, as they perceive that the South African energy sector is capable of reconfiguring in a dynamic energy market.

In summary, sensing uncovers options, but without seizing – contracting, financing, and standard-compliant structuring – the direct effect on adoption will be muted, and reconfiguring will tend to follow rather than lead (Teece, 2018).

Conclusion

Seizing stands out as the primary driver of adoption; sensing and reconfiguring do not show independent effects, suggesting that improving how the organisation mobilises resources (e.g., by converting sensed options into bankable and solid commitments amid CAPEX, certification, and offtake risks) is associated with higher adoption even after accounting for the other capability facets and policy control.

Within the South African green energy sector, GH₂ adoption mostly depends on seizing; sensing and reconfiguring remain necessary but are insufficient to shift adoption without the levers (e.g., commercial closure) that seizing provides (IEA, 2024).

The South African energy industry should consider focusing in leveraging its seizing capabilities (e.g., targeted production subsidies of GH₂) to lower the levelized cost of hydrogen (LCOH) and, in turn, accelerate adoption of green hydrogen technology.

6.7. The moderating role of innovation on the relationship between the dynamic capabilities and the green hydrogen technology

The discussion proceeds in two parts. First, it tests whether innovation moderates the relationship between dynamic capabilities (DC) and the adoption of green hydrogen technology (GHT). Second, it examines innovation's direct effect and whether it differentially influences the three DC dimensions, including sensing, seizing, and reconfiguring. The aim of this second step is to answer the sub-question 2: To what extent does innovation uniquely moderate the three attributes of DC: sensing, seizing, and reconfiguring, and thereof the relationship between dynamic capabilities and GHT adoption?

H3: Innovation moderates the relationship between dynamic capabilities and green hydrogen technology adoption, such that the relationship is robust at a higher level of innovation.

The results indicated that innovation does not exert a statistically significant moderating effect on the relationship between DC and adoption. In practical term, innovation, in this specification, neither amplifies nor dampens that relationship, and the policy control does not alter the substantive conclusion.

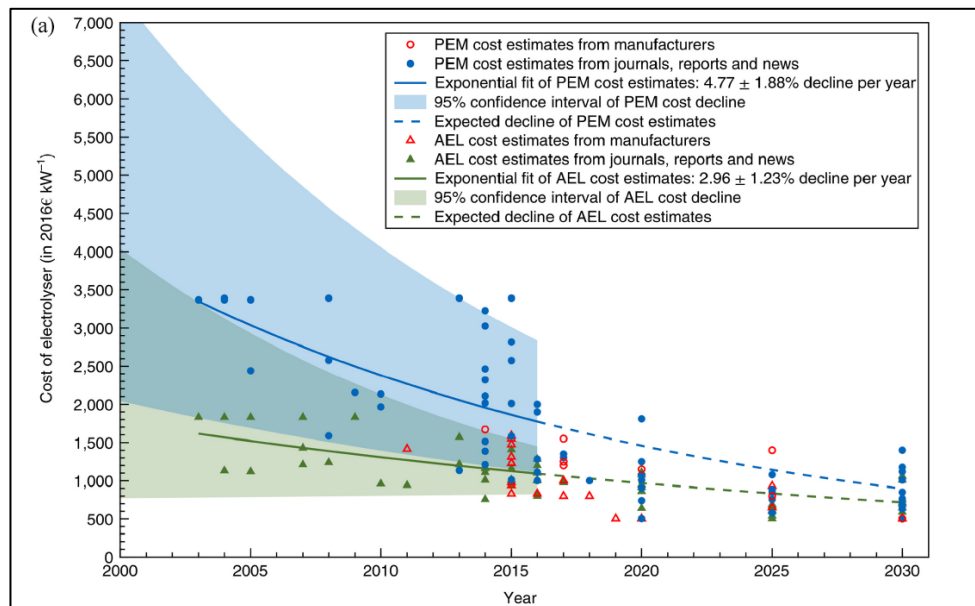
The non-significant moderation of innovation observed in this study appears to be consistent with constraints mentioned in the literature review on technology adoption limitations (see section 2.4). Within the South African context, GHT adoption is shaped by structural constraints – such as high CAPEX due to electrolyser and balance-of-plant costs, and offtake risk – which act as binding conditions (Rezaei et al., 2024; Odenweller & Ueckerdt, 2025). Hence, “being innovative” under such conditions at the industry level may be valued culturally but is insufficient to amplify the pay-off of DC for near-term adoption decisions. Put differently, sensing, seizing, and reconfiguring still matter. Indeed, DC showed a direct main effect, but the slope of that relationship appears insensitive to variance in general innovation climate when hard constraints (e.g., high CAPEX) dominate.

This pattern also aligns with the strategic framing elaborated in Chapter 2, which positions DC as the engine translating opportunities into coordinated action (e.g., structured sensing routines, investment governance for seizing, and asset reconfiguration). From a practical standpoint, this implies that where external constraints and risk-pricing dominate (LCOH), decision rights and financing capability – core expressions of seizing – may therefore have a more immediate effect on adoption than a broad innovation posture (Odenweller & Ueckerdt, 2025).

Figure 17 illustrates the anticipated cost trajectories for prominent electrolysis technologies (e.g., PEM) as projected by the European Union. Based on these projections, an economically attractive electrolyser cost – sufficient to make GH₂ competitive with natural gas – is unlikely to be achieved before 2030, when supply chain scale, and performance improvements plateau. However, Rezaei et al. (2024) argued that with appropriate policy measures (such as grants and risk guarantees) and low interest rates, the green hydrogen costs can possibly drop below 3 USD/kg prior to 2030. This once again underscores the crucial role of DC in the adoption of green hydrogen by the energy sector.

In summary, these observations reinforce the results presented in section 6.5, suggesting that organisations with stronger DC exhibit higher adoption regardless of their innovation orientation.

Figure 17: Projected cost evolution of major electrolysis technologies (Rezaei et al., 2024, p.4)



Nevertheless, it is essential to acknowledge that the preceding finding – suggesting that innovation failed to moderate the relationship between DC and adoption – contradicts the common assertion in the literature, which suggests that organisations with higher innovativeness adopt emerging technologies more readily (Rogers, 1960; IEA, 2024). Further underscoring this idea, Arifin & Frmanzah (2015) highlighted the critical role of innovation in technology adoption. They argued that technological adoption was a functional competence – necessary to mediate the relationship between DC and firm performance, which the organisation generally acquires through innovation.

Consequently, this discrepancy prompted the researcher of this present study to investigate potential respondent biases, such as education level or seniority, that could explain the fact that survey participants appear to recognise innovation’s aspirational value (see Appendix 7) yet discount its decisiveness. The response demographic discussed in section 5.3 showed a broad distribution of academic qualifications (from diplomas to PhDs) across 150 respondents. The moderation test did not report systematic differences by education level in the DC and adoption relationship slope or the innovation measure. Additionally, the hierarchical modelling controls for policy while standardising focal constructs. On this basis, there was no clear evidence that the

education level composition biased the moderation result. However, innovation composite score distributions also suggested that all respondents perceived the South African energy sector as having strong innovative capacity, as discussed in Appendix 7. That said, the researcher still believe that education may still correlate with role seniority, risk tolerance, or exposure to capital projects – factors that future researchers could examine more explicitly through multi-group analyses, inclusion of role or tenure as control variables, exploration of sub-dimensions (e.g., innovation in finance vs. product/process), modelling of non-linear interactions, or assessment of conditional effects across industry segments (e.g., utilities vs. process industries vs. OEMs).

The next paragraph addresses sub-question 2, which asked to what extent innovation uniquely moderated the three attributes of dynamic capabilities (sensing, seizing, and reconfiguring), and thereof the relationship between dynamic capabilities and green hydrogen technology adoption.

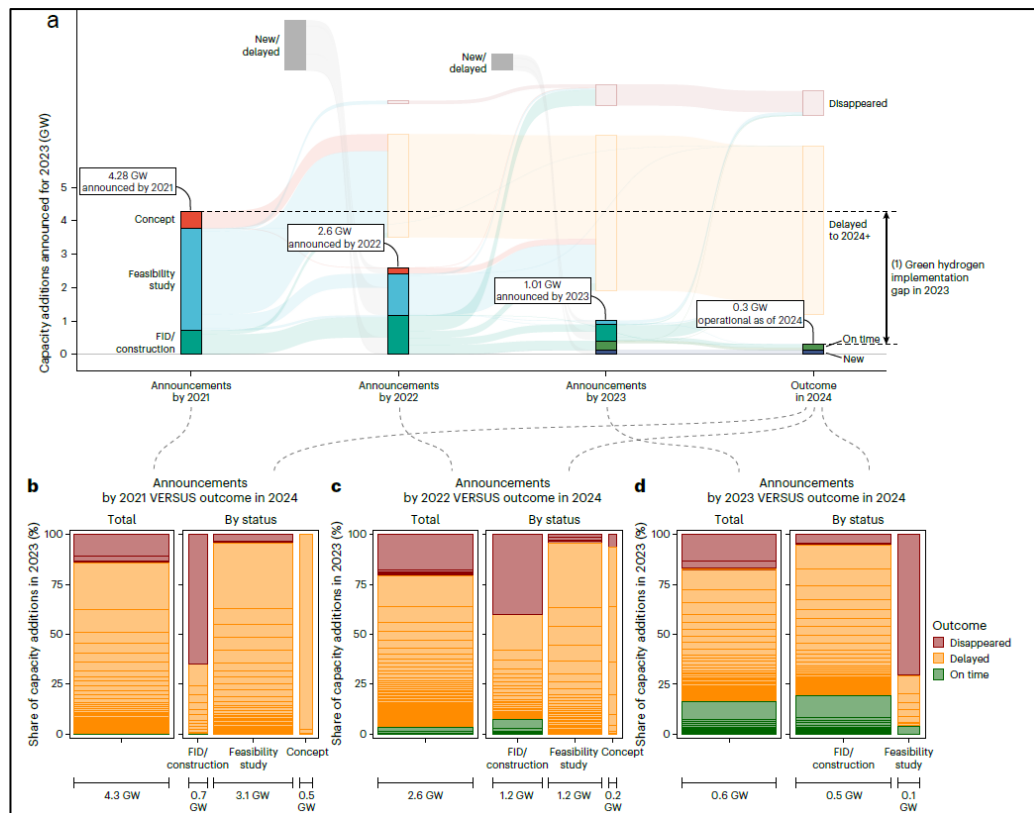
The analysis indicated that innovation did not significantly moderate the three DC dimensions – sensing, seizing, or reconfiguring – as none reached the 0.05 threshold (p -values were $p_{\text{sensing}} = 0.393$, $p_{\text{seizing}} = 0.073$, and $p_{\text{reconfiguring}} = 0.792$). However, the innovation \times seizing term exhibited the smallest p -value (0.073), suggesting a comparatively stronger – even though still statistically non-significant– association than the corresponding innovation \times sensing and innovation \times reconfiguring terms.

This pattern is consistent with earlier results that pointed out the importance that seizing plays when considering the GHT adoption within the South African context. In practical terms, this implies that while a broad "innovation posture" did not amplify the effects of sensing or reconfiguring adoption, there may be a nascent linkage between innovation and the organization's ability to mobilise resources, structure bankable deals, and execute investment commitments (i.e., seize). The relatively lower p -value on seizing aligns directionally with prior evidence that execution-orientated capabilities matter most for near-term GHT adoption.

Extending this argument, recent studies – most notably Odenweller and Ueckerdt (2025) – underscore the centrality of seizing in green hydrogen implementation worldwide.

Figure 18 which tracks project outcomes from 2020 to 2024, suggests that less than 20% of announced projects remained on schedule – even in regions with comparatively mature GH₂ technologies and innovation ecosystems (e.g., European Union). More than 60% experienced delays, and roughly a quarter were cancelled or shelved. One can argue that this pattern once more signals that executional factors associated with seizing (e.g., bankable structuring, offtake contracting, permitting discipline) still play a critical and decisive role, whereas innovation, a well-known competitive advantage of these nations, does not seem to drive the materialisation of green hydrogen technology.

Figure 18: GH₂ implementation gap (Odenweller & Ueckerdt, 2025, p.113)



Conclusion

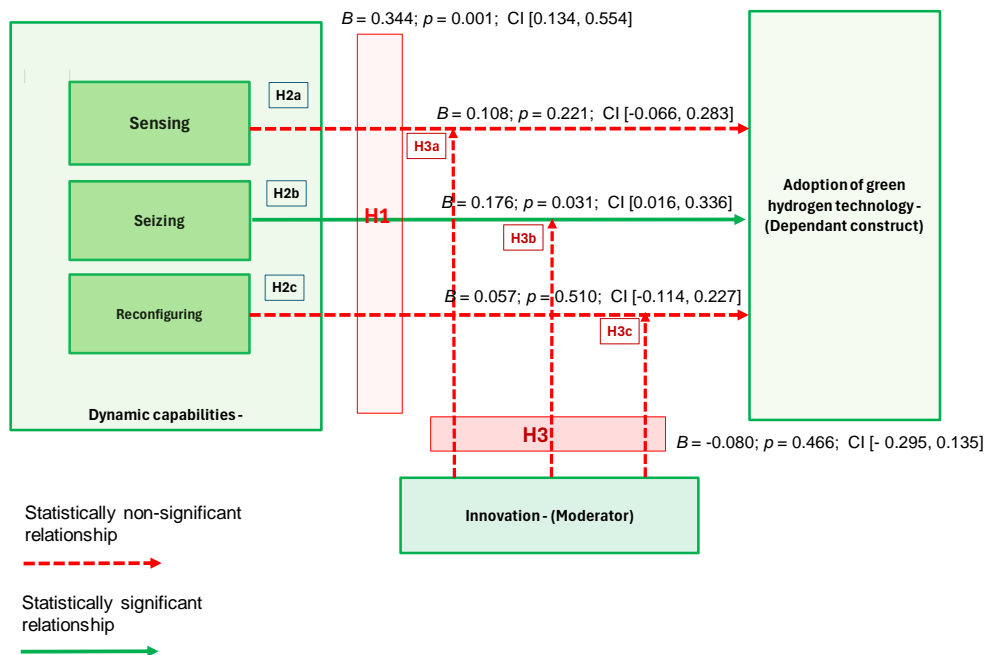
While innovation is valued, in the current South African context it does not appear to enhance the pay-off from dynamic capabilities (DC) in adopting green hydrogen. Strengthening DC – particularly the seizing dimension – is therefore likely to yield more tangible adoption benefits, regardless of the organisation’s level of innovativeness.

Nevertheless, these findings diverge from the prevailing view in the literature, which posits that organisations with greater innovativeness tend to adopt emerging technologies more readily.

6.8. Summarised findings

Figure 19 presents the validated conceptual framework which maps the relationships among the study constructs. The green arrow denotes a statistically significant relationship, whereas the red arrow denotes a non-statistically significant relationship.

Figure 19: Validated conceptual framework



The empirical results align with dynamic capabilities theory, suggesting the following:

- H1: Dynamic capabilities reliably predict technology adoption with innovation as the moderator. However, the effect is modest (Teece, 2018; Hermundsdottir et al., 2024; Rogers, 1960).
- H2: Seizing alone (mobilising resources) offers unique predictive power, whereas sensing and reconfiguring are non-predictive.
- H3: Innovation does not moderate; DC retains importance.

Accordingly, the study's objective which consisted of assessing the impact of dynamic capabilities on the adoption of green hydrogen technology has been achieved.

7. CONCLUSION AND RECOMMENDATIONS

7.1. Summary of the research project

This research study aimed to examine the impacts of the DC on the adoption of GHT in South Africa's energy sector. The motivation arose from the disconnect between South Africa's abundant renewable resources (e.g., wind, solar, and access to seawater) and the lack of tangible value propositions and economic benefits compared to other sub-Saharan African countries, such as Namibia (Lahnaoui et al., 2024).

Prior studies, mainly qualitative, focused on South Africa's economic and technical capacity to produce low-cost green hydrogen (AbouSeada & Hatem, 2022; Ayodele & Munda, 2019; Imasiku et al., 2021). However, few of them have assessed the need for South Africa's energy industry to adopt strategic management tools, such as the DC framework, to position the country as a global player through GHT (Kweiyor Tetteh, Sijadu & Rathilal, 2024). The current research study aimed to address this gap.

The project's purpose was (i) to empirically test whether stronger DC are associated with higher GHT adoption at the industry level and (ii) to unpack the distinct contribution of the DC attributes (e.g., sensing, seizing, and transforming) in South Africa's context and evaluate how innovation moderated the DC-adoption relationship. The relevance of this work was to enable the South African energy sector to harness the nation's abundant renewable energy resources.

Guided by the primary question –“What is the impact of dynamic capabilities on the adoption of green hydrogen technology moderated by innovation?”–Three hypotheses were formulated.

7.2. Principal conclusions

Based on the statistical analysis of data obtained through the survey, the empirical evidence supported the following findings:

Hypothesis 1: Dynamic capabilities (sensing, seizing, and reconfiguring) positively influence the adoption of green hydrogen technology.

DC is positively associated with GHT in the South African energy sector. The impact of DC on adoption is statistically reliable yet modest in magnitude, indicating that capability strength matters, but external constraints – such as high financing terms, CAPEX, and market dynamics – could explain substantial residual variations. Therefore, institutionalising the DC framework could provide a viable managerial pathway for South Africa to accelerate the adoption of GHT in its energy sector (Hermundsdottir et al., 2024; Zhang et al., 2024).

A suitable reference DC model that South Africa could adopt is the European Union's Hydrogen Strategy (2020) and the Fit-for-55 package (2021), which promote and accelerate the EU's decarbonisation agenda and establish GH₂ as a cornerstone of the energy transition (IRENA, 2023).

Hypothesis 2: The three attributes of the dynamic capabilities (Sensing – H2a, seizing – H2b, and reconfiguring – H2c) have distinct impacts on green hydrogen technology adoption.

The relative weight of the capability dimensions is decisive. Seizing, which is an execution-centric capability that converts sensed options into bankable commitments, emerged as the principal driver of adoption. Sensing and reconfiguring remained necessary for opportunity identification and organisational alignment, yet did not produce independent adoption gains without the resource mobilisation embedded in seizing. Practically, strengthening investment cases appears to be the lever that shifts projects from exploration to implementation (IEA, 2024; Odenweller & Ueckerdt, 2025). Thus, it is imperative that South Africa consider leveraging its seizing capabilities by prioritising initiatives – such as temporary subsidies to lower GH₂ production costs – to accelerate green-hydrogen technology adoption.

Hypothesis 3: Innovation moderates the relationship between dynamic capabilities and green hydrogen technology adoption, such that the relationship is robust at a higher level of innovation.

Innovation, while valued, did not amplify the payoff from DC for adopting GH₂ under current conditions. While innovation correlated positively with adoption and with DC at zero-order, the interaction term was small and non-significant.

In South Africa's current market conditions, an "innovative posture" alone does not amplify the payoff from DC for near-term adoption decisions. Targeted improvements through seizing capabilities are likely to yield more tangible adoption benefits than broad innovation initiatives alone. Innovation does not uniquely moderate the three DC attributes: e.g., sensing, seizing, and reconfiguring.

The non-moderation result contradicts the common assertion in the literature that organisations with higher innovativeness adopt emerging technologies more readily (IEA, 2024; Rezaei et al., 2024). In this research, seizing capacity (execution, financing, contracting) appears to dominate the slope, with innovation not altering the strength of the DC-adoption link. This result warrants further studies into the relationship between innovation and technology adoption constructs.

7.3. Recommendations and implications

7.3.1. For the organisations

DC is not an abstract theory. The South African energy industry should consider adopting the DC framework. This is because the DC framework's three attributes, particularly seizing, provide a valuable strategic lens through which the industry can adjust its business strategy in response to both internal and external factors and navigate the changing green energy landscape more effectively. Following this line of reasoning, the South African energy industry should note that sensing and reconfiguring remain necessary conditions, but they do not generate independent adoption gains without seizing (Bandiri et al., 2024; Hermundsdottir et al., 2024; Teece, 2018).

When adopting the DC framework, the South African energy industry must balance its DC portfolio throughout the adoption lifecycle, given certain limitations: DC effectiveness is context-sensitive and dependent on leadership. It can be diminished by regulatory and geopolitical shocks (Rezaei et al., 2024).

The outcomes of this study have laid the foundation that the South African energy industry needs, to support its ambition to develop adequate strategies that will enable the nation to navigate the complexities of integrating the green hydrogen solutions and to enhance its competitiveness in the global market. Furthermore, these findings should

equip policymakers to make informed decisions (Department of Mineral Resources and Energy, 2021).

7.3.2. For the academia

This empirical study has offered fresh academic perspectives on how the DC impacts the adoption of renewable energy technology in South Africa and, to some extent, in other African nations endowed with abundant renewable resources. Hence, academia should consider analysing DC by facets (e.g., sensing, seizing, and reconfiguring) rather than treating it as a single construct. For example, empirical results show that seizing makes a distinct, incremental contribution when the facets are estimated concurrently (Harichandan & Kar, 2023; Zhu et al., 2023). This point is critical, as several contemporary studies exploring the applicability of the DC theory generally assume that the terminology “strong dynamic capabilities” implies a high level of strength across all three attributes (e.g., sensing, seizing, and reconfiguring) at similar magnitudes (Teece, 2018). Limited studies acknowledge the uneven strengths across sensing, seizing, and reconfiguring (Teece, 2018; Easterby-Smith et al., 2009). For example, an organisation may identify opportunities well yet lag in executing and adapting strategy or craft a sound strategy but still struggle to implement it.

7.3.3. For business schools

Drawing on this perspective, business schools should consider establishing interdisciplinary workshops that convene scientists, engineers, financiers, and policy students to simulate coalition formation and risk-mitigation processes, thereby mirroring the dynamics of adoption in emergent sectors. Such pedagogy aligns with contemporary MBA programmes, which focus on leadership in complex, highly regulated, technology-intensive contexts (Aithal & Karanth, 2024; Sroufe et al., 2021). Several scholars also suggested that effective, robust leadership was essential for promoting agility and cross-functional collaboration throughout the organisation (Teece, 2018).

7.3.4. Future research

The findings of this empirical study seem to contradict the common assertion in the literature, which suggests that organisations with greater innovativeness adopt emerging technologies more readily (Ayodele & Munda, 2019; IEA, 2024; Mukelabai et

al., 2022). Given this contradiction, researchers (e.g., GIBS) should consider initiating further research studies that will reconcile these findings with prevailing literature on innovativeness and early adoption.

When evaluating the impact of the DC on adoption of the green energy, future research studies should retain a facet-level specification and explore non-linear effects and indirect pathways (e.g., mediation and moderated mediation).

7.4. Limitations

The limitations of this research study reside at different levels, including:

- **Sampling**

Data availability constraints in an emerging field: Quantitative studies typically require large samples to attain adequate statistical power. However, because green hydrogen remains emergent, assembling a substantial respondent pool in South Africa proved difficult and may have affected the results. As shown in Figures 12 and 14, the sample skewed toward energy-centric, private-sector participants – primarily oil, gas, and petrochemicals (>35%) – with minimal representation from government and policy stakeholders (<5%).

Under-representation of key stakeholders: Various key stakeholders, including policy/regulatory bodies, supply chains, and end-users, were under-sampled. Hence, this imbalance has introduced potential sampling bias, constraining the generalisability of the findings to other economic sectors such as mobility and finance (Wegner, 2020). A similar finding was reported by Arifin & Frmanzah (2015) while investigating the effect of dynamic capability on technology adoption and its determinant factors for improving the firm's performance.

- **Methodology choice**

Response and desirability biases: The mono-method quantitatively privileges statistical associations while only partially accounting for the wider social and cultural factors that may shape respondent behaviour (Saunders & Lewis, 2017; Wegner, 2020). For instance, participants might offer skewed, non-representative answers to signal an industry-level environmental stance or to

present themselves as environmentally responsible (self-reporting data). It is therefore imperative that future studies adopt a mixed-method approach, as this will enable the researcher to develop a more holistic view of the problem.

- **Context sensitivity of effects**

The literature survey has revealed that the impact of dynamic capabilities is context sensitive and can shift due changes in regulatory requirements and geopolitics. As a result, the findings of this study should be generalised with cautious (Parente et al., 2024; Teece, 2018; Zhang et al., 2024).

7.5. Concluding remarks

This study demonstrated that DC are necessary for green hydrogen adoption in South Africa, but the manner in which they exert influence is decisive. The aggregate DC index relates positively to adoption (H1), however, seizing – defined as the capability to commit and mobilise – emerges as the unique and main driver when capabilities compete for explanatory power (H2). Contrary to expectations, innovation, as a moderator, does not strengthen this relationship under current constraints (H3).

The main objective of the research, which is to assess the impact of DC on GHT adoption with specific attention to DC sub-dimensions has been achieved.

For practitioners, it is not an abstract theory but rather a centring executive capability that can be effectively utilised to capacitate policymakers and industry stakeholders to navigate the country's energy transition.

These findings have prompted a more granular, context-specific modelling of DC mechanisms and their limits.

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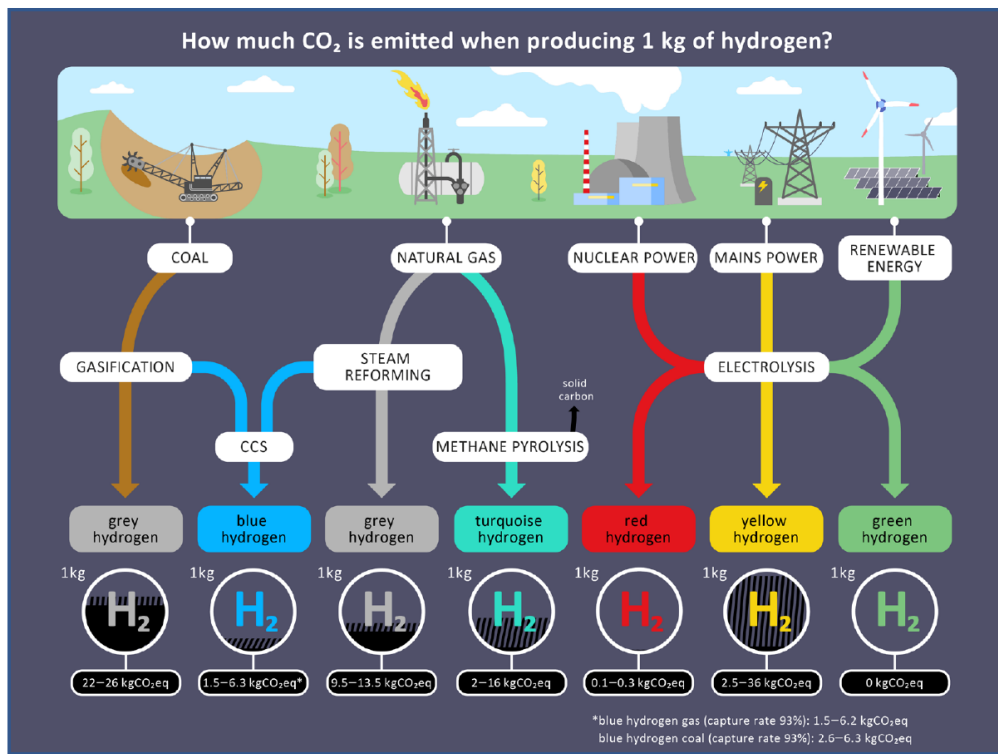
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APPENDICES

Appendix 1: Hydrogen classification and CO₂ emission

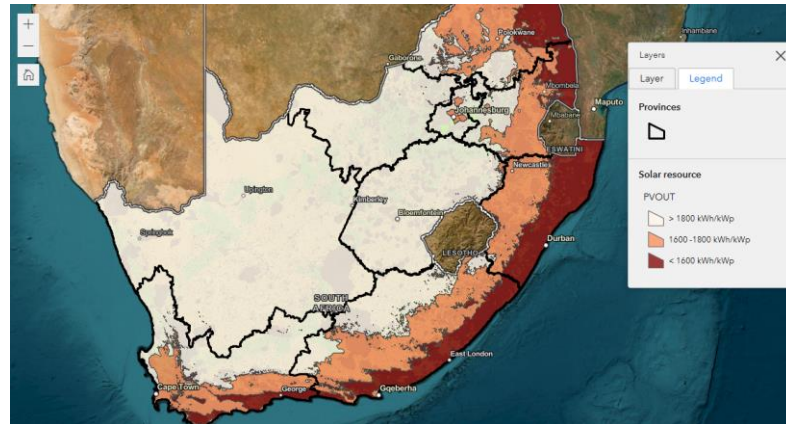
The figure below illustrates the environmental benefits of GH₂ (Wurbs et al., 2024) and classifies hydrogen types by production pathway and associated CO₂ emissions. It distinguishes how differing feedstocks and energy sources translate into markedly different lifecycle emission profiles.

Hydrogen classification and CO₂ emission (Wurbs et al., 2024, p. 6)

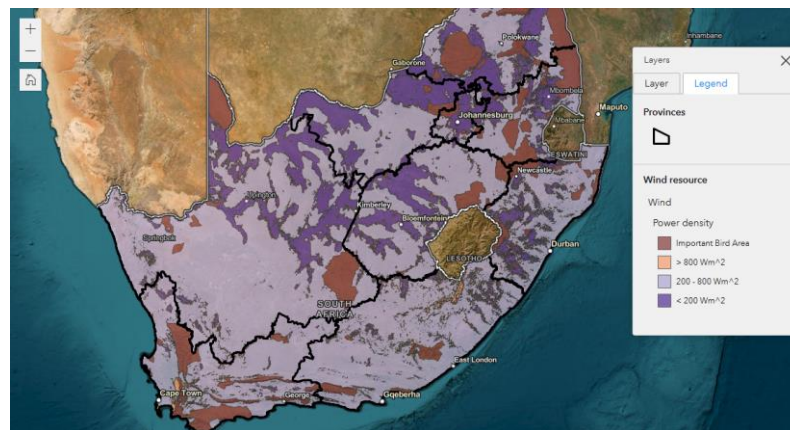


Appendix 2: South Africa solar and winds distribution

South Africa Solar Resources (Council for Scientific and Industrial Research, n.d.)



South Africa Wind Resources (Council for Scientific and Industrial Research, n.d.)



The above figures show the abundant South Africa solar and wind potential resources, particularly in sun-drenched regions and coastal areas. These resources provide ideal conditions for cost-effective green electricity production to power green hydrogen initiatives.

Appendix 3: Consistency matrix

Consistency matrix table

Questions	Literature review	Data collection tool	Analysis
<p>Research question 1</p> <p>What is the impact of dynamic capabilities on the adoption of green hydrogen technology moderated by innovation?</p>	<p>Wilden and Gudergan (2015), Nawab and Shafiq (2024), Nawab and Shafiq (2024).</p>	<p>Section 1: Dynamic capabilities (Independent Variable)</p>	<p>Simple Linear Regression</p>
<p>Research question 2</p> <p>What are the distinct impacts of the three attributes of the dynamic capabilities (sensing, seizing, and reconfiguring) on green hydrogen technology adoption?</p>	<p>(Makkonen et Al., 2014); Teece (1998), Teece et al. (1997), Mousavi et al. (2018), Chen (2024), Mousavi et al. (2018), Taghizadeh et al. (2024),</p>	<p>Section 2: Green hydrogen technology Adoption (Dependent Variable)</p>	<p>Multiple Linear Regression</p>
<p>Research question 3</p> <p>To what extent does innovation uniquely moderate the three attributes of dynamic capabilities: sensing, seizing, and reconfiguring, and thereof the relationship between dynamic capabilities and green hydrogen technology adoption?</p>	<p>Mousavi et al. (2018), Makkonen et Al. (2014); Teece (1998), Teece et al. (1997); Zhu et al. (2023), Bermejo (2016).</p>	<p>Section 3: Innovation (Moderator)</p>	<p>Moderator: Moderated Multiple Regression (interaction term)</p>

Appendix 4: Ethical clearance

Asumani, Oscar (OML)

Subject: FW: Ethical Clearance Approved
Attachments: EthicalClearanceReport.pdf

----- Forwarded message -----

From: **Masters Research** <MastersResearch@gibs.co.za>
Date: Mon, 11 Aug 2025 at 11:36
Subject: Ethical Clearance Approved
To: 05127557@mygibs.co.za <05127557@mygibs.co.za>
Cc: Masters Research <MastersResearch@gibs.co.za>

**Gordon Institute
of Business Science**
University of Pretoria

**Ethical Clearance
Approved**

Dear Oscar Asumani,

Please be advised that your application for Ethical Clearance has been approved.
You are therefore allowed to continue collecting your data.
We wish you everything of the best for the rest of the project.

[Ethical Clearance Form](#)

Kind Regards

This email has been sent from an unmonitored email account. If you have any comments or concerns, please contact the GIBS Research Admin team.

Appendix 5: Survey questionnaire

Dear Respondent

I am currently a student undertaking an MBA at the University of Pretoria's Gordon Institute of Business Science, where I am conducting research in partial fulfilment of the degree requirements.

The research work consists of assessing the impact of dynamic capabilities (DC) on the adoption of green hydrogen technology. It seeks to enhance the existing body of knowledge by providing innovative academic and practical insights into how strategic management principles, specifically the dynamic capabilities theory, can be utilised to empower the South African energy industry and the African continent in general to expedite the adoption of the green hydrogen technology.

To that end, you are asked to participate in this survey by completing a set number of questions in your personal capacity, not on behalf of your organisation. Note that the questionnaire should take no more than 25 minutes of your time. Your participation is voluntary and anonymous, and only aggregated data will be reported. You are allowed to withdraw at any time without penalty.

All the information collected is confidential and anonymous, and the responses provided will not be used to identify any participants. Data will be handled following the University of Pretoria's confidentiality policies.

By completing the questionnaire, you indicate that you voluntarily participate in this research. Should you have any concerns, please contact me or my supervisor. Our details are provided below.

Researcher: Oscar Asumani

Email: 05127557@mygibs.co.za

Phone: 066 250 4835

Supervisor: Dr Kelly Alexander

Email: alexanderk@gibs.co.za

Phone: -----

Section 1

Please indicate the option that is applicable to you using a tick symbol [X]

1 - Your highest Academic Degree

____ National Certificate/Diploma, ____ Bachelor/Honours, ____ Postgraduate (Master), ____ Postgraduate (PhD), ____ Others, ____ Undisclosed.

2 - Industry you work in

____ Energy (Renewables: Wind or Solar), ____ Energy (Oil & Gas/Petrochemical),

____ Energy (Green Energy), ____ Energy (Hydroelectric), ____ Energy (Coal),
____ Transportation/Mobility, ____ Mining, ____ Manufacturing,

____ Energy (Utilities/Distributor), ____ Financial Service,

____ Academia (Universities or other higher education institutions),

____ Policymakers, ____ Government/Regulatory Body,

____ Consulting & Professional Services, ____ Research & Development,

____ Non-Governmental Organizations, ____ others.

3 - Number of years you have been involved in the energy domain

____ (1 – 5), ____ (6 – 15), ____ (16 – 25), ____ 26 or above

4 - Professional Discipline (Your role)

____ Engineering/Technical, ____ Project Management, ____ Senior Manager,

____ Middle Manager, ____ Professor, ____ Business), ____ (Policy/Assurance),

____ Consultant, ____ Others.

5 – Geographical region of professional activity

_____ With in South Africa, _____ Outside South Africa, _____ Undisclosed.

6 - Financial and project execution experience (e.g., participation in the design concept of green hydrogen projects, involvement in the Final Investment Decision, and project financial closure), including the specific role played in each case.

_____ Engineering/Technical, _____(Project Management), _____(Senior Manager), _____(Middle Manager), _____ Professor, _____(Business), _____(Policy/Assurance), _____Consultant, _____Others.

Section 2

This section comprises questions designed to assess your evaluations of green hydrogen technology and its adoption. Please indicate the extent to which you agree with each statement by selecting the appropriate response on the scale provided.

Scale

1	Strongly Disagree
2	Disagree
3	Somewhat Disagree
4	Neutral
5	Somewhat Agree,
6	Agree
7	Strongly Agree

Dynamic Capabilities

Items	Questions (Dynamic capabilities - Sensing)	Select the appropriate response using the scale						
1	The South African energy industry has the ability to scan the environment and identify new business opportunities in green hydrogen energy							
2	The South African energy sector regularly evaluates the potential impacts of changes in the international energy market on its business strategy.							
3	The South African energy sector regularly evaluates the potential impacts of changes in the international energy market on consumer demand and preferences.							
4	The South African energy industry often reviews its product development efforts on green energy technology to ensure they are in line with market demand.							
5	The South African abilities to adopt new technology relays on its capacity to sense new opportunities (e.g. abilities to discover new opportunities within the renewable energy sector)							
Items	Questions (Dynamic capabilities - Seizing)	Select the appropriate response using the scale						
6	The South African energy industry has adequate resources (systems and tools, standardisation and certification schemes)							

	to position itself favourably in the present environment to explore new business opportunities.							
7	The South African energy industry devotes sufficient time to implementing innovative ideas for new products (e.g. green energy) and improving the existing green energy landscape.							
8	The South African energy industry collaborates with other local or international institutions (e.g., academia, consulting & professional services, R&D and policymakers) to ensure that there is adequate technical expertise locally.							
9	The South African abilities to adopt new technology relies on its capabilities to seize new opportunities (e.g. abilities to promptly select a new opportunity that it has identified within renewable energy sector)							
Items	Questions (Dynamic capabilities - Reconfiguring)							
10	The national regulatory body has frameworks / regulations / policies that capacitate the energy industry to adopt, acquire and create new resources (e.g. expertise, manpower, etc.).							
11	The South African energy industry has the capability to utilise and deploy its existing resources (e.g. expertise, manpower) to replicate an operational capability (e.g. new technology) in a new market.							
12	The South African energy industry has the capability to continuously and purposefully reconfigure its existing resource							

	base, enabling itself to transform and exploit its existing knowledge.							
13	The South African energy industry has business practices (i.e. supply chain management, knowledge management, etc.) that adequately support the green hydrogen business.							
14	The South African innovative ability relays on its ability to transform (e.g. abilities to redeploy its existing knowledge and resources and establish new organizational forms							

Items	Questions (Technology adoption)	Select the appropriate response using the scale						
1	The existing South African national professional development framework supports innovation in the energy industry (e.g., the introduction of product or process innovations).							
2	The South African energy industry is capable of effectively deploying resources for the development of green innovations.							
3	The South African energy industry exploits, integrates, combines, creates, shares and converts new technology.							
4	The South African energy industry is fast in adopting the latest technological innovations (e.g., new green hydrogen production technologies).							

5	The South African energy industry adeptly manages and integrates specialised technology within the marketplace.							
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Items	Questions (Innovation)	Select the appropriate response using the scale						
1	The South African energy industry has the capability to continuously create and absorb new knowledge and to develop innovative products or processes.							
2	The South African energy industry has introduced new products that suggests adoption of innovation, for the past 10 years.							
3	There is an adequate partnership and collaboration with other industries and/or stakeholders (e.g., public institutions, academia/research & development, financial institutions, etc.) to develop an innovative strategy to support the energy transition.							
4	The South African energy industry makes use of external mechanisms (e.g, symposium, conferences, etc.) to share its challenges and get ideas and rewards for innovative energy solutions.							
5	The South African energy industry's ability to adopt new technologies (e.g., green hydrogen) depends on the speed and extent of its innovative capabilities							

Items	Questions (Control variables)	Select the appropriate response using the scale						
CTVAR1	The lack of aligned standardisation and certification schemes presents a significant barrier to the adoption of green hydrogen across regions and commodity sectors.							
CTVAR2	South Africa has established clear and specific green energy policy guidelines and frameworks that outline the requirements for green hydrogen development.							
CTVAR3	South Africa has made significant progress in the process of developing national green standardisation and certification schemes for green hydrogen.							
CTVAR4	South Africa has an integrated policy framework that effectively supports the implementation of the Green Hydrogen Roadmap.							
CTVAR5	The green hydrogen roadmap, as outlined by the Department of Mineral Resources and Energy, has been effectively communicated to key stakeholders, including academia, industry, researchers, and end-users							

Appendix 6: Variables, items, abbreviations, and composite scoring method

Variable	Subdimension	No. of Items	Item Abbreviations	Composite Scoring Method
Dynamic Capabilities (IV)	Sensing	5	DCS1, DCS2, DCS3, DCS4, DCS5	Mean of 5 item scores
	Seizing	4	DCZ1, DCZ2, DCZ3, DCZ4	Mean of 4 item scores
	Reconfiguring	5	DCR1, DCR2, DCR3, DCR4, DCR5	Mean of 5 item scores
	Composite Total	14	All above (DCS1–DCR4)	Mean of the 3 subdimension means (or mean of all 14 items if unidimensional)
Green Hydrogen Technology Adoption (DV)	—	5	GHTA1, GHTA2, GHTA3, GHTA4, GHTA5	Mean of 5 item scores
Innovation (Moderator)	—	5	INNOV1, INNOV2, INNOV3, INNOV4	Mean of 5 item scores
Control Variables	—	4	Education Level, Industry experience, numbers of years spent in the energy discipline	dummy-coded
Control Variables (Additional)		4	CTVAR1, CTVAR2, CTVAR3, CTVAR4	Mean of 4 item scores

Appendix 7: Composite score distributions

Introduction

The data cleaning and screening results are presented below. The composite score distribution analysis examined how the composite scores for DC and their subscales (e.g., sensing, seizing, and reconfiguring) were distributed. The main objective of the analysis was to assess where responses clustered, how widely they spread, and whether ceiling or floor effects might bias interpretation. Composite scores were computed by averaging the items within each construct, as described in Chapter 5.

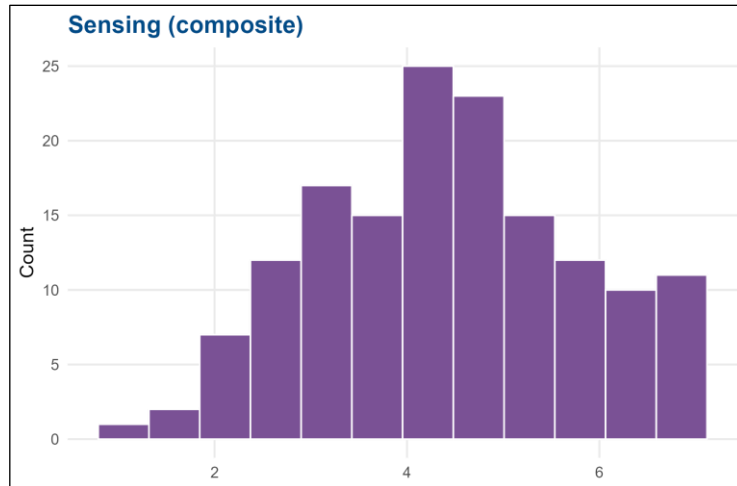
The resulting distributions provided concise diagnostics of central tendency and dispersion, established that variance was sufficient for hypothesis tests, and offered an early indication of face validity before moving to correlation and regression.

Because the dataset contained no missing values, Little's MCAR test – used to assess the pattern of missing data – was not applicable, so it was not performed (Saunders & Lewis, 2017; Doane & Seward, 2024). The survey protocol required respondents to complete each item before proceeding to the next, thereby preventing missing data.

Dynamic capabilities composite score distributions

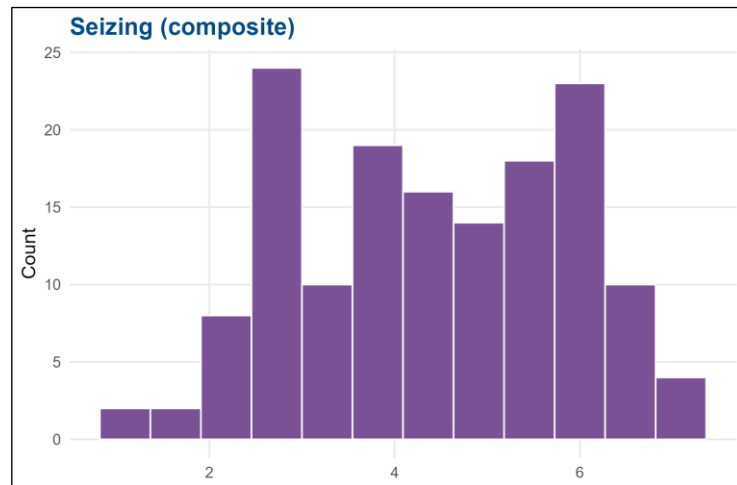
- **Sensing composite score distributions**

The chart shows that scores cluster toward the upper end of the 1 - 7 scale. This suggests a general agreement with the sensing items. The distribution is slightly left-skewed (negative skew), with relatively few low ratings. Whereas, the dispersion is modest, but consistent with the items on a 7-point scale. These patterns suggest respondents report strong sensing capability across the sample.



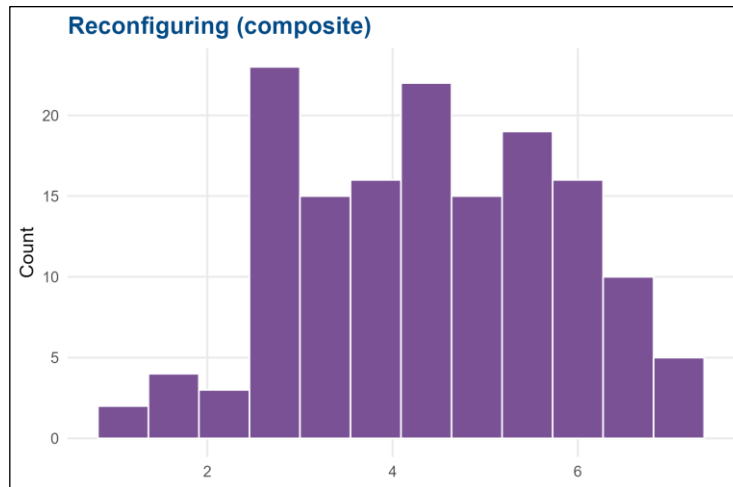
- **Seizing composite score distributions**

This chart shows that distribution is again top heavy with many scores above the midpoint (3). There appears to be a mild ceiling effect, with many scores at 4 - 5, but it isn't severe as some spread remains. Although the distribution is a bit broader than sensing, it remains fairly tight overall. These observations suggest that respondents somewhat agree that South Africa engages in seizing behaviours.



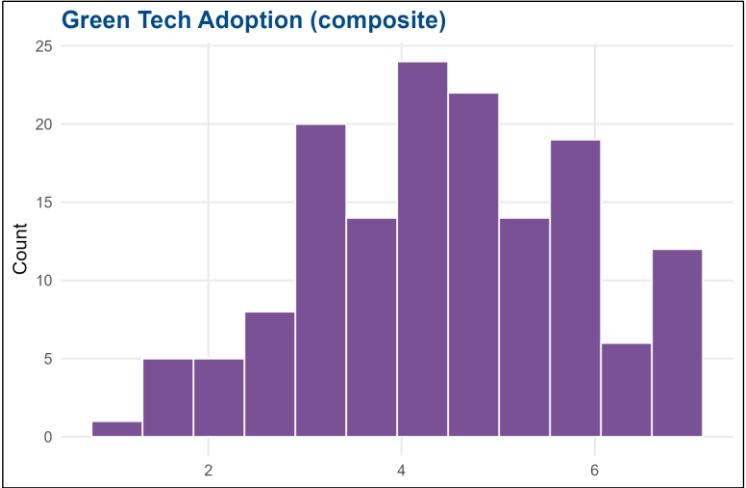
- **Reconfiguring composite score distributions**

Figure below shows high scores clustered mainly between 3.8 and 4.6 (Somewhat disagree and Neutral). However the shape appears to be slightly left skewed, which is consistent with positive agreement. Only a few low outliers appear between 1 and 3, indicating broad neutrality on sound reconfiguring practices. Overall, the results suggest that most respondents view reconfiguring favourably; they consider the South African energy sector capable of reconfiguring in a dynamic energy market.



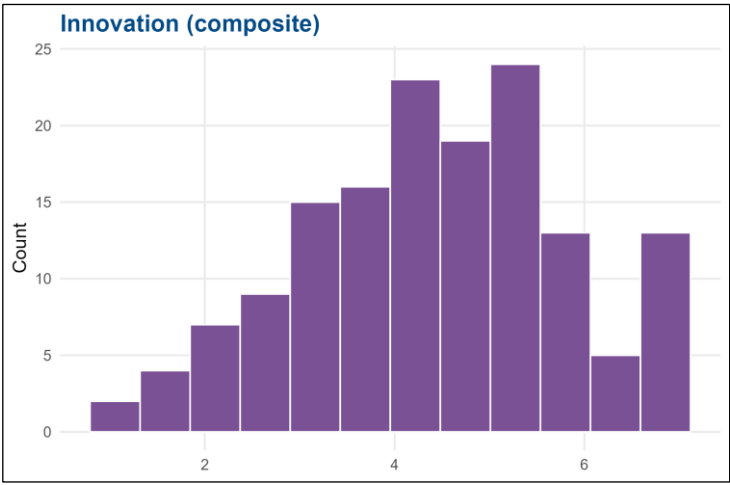
Technology adoption composite score distributions

Chart below shows scores concentrated in the upper half of the scale, with most values around 4. This distribution indicates a mild ceiling effect—many strong-agreement responses—yet there is still visible variability. The scarcity of low scores points to broad endorsement of innovative behaviours and outcomes.



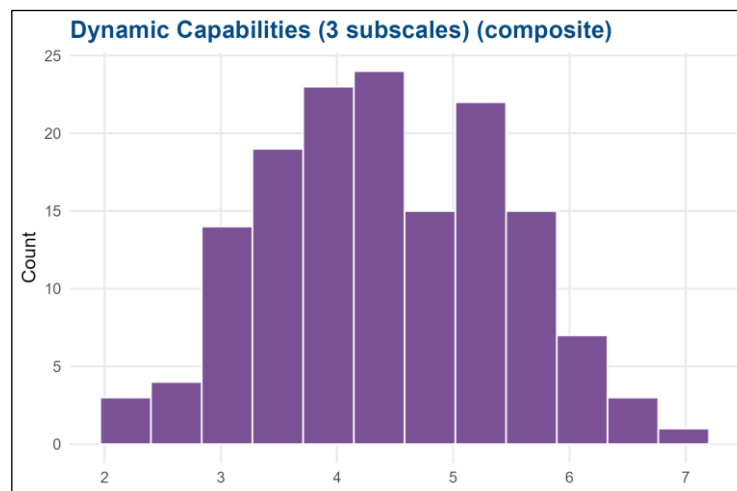
Innovation composite score distributions

The chart shows a high and compact distribution, with many values in the 4–5 range, suggesting a mild ceiling effect – strong agreement – while still retaining some variability. Limited low scores indicate broad endorsement of innovative behaviours and outcomes. Overall, respondents perceived the South African energy sector as having strong innovative capacity.



Dynamic Capabilities (3 subscales) (composite)

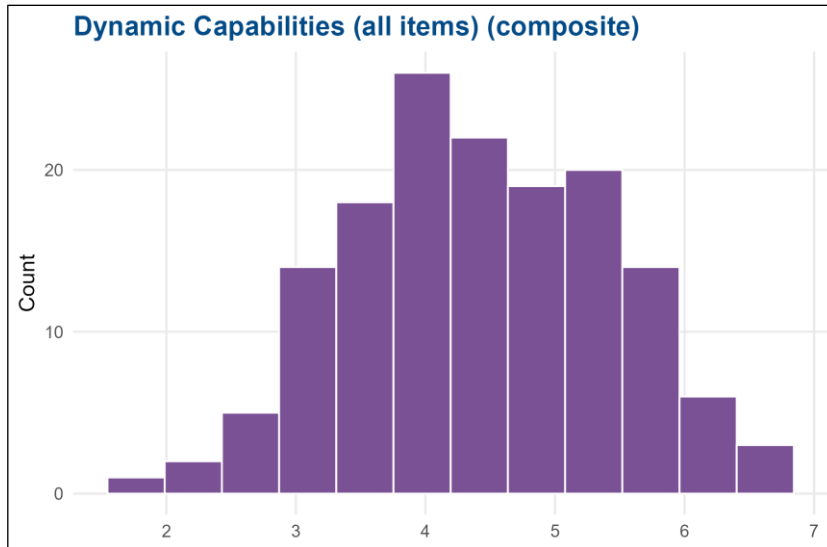
On the 1 – 7 scale (higher = stronger capability), most scores sit in the 4–5 band, with a gentle pile-up around 4.5. The shape is close to bell-shaped with a slight lean toward the higher side, meaning respondents generally see their organisations as more capable than not. Very low ratings are rare, and there’s a thin tail above 6, so only a few respondents view the dynamic capability as truly exceptional. In short, there are solid, consistently positive views across the three subscales, with room to lift the top end from “good” to “excellent.”



Dynamic Capabilities (all items) (composite)

On a 1 – 7 scale (1 = strongly disagree, 7 = strongly agree), most people landed in the middle-to-upper range, with a gentle peak around 4 and most scores sitting between 3.5 and 5.5.

In practical terms, one can posit that respondents generally feel that South African energy sector adopted the dynamic capabilities approach, but they’re not shouting “excellent” - more a solid “fair to good”. Very few chose the extremes (very low or very high), which suggests a shared, moderate confidence rather than polarised views. Overall, there’s real capability on the ground, with clear headroom to strengthen it.



Conclusion

The findings suggested that sensing pointed to a broad agreement on strong sensing capability. Seizing displayed a similar upper-range concentration with a mild ceiling tendency but retained useful variation. Reconfiguring suggested favourable views of adaptive capacity.

Taken together, the patterns were positive without being saturated and had enough dispersion to support modelling; these features guided how the inferential results in Chapter 5 were framed and read.

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Appendix 8: Descriptive items

Descriptive scales

Variable	vars	n	mean	sd	median	trimmed	mad	min	max	range	skew	kurtosis	se
Sensing_mean	1	150	4.437	1.365	4.4	4.452	1.483	1.2	7	5.8	-0.085	-0.646	0.111
Seizing_mean	2	150	4.405	1.473	4.5	4.425	1.853	1	7	6	-0.107	-0.987	0.12
Reconfiguring_mean	3	150	4.415	1.396	4.6	4.417	1.779	1	7	6	-0.071	-0.789	0.114
GHT_Adoption_mean	4	150	4.452	1.383	4.4	4.478	1.483	1.2	7	5.8	-0.142	-0.614	0.113
Innovation_mean	5	150	4.416	1.394	4.4	4.437	1.483	1.2	7	5.8	-0.136	-0.535	0.114
DynamicCapabilities_mean_3subscales	6	150	4.419	1.036	4.358	4.418	1.223	1.967	6.767	4.8	0.022	-0.741	0.085
DynamicCapabilities_mean_items	7	150	4.42	1.035	4.393	4.419	1.218	1.929	6.786	4.857	0.023	-0.723	0.085

Appendix 9: Frequency

Frequency Education

Level	n	pct
Bachelor/Honours	58	38.7
Postgraduate (Master)	29	19.3
National Certificate/Diploma	25	16.7
Postgraduate (PhD)	20	13.3
Others	18	12

Frequency Industry Sector

Level	n	pct
Energy (Oil & Gas/Petrochemical)	26	17.3
Energy (Renewable: Wind or Solar)	17	11.3
Academia	15	10
Energy (Green Energy)	14	9.3
Financial	14	9.3
Research & Development	13	8.7
Consultant	11	7.3
Transportation/Mobility	10	6.7
Government/Regulatory Body	9	6
Manufacturing	7	4.7
Mining	4	2.7
Policymakers	4	2.7
Energy (Utilities/Distributor)	3	2
Energy (Hydroelectric)	2	1.3
Energy (Coal)	1	0.7
Non-Governmental Organizations	0	0
Others	0	0

Frequency Role

Level	n	pct
Engineering/Technical	41	27.3
Project Management	33	22
Middle Manager	25	16.7
Senior Manager	14	9.3
Professor	11	7.3
Business	11	7.3
Consultant	8	5.3
Policy/Assurance	4	2.7
Others	3	2

Frequency Region

Level	n	pct
Within South Africa	110	73.3
Outside South Africa	23	15.3
Undisclosed	17	11.3

Frequency Professional Roles

Level	n	pct
Engineering/Technical	47	31.3
Project Management	38	25.3
Middle Manager	23	15.3
Senior Manager	12	8
Policy/Assurance	8	5.3
Consultant	8	5.3
Business	7	4.7
Professor	6	4
Others	1	0.7

Frequency professional experience levels

Level	n	pct
6–15	67	44.7
1–5	57	38
16–25	21	14
26+	5	3.3

Appendix 10: Cronbach's alpha results

Dynamic capabilities Cronbach's Alpha values results (Cronbach, 1951)

Sensing (DCS)

The table shows that all five items (DCS1–DCS5) align well with the scale, with corrected item–total correlations ranging from 0.602 (DCS5, lowest) to 0.690 (DCS2, highest), all comfortably above the 0.30 threshold. On the other hand, the Alpha if item deleted values range from 0.796 to 0.820 - each slightly below the observed α (≈ 0.841) -suggesting that dropping any item would not increase reliability; all items were therefore retained. The scale mean-if-deleted values range from 4.42 to 4.45, reflecting uniformly positive responses and showing that no single item disproportionately drives the overall mean.

Sensing reliability statistics

	Scale Mean if Item Deleted.y	Corrected Item-Total Correlation	Scale Variance if Deleted.y	Cronbach's Alpha if Item Deleted
DCS1	4.44	0.630	1.962	0.813
DCS2	4.45	0.690	1.880	0.796
DCS3	4.44	0.679	1.882	0.799
DCS4	4.42	0.625	1.942	0.815
DCS5	4.43	0.602	2.023	0.820

Seizing (DCZ)

Results in the table below indicate that all four items (DCZ1 - DCZ4) are highly consistent, with corrected item–total correlations ranging between 0.717 and 0.736, hence confirming strong item–scale relationships across the board. The α -if-deleted values (0.830 - 0.838) sit just below the observed alpha (0.871), indicating that dropping any item would not yield a meaningful gain in reliability. The mean-if-deleted values cluster tightly ranging between 4.40 and 4.41, showing a stable central tendency with no single item that unduly influences the scale mean.

Seizing reliability statistics

	Scale Mean if Item Deleted.	Corrected Item-Total Correlation	Scale Variance if Item Deleted.	Cronbach's Alpha if Item Deleted
DCZ1	4.41	0.725	2.250	0.834
DCZ2	4.40	0.736	2.252	0.830
DCZ3	4.40	0.719	2.200	0.837
DCZ4	4.41	0.717	2.356	0.838

Reconfiguring (DCR)

The table below shows that all five items (DCR1 - DCR5) perform well, with corrected item–total correlations ranging from 0.660 to 0.706 - all in the good range and indicating strong alignment with the total scale. The α -if-deleted values (0.829 - 0.840) sit just below the observed alpha (0.864), indicating that removing any item would not improve reliability. The mean-if-deleted values ranging between 4.41 and 4.42 are similar across all items, showing a stable central tendency with no item inflating or depressing the overall mean.

Reconfiguring reliability statistics

	Scale Mean if Item Deleted.y	Corrected Item-Total Correlation	Scale Variance if Item Deleted.y	Cronbach's Alpha if Item Deleted
DCR1	4.42	0.696	2.030	0.832
DCR2	4.42	0.660	2.074	0.840
DCR3	4.41	0.682	2.005	0.835
DCR4	4.42	0.706	1.981	0.829
DCR5	4.41	0.671	1.986	0.838

Tech Adoption (GHTA) Cronbach's Alpha values results (Cronbach, 1951)

The below in the table shows that all five Green Tech Adoption items align strongly with their scale, with corrected item–total correlations from 0.622 to 0.736 - one item at 0.622 and most between 0.692 and 0.736 - suggesting solid relationships to the construct. The α -if-deleted values (0.828 - 0.856) sit just below the observed α (0.870), so removing any item would not improve reliability. The mean-if-deleted values (4.44 - 4.46) are tightly clustered, indicating consistently high agreement across items.

Technology adoption reliability statistics

	Scale Mean if Item Deleted.y	Corrected Item-Total Correlation	Scale Variance if Item Deleted.y	Cronbach's Alpha if Item Deleted
GHTA1	4.46	0.692	1.985	0.839
GHTA2	4.46	0.622	2.046	0.856
GHTA3	4.45	0.736	1.925	0.828
GHTA4	4.46	0.698	1.931	0.838
GHTA5	4.44	0.706	1.993	0.836

Innovation (INNOV) Cronbach's Alpha values results (Cronbach, 1951)

Results in table below indicate that the innovation items are coherent and reliable, with corrected item–total correlations of 0.667 - 0.754, evidencing strong relationships with the underlying construct. The α -if-deleted values (0.840–0.880) are comparable to the observed α (0.879), indicating that removing any item would not meaningfully improve reliability. The mean-if-deleted values (4.40 - 4.43) are tightly clustered, showing no single item is problematic or unduly influencing the scale mean.

Innovation reliability statistics

	Scale Mean if Item Deleted.	Corrected Item-Total Correlation	Scale Variance if Item Deleted.	Cronbach's Alpha if Item Deleted
INNOV1	4.42	0.667	2.043	0.863
INNOV2	4.40	0.742	1.966	0.846
INNOV3	4.42	0.695	2.030	0.857
INNOV4	4.42	0.700	1.979	0.856
INNOV5	4.43	0.754	1.995	0.843

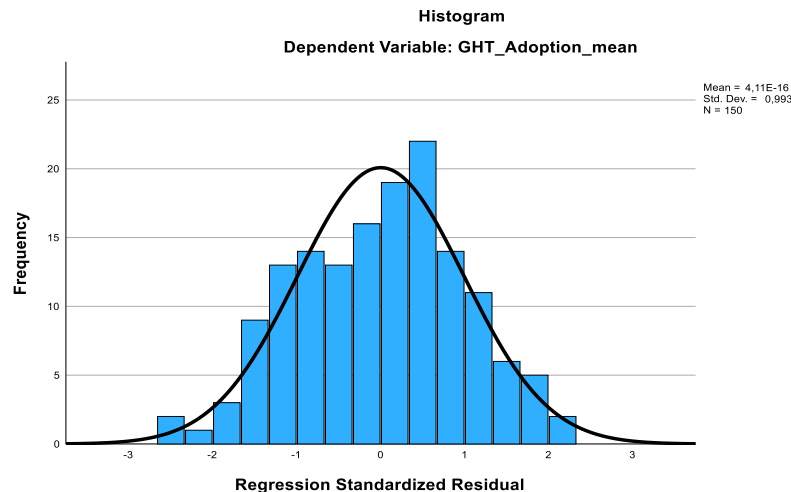
Summarising the results, it is evident that all items meet or exceed the Scale Variance if Item Deleted thresholds outlined above, and none produces an α -if-deleted higher than the overall α by a meaningful margin. Accordingly, all items were retained; the reliability diagnostics indicated no need for rewording or rescaling (Wegner, 2020; Saunders & Lewis, 2017; Kaiser, 1974).

Appendix 11: Hypothesis - Cronbach's Alpha results

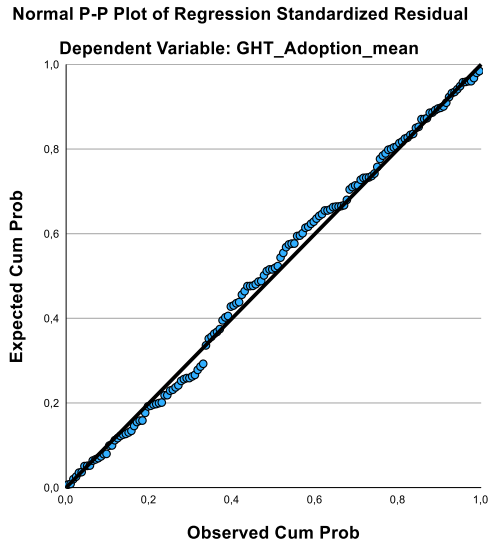
This appendix reports the results of the linearity assessment and the normality and homoskedasticity tests for all three hypotheses (H1, H2/H2a, H2b, H2c; and H3). Linearity was examined to confirm that the conditional expectation of adoption is adequately captured by a linear specification, while normality and homoskedasticity were evaluated to support the validity of standard errors, confidence intervals, and significance tests. For all three hypotheses, the residuals exhibited an approximately symmetric, bell-shaped distribution centred on zero, with dispersion consistent with the model's residual standard deviation, thereby supporting these assumptions.

Hypothesis 1

Below Figure shows an approximately symmetric, bell-shaped residual distribution centred near zero, with dispersion consistent with the model's residual standard deviation; this pattern is consistent with the normality and homoskedasticity assumptions.

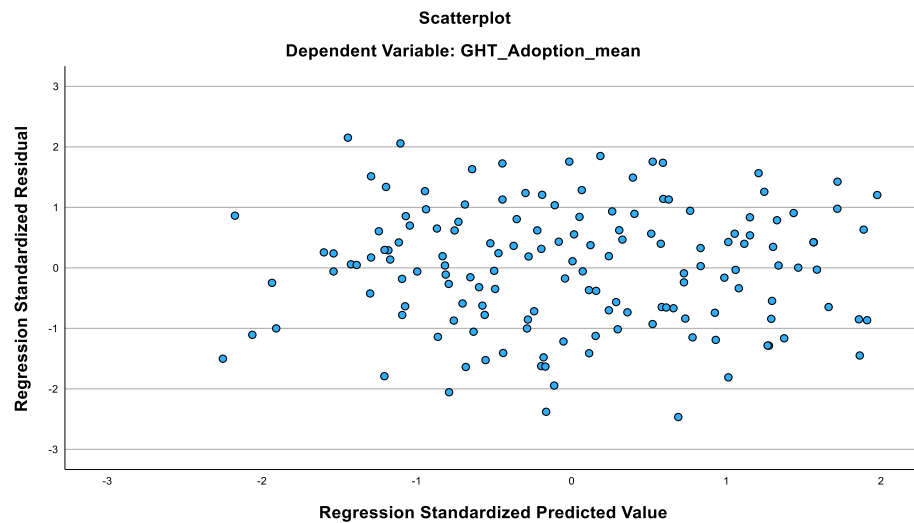


Normal Q–Q plot shows that most points lie close to the reference line with only mild tail deviations, suggesting errors are approximately normal, therefore inference is reliable.



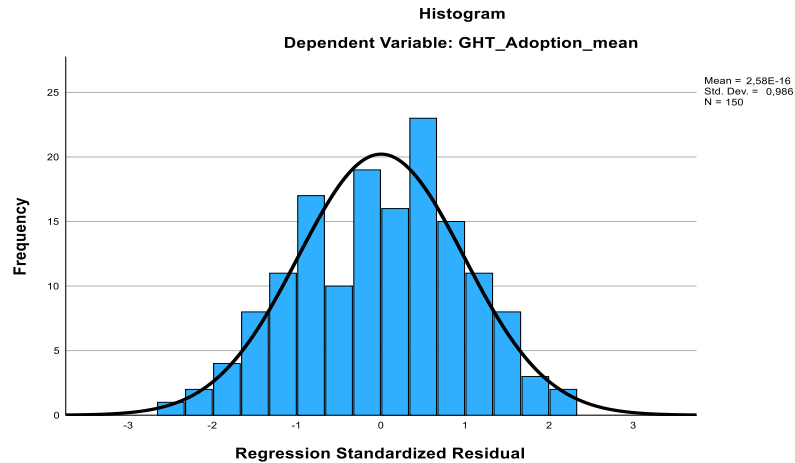
Residuals vs Fitted (Linearity): Figure below indicates that residuals are approximately centred around zero across the fitted range, with no evident systematic curvature. This pattern is consistent with a linear conditional mean and supports the linearity assumption for Hypothesis 1.

Homoscedasticity: Residuals are approximately mean-zero and exhibit roughly constant dispersion across fitted values, providing no material evidence of heteroskedasticity; the homoskedasticity (constant-variance) assumption therefore appears tenable.

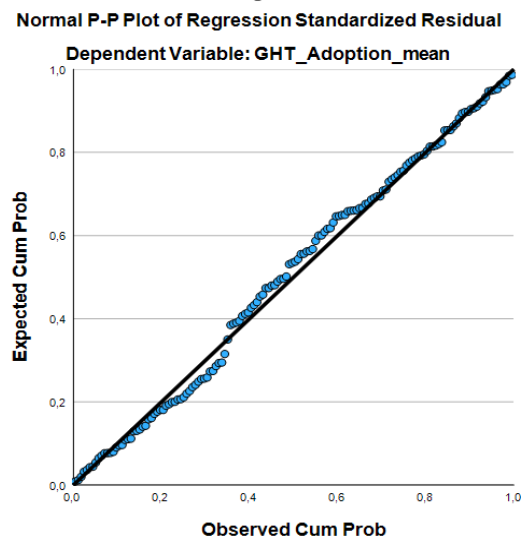


Hypothesis 2

As illustrated in below figure, the residuals are approximately symmetric and bell-shaped around zero, and their dispersion aligns with the model's residual standard deviation - evidence consistent with the normality and homoscedasticity assumptions.

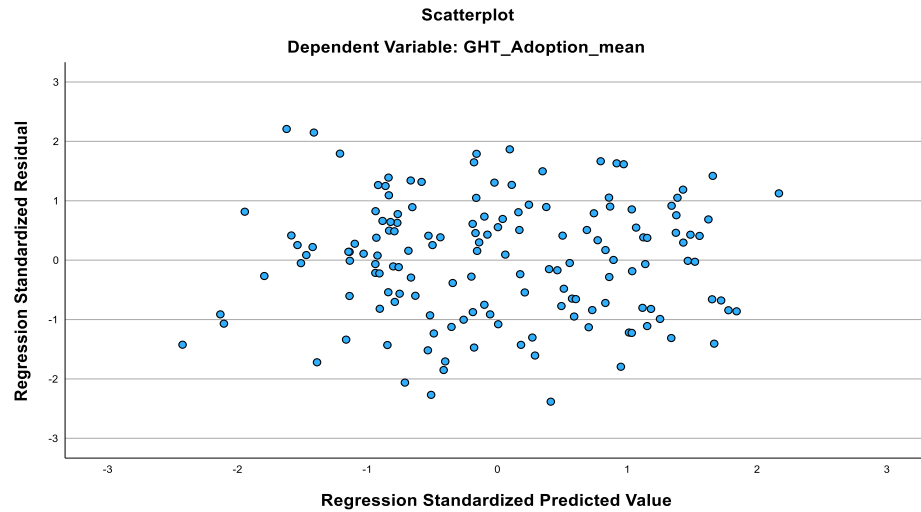


Q–Q plot shows points lying close to the 45° line, with only mild tail deviations, indicating that the normality assumption is adequate for inference.



The cloud of points (see figure below) is roughly centred around zero with no strong curves, suggesting an acceptable linearity. The Durbin–Watson statistic is 2.03—

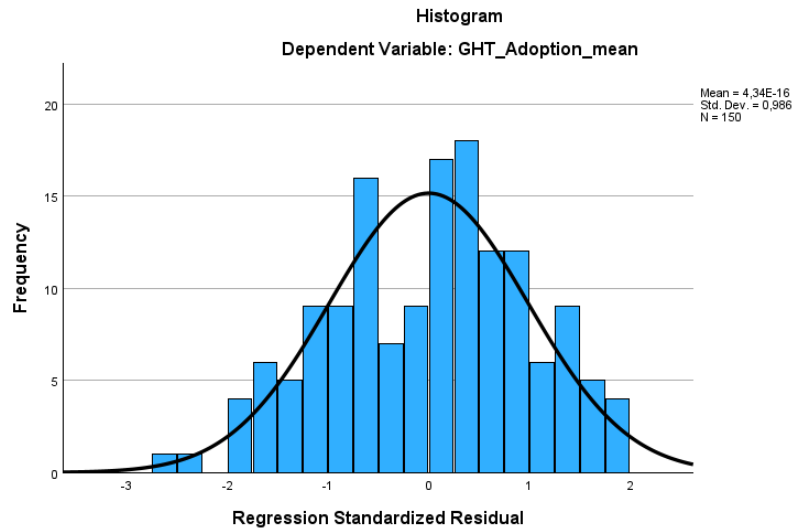
approximately 2—indicating no material autocorrelation. VIFs of ~1.03–1.19 and tolerances of .84–.97 suggest negligible multicollinearity among predictors. Standardised residuals fall roughly within ± 2.4 (residual SD ≈ 1.33), indicating no severe outliers.



Hypothesis 3

Figure below shows that the residuals display an approximately bell-shaped distribution which is centered near zero. And there is no evident skewness or heavy tails. Also, most values cluster around the mean and taper smoothly on both sides, and standardised residuals lie largely within ± 2.5 .

This pattern, in line with that observed for Hypotheses 1 and 2, is consistent with the normality of errors assumption underpinning confidence intervals and p-values.



Q–Q plot shows points lying close to the 45° line, with only mild tail deviations, suggesting that the normality assumption is adequate for inference.

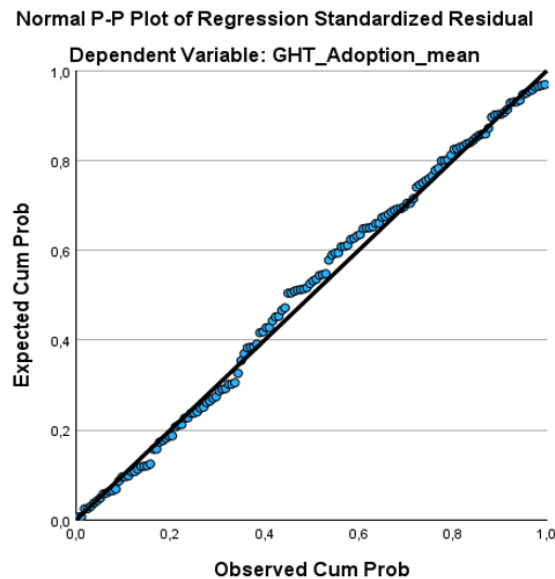
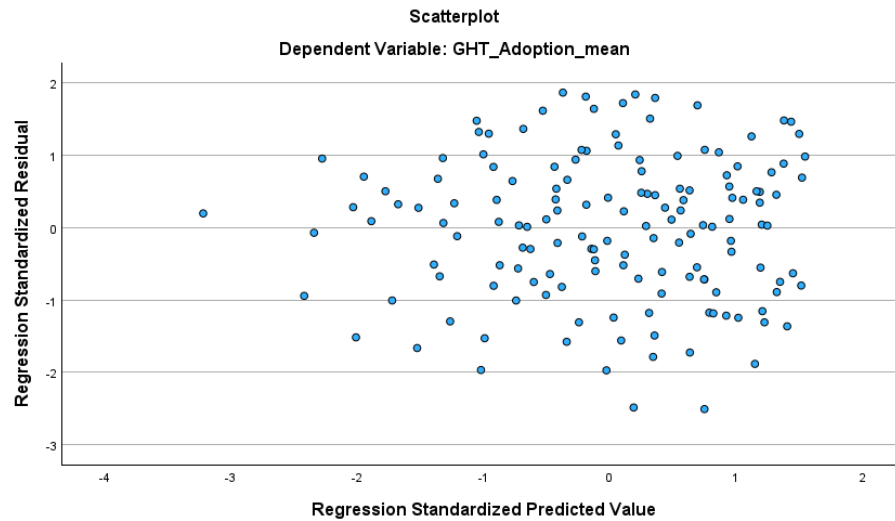


Figure below shows that residuals are evenly dispersed around zero across the fitted range, with no discernible curvature (which would indicate a mis-specified functional form) and no funneling or banding (which would indicate heteroskedasticity). These observations suggest that the conditional mean of Adoption is adequately described by a linear combination of the predictors used in the model. Furthermore, the roughly uniform scatter supports homoskedasticity (constant variance), and this implies that the

reported standard errors, t-tests, and confidence intervals are appropriately calibrated for managerial inference. Accordingly, no re-specification of the model for linearity or variance was warranted at this stage.



Appendix 12: Linear regression

Linear regression

	Predictor	Estimate	SE	t	<i>p</i>
Intercept	2.934	0.483	6.072	6.072	< .001
Sensing_mean	0.1016	0.087	1.159	1.159	0.248
Seizing_mean	0.1845	0.080	2.304	2.304	0.023
Reconfiguring_mean	0.0576	0.086	0.668	0.668	0.505