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Financing cost impacts on cost competitiveness of green hydrogen in emerging and developing economies

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Keywords: green hydrogen; cost of capital; cost competitiveness of green hydrogen; industry decarbonisation; levelised cost of hydrogen.

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Abstract

Green hydrogen, produced from water and renewable power through the electrolysis process, can play a crucial role in the low-carbon transition to achieve net-zero emission targets. Currently, the production cost of green hydrogen is not competitive when compared to hydrogen produced from natural gas. High capital costs are a major factor constraining its cost-competitiveness. This working paper utilises financial market data to address the knowledge gap concerning the range of Weighted Average Cost of Capital (WACC) for green hydrogen projects. It also conducts a survey among investors and financiers to identify key risk factors contributing to the high WACC. The key risks that have been identified include offtaker risks, lack of credible offtakers, price uncertainty of green hydrogen, and the absence of hydrogen trading markets. These risks are closely connected to the available risk mitigation strategies and tools. The paper summarises key risk mitigation strategies identified through case studies of lighthouse green hydrogen projects that have either reached or are nearly at the point of reaching financial investment decisions.

Keywords: green hydrogen; cost of capital; cost competitiveness of green hydrogen; industry decarbonisation; levelised cost of hydrogen.

JEL classification: L20, O14, O25, Q42, Q48

Résumé

L'hydrogène vert, produit par électrolyse de l'eau à partir d'électricité renouvelable, peut jouer un rôle crucial dans la transition bas-carbone afin d'atteindre l'objectif de zéro émission nette. Actuellement, l'hydrogène vert n'est pas compétitif par rapport à l'hydrogène produit à partir de gaz naturel, à cause de coûts de production trop élevés. Un coût du capital élevé est un facteur majeur limitant la compétitivité-prix de l'hydrogène vert. Ce document de travail utilise des données issues des marchés financiers pour combler le déficit de connaissances relatif au coût moyen pondéré du capital (CMPC) pour les projets d'hydrogène vert. De plus, il présente une enquête menée auprès d'investisseurs et d'organisations financières pour identifier les principaux facteurs de risques contribuant à un CMPC élevé. Les risques clefs identifiés comprennent le risque de soutirage, le manque d'acheteurs crédibles, les incertitudes sur le prix de l'hydrogène vert, et l'absence de marché de gros pour l'hydrogène. Ces risques sont étroitement liés avec les stratégies et outils d'atténuation des risques. Ce rapport résume les stratégies clefs d'atténuation des risques mises en évidence à travers des études de cas de projets phares d'hydrogène vert ayant atteint ou étant sur le point d'atteindre une décision finale d'investissement.

Mots-clés : l'hydrogène vert; coût moyen pondéré du capital; compétitivité des coûts de l'hydrogène vert; décarbonation de l'industrie; coût actualisé de l'hydrogène.

Classification JEL : L20, O14, O25, Q42, Q48

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Acronyms and units of measure

Bps	Basis points
BESS	Battery energy storage system
CAPM	Capital Asset Pricing Model
CAPEX	Capital expenditures
CBAM	Carbon Border Adjustment Mechanism
CCUS	Carbon capture, utilisation, and storage
CO2	Carbon dioxide
CO2e	Carbon dioxide equivalent
CRP	Country risk premium
DFI	Development financial institutions
EMDE	Emerging markets and developing economies
EPA	Export credit agencies
EPC	Engineering, Procurement and Construction
FID	Final investment decision
GW	Gigawatt
HPA	Hydrogen Purchase Agreements
KWh	Kilowatt-hour
LCOE	Levelised cost of electricity
LCOH	Levelised cost of hydrogen
Mt	Megatons

MW	Megawatt
MWh	Megawatt hour
OPEX	Operational expenditure
PPA	Power Purchase Agreement
PEM	Proton exchange membrane
PPP	Public-private partnership
PV	Solar photovoltaic
PtX	Power-to-X
R&D	Research and development
SPVs	Special Purpose Vehicles
SOEC	Solid oxide electrolysis cell
SWF	Sovereign wealth funds
SMR	Steam Methane Reformer unit
WACC	Weighted average cost of capital

Executive Summary

Current research primarily deals with the role of reducing the cost of renewable power and electrolyser technologies to improve cost competitiveness of green hydrogen. This working paper provides new insights as it explores the role of the cost of capital and how it is impacted by the perceived risks of green hydrogen. Therefore, the paper contributes to closing an important knowledge gap about factors that contribute to the levelised cost of hydrogen (LCOH) and how their impacts can be reduced. However, evidence concerning the cost of capital for low-carbon assets such as green hydrogen at project level is limited, primarily due to the confidential nature of financing structures and the absence of disclosed financial particulars.

To overcome this data availability challenge, two interlinked analyses have been carried out. In a market-based approach using financial proxy data for off-balance-sheet Special Purpose Vehicles (SPVs), the project-specific cost of capital was estimated. This resulted in a weighted average cost of capital (WACC or cost of capital) ranging from 6.4% to 24%. Analysis suggests that tax treatment plays a significant role in lower WACC values, highlighting the importance of favourable policies in stabilising project cash flows. Equity financing remains vital, especially for nascent technologies and high-risk regions, with affordable debt becoming crucial as the market matures.

The second analysis builds on a targeted survey conducted by the OECD, the World Bank and the Global Infrastructure Facility between July and August 2023 with 39 project developers, financing institutions and hydrogen stakeholders. The objective was to identify key priority risks impacting the high cost of capital for green hydrogen projects. According to the results of this survey, key risk factors are (in descending order of impact): uncertain market demand; a shortage of credible offtakers; price uncertainty; lack of trading markets; political risks; and insufficient infrastructure. These findings have been complemented by five case studies mainly from projects that are close to or have reached final investment decision in emerging and developing economies. The preparation of these case studies is a continuation of the OECD work that started in 2022 to identify successful business models, project governance structures, needed enabling conditions and financing instruments for green hydrogen projects.

Identifying suitable de-risking measures to reduce the cost of capital emerges as a priority in ensuring the cost competitiveness of green hydrogen projects, particularly in emerging and developing economies that are prone to high risks. An important aspect for policies is to tailor them to market maturity and respective needs. In early market stage, policy support should focus on demand creation, regulatory clarity and revenue stream support. In mature projects at the stage of final investment decision, policies can ensure certainty in off-take volumes and pricing through mechanisms such as feed-in tariffs, carbon pricing and auctions. While tailored policy support to mitigate high risk factors are essential for market creation and growth, they also carry the risk of market distortion and discouraging private sector involvement. Long-term solutions that build on better enabling conditions are needed to create an environment that can mobilise private capital and reduce dependency on the limited availability of public finance.

Many emerging and developing nations possess abundant renewable resources but face challenges related to higher capital expenses, making investment decisions more complex. Consequently, addressing financing costs represented by the cost of capital and exploring strategies to mitigate them are of paramount importance as demonstrated in this working paper. Building on these insights, future research should focus on how to improve enabling conditions and develop new financing solutions for large-scale green hydrogen projects whilst mobilising private capital.

1 Introduction

Green hydrogen for decarbonisation and financial cost barrier

In net-zero emission scenarios, the role of hydrogen from low-carbon production routes emphasises hard-to-abate industrial sectors where the availability of feasible low-carbon alternatives for deep decarbonisation is constrained, such as steel, cement and fertilisers. According to (IEA, 2022[1]), annual hydrogen use stood at 94 million tonnes (Mt) in 2021, practically all for the refining of crude oil and industrial applications, such as green ammonia. Currently, hydrogen is produced almost exclusively from fossil fuels (76% comes from natural gas and 23% from coal). So far, the share of low-carbon hydrogen[1] is less than 1% of all hydrogen produced worldwide, with the majority of the hydrogen currently being produced from plants that use fossil fuels for their production, but are equipped with carbon capture, utilisation and storage (CCUS) (IEA, 2022[1]).[2]

Green hydrogen produced from renewable power via the electrolysis process can aid the low-carbon transition by decarbonising emission-intensive heavy industries and transportation as well as by integrating more variable renewable energy into the power system. It can also be transformed into green ammonia or synthetic fuels for other uses (OECD, 2022[2]). Green hydrogen could also offer some emerging and developing countries the possibility to contribute to their industrial and economic development by locally producing a renewable fuel or feedstock for their domestic industry (ESMAP, 2020[3]). Thus, to optimise the economic and climate benefits of hydrogen, green hydrogen needs to be scaled up under the right conditions.

Globally, investment in low-carbon hydrogen should increase to an annual average of USD 1 trillion in production capacity and USD 1 trillion in hydrogen infrastructure and end-use equipment between now and 2030. This is based on the projected production of 40 Mt of low-carbon hydrogen by 2030, based on announced and planned projects as of January 2023 (two thirds green hydrogen and one third blue hydrogen), mainly for industrial applications of hydrogen in hard to abate sectors (ESMAP, OECD, Global Infrastructure Facility, and Hydrogen Council, 2023[4]).[3] By 2050, projected hydrogen production levels diverge depending on the scenario, spanning from 235-240 Mt, as outlined by Shell and DNV GL, to a more ambitious estimate of 682 Mt per year, as envisioned by the Hydrogen Council. Irrespective of the

[1] Low carbon hydrogen offers a broader definition encompassing hydrogen production method with minimal or no greenhouse gas emissions, encompassing both green hydrogen and blue hydrogen. Green hydrogen is produced by electrolysis using renewable electricity (often also called renewable hydrogen or clean hydrogen). Blue hydrogen is produced via the same process as grey hydrogen (made of natural gas through steam reforming), but where CO2 is captured and stored. (OECD, 2023[66]).

[2] CCUS is an enabler of least-cost low-carbon hydrogen production. CCUS can remove CO2 from the atmosphere by combining it with bioenergy or direct air capture to balance emissions that are unavoidable or technically difficult to abate. (IEA, 2020[67]).

[3] The upcoming World Bank-OECD analysis provides a varying range of hydrogen supply projections in 2030, between 11 and 90 Mt per year.

scenario, it is evident that the demand for clean hydrogen in 2050 far will surpass the current total hydrogen use.

Currently green hydrogen production costs are not cost competitive compared to carbon intensive hydrogen (e.g. Blue Hydrogen[4] or Grey Hydrogen[5]). According to (ESMAP, OECD, Global Infrastructure Facility, and Hydrogen Council, 2023[4]) and the (IEA, 2022[1]), the range of current production costs of green hydrogen, based on the cost estimation in the market, varies from USD 3/kg to USD 10/kg, depending on geographical location, which impacts economic and investment conditions as well as renewable energy resource quality. This is significantly higher than fossil fuel-based counterparts for which production costs can be as low as USD 1/kg hydrogen with favourable natural gas prices.[6] By comparison, blue hydrogen costs are estimated at around USD 2/kg where carbon dioxide (CO_2) emissions from natural gas are captured for use and storage dependent on the location and the availability of storage.

Previous analysis conducted by the OECD (Cordonnier and Saygin, 2022[5]), indicates that the costs associated with green hydrogen production are influenced by two key factors: the levelised cost of renewable electricity[7] and the capital cost of electrolysers. These factors, in turn, are influenced by a combination of the availability of renewable energy resources, capacity factors[8] of renewable power plants and electrolysers, and the cost of capital (see Box 1.1 for details).

The global pipeline of green hydrogen projects is growing at an impressive speed. According to the (Hydrogen Council, McKinsey & Company, 2023[6]), more than 1,046 large scale projects have been announced as of January 2023, collectively valued at approximately USD 320 billion, which is a 35% increase compared to May 2022. However, final investment decisions are not keeping up with this rate of project pipeline increase. Less than 10% of the USD 320 billion announced investments through 2030 is real committed capital, more than 1,046 large scale projects have been announced as of January 2023, collectively valued at approximately USD 320 billion, which is a 35% increase compared to May 2022. Less than 10% of the USD 320 billion announced investments through 2030 is real committed capital (Hydrogen Council, McKinsey & Company, 2023[6]). While significant green hydrogen production capacity is being developed in a number of emerging and developing countries,[9] only about 20 clean hydrogen projects in emerging and developing economies outside China have reached the final investment decision (FID) stage (ESMAP, OECD, Global Infrastructure Facility, and Hydrogen Council, 2023[4]).

These green hydrogen project proposals are contingent upon the presence of enabling conditions, including the establishment of supportive regulations and the creation of a stable market demand for green hydrogen and its derivatives, as also emphasised by (Cordonnier and Saygin, 2022[5]) since these

[4] Blue hydrogen is produced via the same process as grey hydrogen (made of natural gas through steam reforming), but where CO_2 is captured and stored (OECD, 2023[66]).

[5] Hydrogen made from fossil methane is often classified as "grey" hydrogen.

[6] It should be noted that the assumed price range for natural gas is based on an average hedged price and does not take into account the current spot price.

[7] According to the IEA, it can be measured through different sets of indicators such as equipment cost, financing costs, total installed costs, fixed and variable operating and maintenance cost, fuel costs (if applicable) and LCOE. LCOE is the most used indicator, and the value varies across the different renewable energy technologies, country and project, capital and operating costs, and the efficiency/performance of respective renewable energy technologies. The LCOE is a critical metric used in the energy sector to assess the economic feasibility of power generation methods. It calculates how much it costs to build and run a power plant over its lifetime and then divides that total cost by the amount of energy the plant generates.

[8] The capacity factor in green hydrogen electrolysers measures how efficiently they are producing hydrogen compared to their maximum potential. It's usually expressed as a percentage, with a higher percentage indicating more efficient use of the electrolyser's capacity.

[9] The countries of the Gulf Cooperation Council stand out (Oman, Saudi Arabia, United Arab Emirates), as well as Egypt, Chile, and Brazil. Also, India has very ambitious plans.

constitute among the most important success factors. Without enabling conditions, projects will continue to struggle to reach FID.

The high cost of capital is one such major factor that constrains the cost-competitiveness of green hydrogen as for other low-carbon technologies that are needed for net-zero emissions. This is due to high perceived investment risks stemming from, for example, offtake risk (price and volume), country risk, liquidity risk, technology risk and price risk, in the context of green hydrogen projects, resulting in some projects originally intended for operation in 2022 and 2023, now experiencing delays. These factors contributing to the perceived risks will be discussed in detail in Chapter 3.

Box 1.1. Cost of Capital Definition

The cost of finance is particularly important for front-loaded capital structure projects. Access to low-cost finance can reduce the cost of clean electricity by as much as 20% in developed countries (Zuckerman et al., 2006[7]) and as much as 30% in developing countries (Nelson and Shrimali, 2014[8]).

The cost of commodities, whether renewable electricity or a feedstock produced from clean energy resources, is contingent on the cost of capital (commonly expressed as weighted average cost of capital, WACC). WACC depends on the credit risk perception of investors. Credit ratings usually measure credit risk in both the banking and institutional investor channels, and credit ratings influence both pricing and capital allocation.

WACC (herein used interchangeably with cost of capital) is a critical component in modern finance theory for making investment or divestment decisions, economic profit forecasts and enhancing performance efficiency (Bruner et al., 1998[9]). Another way to view the importance of the cost of capital is through its use in evaluating investment projects. This involves determining the minimum expected return rate that investors would find acceptable, given the risk level involved.

Companies consider it as one of the main factors influencing decisions on capital structure and optimising future financial paths (Frank and Goyal, 2009[10]). It acts as a crucial link in transforming the expected stream of future net income into present value.

The post-tax WACC is defined by the equation below:

$$WACC = \frac{E}{E+D} * R_E + \frac{D}{E+D} * R_D * (1-T)$$

E= Equity Market Value, Re= Required rate of return on equity
D= Debt Market Value, Rd=Cost of Debt, T= applicable tax (or tax shield)

The calculation of cost of capital is usually more straightforward in corporate finance. If a company's stock is publicly traded, you can calculate the cost of equity using the CAPM model, relying on historical beta estimates. If a company has publicly traded debt, you can determine the cost of capital from market prices. In situations where a company's securities aren't publicly traded, you can establish the cost of debt by analysing financial statements, especially interest expenses concerning the outstanding debt on the balance sheet (Zhou et al., 2023[11]).

WACC can differ even within countries due to the nature of the enterprise, the duration of capital use, regulatory policies, limited access to funding, the risk perception of financial institutions, and macroeconomic factors such as inflation and credit demand. In some jurisdictions where competition in the financial industry is minimal, investors' risk tolerance may be different depending on their transaction experiences.

It is essential to keep in mind that a higher WACC does not necessarily imply greater risk, but rather may indicate a higher potential for profit and return on investment (e.g. the level of risk associated with certain renewable energy projects may appear elevated when considering construction in a country with a lower sovereign credit rating. However, when such projects manage to secure long-term Power Purchase Agreements (PPAs) with reputable offtakers, coupled with guarantees from Multilateral Development Banks (MDBs), the apparent risk can significantly diminish. This reduction primarily arises from the predictability and assurance of cash flow generated by the project). Thus, it is crucial to comprehend local conditions and their influence on perceived investment risks, as reflected in WACC derived from diverse funding sources.

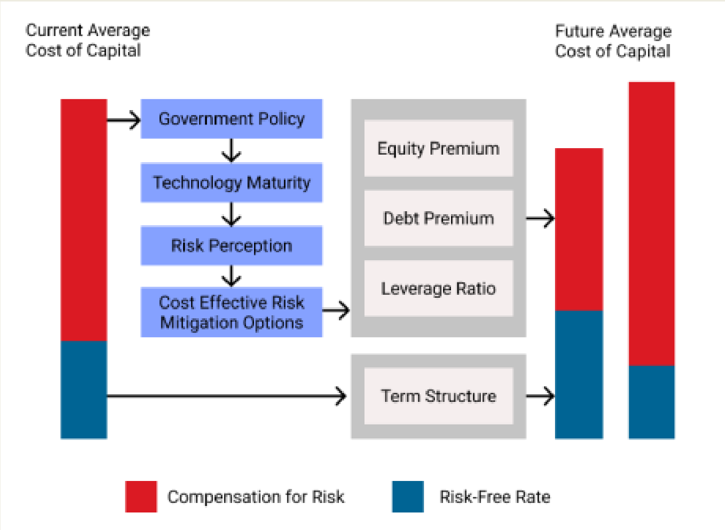
Table 1.1. Use of Internal Rate of Return, Hurdle Rate, Cost of Capital

Term	Internal Rate of Return (IRR)	Hurdle Rate (MARR)	Cost of Capital
Definition	The internal rate of return (IRR) is a discount rate that makes the net present value (NPV) of all cash flows equal to zero in a discounted cash flow analysis.	The hurdle rate, also called the minimum acceptable rate of return (MARR), is the lowest rate of return that the project must earn in order to offset the costs of the investment.	The expected rate of return that market participants require to attract funds to a particular investment
Use of investment decision-	Expected and levelised returns may differ	Often equal to cost of capital	Estimates may vary based on market premium
	Targeted to be higher than the hurdle rate		Used interchangeably with WACC or discount rate

Note: In the NPV method, a discount rate is used to calculate the present value of future cash flows. Discount rate would reflect the cost of financing calculated as a prevailing WACC for a technology or sector (Coleman, 2021[12]).
Sources: JP Morgan Corporate Finance Advisory, (Zhou et al., 2023[11])

Drivers of cost of capital

Figure 1.1. Drivers of cost of capital



Source: (Coleman, 2021[12])

A multitude of factors can influence the cost of capital for low-carbon technologies. These factors encompass various aspects, including the operational efficiency of the technology, its cost structure, technology maturity, government policies and regulation, electricity prices, accessibility of cost-effective risk mitigation optio, transaction experience and knowledge over time. Figure 1.1 is a simplified representation of WACC drivers. Both the debt and equity components consist of a risk-free or base rate component, which remains constant regardless of the project's risk profile or sectoral policies. The primary driver for determining the premium on equity and debt, as well as the allowable leverage ratio is the impact of risk—both real and perceived—on the certainty of project cash flows.

According to (Oxera, 2011[13]), two key factors are important for cost of capital: technology maturity, which is intrinsic, and policy risk, which is extrinsic.

- Technology maturity involves several risk elements related to early-stage technologies like low-carbon options. These encompass considerations such as capital expenditure, investment size, construction duration, payback periods, technological maturity, and the potential risks associated with subsidies, tax credits, or grants. Early-stage technologies, which have not yet been proven to be technically or commercially viable, are often perceived as risky investments with higher capital costs. This perception stems from the uncertainty surrounding their feasibility.
- Policy risk, on the other hand, centres on uncertainties concerning future policy directions, which can significantly influence risk perceptions. These uncertainties extend not only to the overall structure of future market arrangements but also to specific elements like the tax treatment of investments in different technologies. Furthermore, there is a risk that shifts in public opinion and the acceptance of certain generation technologies could lead to alterations in government energy policies.

Mitigating these risks can be achieved through various strategies, such as offering deployment incentives to reduce the cost of equity, leveraging enhanced access to debt capital, or reducing debt premiums through partial risk guarantees (Oxera, 2011[13]).

Overview of the paper

Rationale

Research interest in the cost of capital's impact on low-carbon technology deployment is growing. The (IRENA, 2022[14]) has released a report on the current and short-term projections of cost of capital at the country level and assessed their impact on renewable power technologies. (Egli, Steffen and Schmidt, 2018[15]) have gathered project-specific data from Germany and utilised various weighted average cost of capital (WACC) determinants, including return rates and financing shares, to infer the WACC for solar photovoltaic (PV) and wind projects. (Steffen, 2020[16]), (Franc-Dąbrowska, Mądra-Sawicka and Milewska, 2021[17]) (Chan et al., 2011[18]) analysed cost of capital's importance for solar PV, onshore and offshore wind, and CCUS. These studies conclude that the faster reduction in WACC would enable developing economies to achieve a significantly higher level of low-carbon electricity deployment and expedite the process of emissions reduction (Ameli et al., 2021[19]) (Masini and Menichetti, 2012[20]). This is because the cost of capital is an important input to the calculation of LCOE, as it determines the rate by which both costs and electricity yields are discounted over the lifetime of low carbon technologies (Ondraczek, Komendantova and Patt, 2015[21]).

A forthcoming OECD working paper by (Montague and Raiser, Forthcoming[22]) discusses the importance of cost of capital for various low-carbon technologies. It will help to fill the gap on the role of cost of capital for emerging low-carbon technologies. However, there is little information available on the role of costs of capital for green hydrogen and its production cost. Filling this knowledge gap is particularly important to complement the growing body of literature and research on green hydrogen's potential for decarbonisation, its no-regret usage case, the green hydrogen value chain, and enabling policies. In particular, understanding the role of costs of capital will be crucial to fill the investment gap for green hydrogen.

Aim

This working paper aims to equip policymakers and hydrogen economy stakeholders (i.e. developers, investors and financiers) with the necessary knowledge and will help close an important knowledge gap in the available literature on cost of capital associated with green hydrogen projects, in order to unlock financing for green hydrogen. While some emerging and developing economies possess abundant renewable resources, they grapple with higher capital expenses, adding complexity to investment decisions. As a result, there is a crucial need to address financing costs and explore strategies to alleviate them.

This paper pays particular attention to the implications of high cost of capital on policy formulation whilst complex policy recommendations are left outside of the scope of the paper. Instead, it is focuses on exploring the cost of capital for green hydrogen, a relatively unknown area, and the various risks involved that impact high financing costs for green hydrogen. Given the absence of essential information necessary for policymakers to design effective support measures, the study is dedicated to addressing this specific knowledge gap.

Methodology and scope

The paper encompasses two primary analyses to gather new evidence (see Figure 1.2):

- The first analysis is centred around a qualitative survey conducted by the OECD, the World Bank and the Global Infrastructure Facility between July and August 2023 with 39 project developers, financing institutions, and hydrogen stakeholders (Full survey available in Annex D). The survey's primary objective was to discern the intricate risk elements that drive heightened capital costs in the domain of green hydrogen projects. Additionally, it sought to ascertain the requisite risk premiums across diverse credit contexts and, in a nuanced fashion, shed light on strategies for effectively mitigating these multifaceted risks (details in Chapter 4). This survey was conducted within the context of the World Bank-OECD-GIF flagship publication titled “Scaling Hydrogen Financing for Development”.
- The risks identified through the survey have been cross-checked and discussed more comprehensively through case studies of actual green hydrogen projects. These case studies represent projects that are completed or close to reaching a final investment decision. This is a continuation of the activity which the Clean Energy Finance and Investment Mobilisation (CEFIM) team began in 2022 in the context of its work on green hydrogen.[10]
- The second analysis includes an in-house analysis of financial market proxy data for off-balance-sheet Special Purpose Vehicles (SPVs) to estimate green hydrogen project the specific cost of capital. This is a methodology typically used when evaluating early-stage business models, as in the case of green hydrogen projects. Box 1.1 provides essential information about the definition of cost of capital and definitions of other terminology referred to in this context. Additionally, steps to estimate the cost of capital is provided (detailed methodology is in Annex A). In this working paper, cost of capital and the weighted average cost of capital (WACC) are used interchangeably for reasons explained in Box 1.1.
- This paper focuses on publicly available early-stage firms operating in the green hydrogen sector, backed by high-risk tolerance investors and selected based on specific criteria. The applied key selection criteria include the company's alignment with the green hydrogen value chain, its size and operational focus, geographic coverage, revenue exclusively derived from the green hydrogen value chain, exclusion of government-owned companies, and the inclusion of two additional

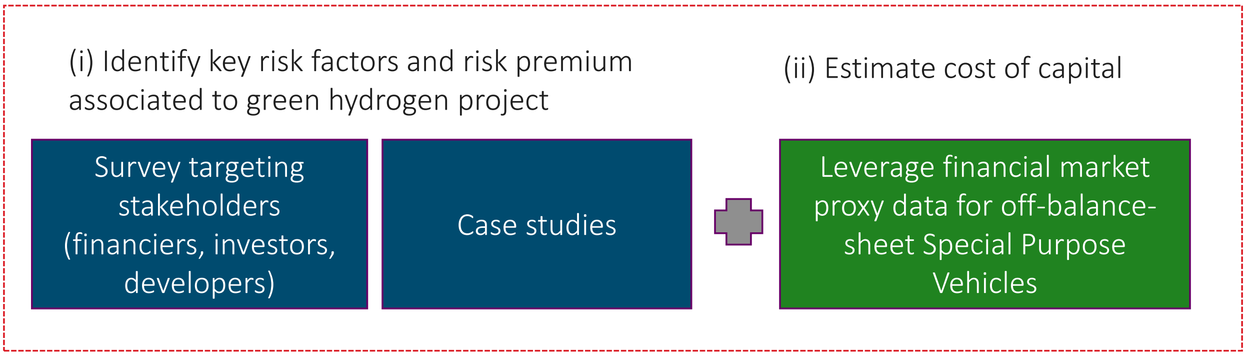
[10] https://www.oecd.org/cefim/green-hydrogen/.

samples, namely end-users of green hydrogen and renewable energy project developers, along with equipment producers, for comparative purposes and methodology validation.

- The financial data utilised in this study was gathered from diverse platforms including Yahoo Finance, Marketscreener, and Refinitiv, which are private data providers offering comprehensive information encompassing aspects such as companies' balance sheets, income statements, cash flows, investment strategies and historical capital structures.

It is imperative to recognise that while the working paper adopts an innovative approach by utilising financial market data as a proxy to estimate the project-level cost of capital for green hydrogen, this methodology and the available data possess inherent limitations. These limitations stem primarily from the absence of well-established policy frameworks within the current market landscape. Moreover, the dataset at hand predominantly comprises privately undertaken projects, and market dynamics are susceptible to fluctuations driven by investor speculation, leading to volatile pricing. Consequently, relying solely on the capital asset pricing model (CAPM) may not provide a precise representation of the financial prerequisites that investors seek when contemplating their investments.

Figure 1.2. The combination of two methodologies applied in this working paper to assess the cost of capital for green hydrogen projects and the risk premium



Source: Authors

This report is structured as follow:

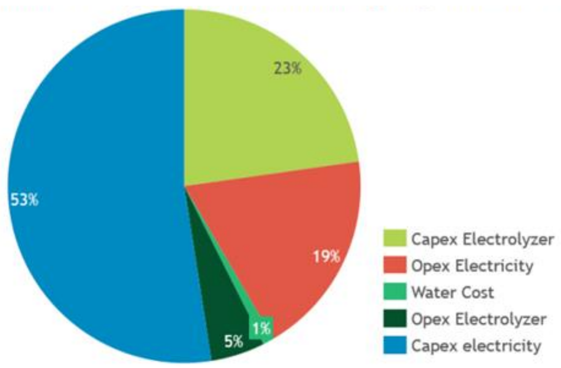
- Chapter 2 discusses the impact of cost of capital on green hydrogen production cost.
- Chapter 3 provides a concise overview of the financing landscape for green hydrogen and key risk factors that are crucial in the context of cost of capital.
- Chapter 4 employs the two dual methodologies developed for this working paper to calculate the cost of capital for green hydrogen projects and identify high-priority risks that must be managed to reduce perceived risk and understand the necessary risk premium for these projects.
- Chapter 5 examines how the high cost of capital and the related risks identified in Chapter 3 and Chapter 4 have implications on policy discussions.

2 Impact of Cost of Capital on green hydrogen production cost

Chapter 2 examines how the cost of capital impacts green hydrogen production costs. Green hydrogen projects, like renewable energy project, due to its front-loaded capital structures and substantial upfront investments, are susceptible to changes in the cost of capital. The chapter includes a sensitivity analysis on LOCE and LOCH concerning the cost of capital.

The electrolyser capital costs and electricity generation cost (see Figure 2.1) are two major factors that impact levelised cost of hydrogen (LCOH)[11] as argued by (Cordonnier and Saygin, 2022[5]) and (ESMAP, OECD, Global Infrastructure Facility, and Hydrogen Council, 2023[4]). The cost of electrolysers remain high but are expected to decline in the next decade. According to (IEA, 2023[23]), the average installed cost of electrolysers today is in the range of USD 500-1,400/kW for the alkaline variety, USD 1,100–1,800/kW for proton exchange membrane (PEM) units, and USD 2,800-5,600/kW for a solid oxide electrolysis cell (SOEC). Nevertheless, these costs are anticipated to decline significantly, and by 2030, the capital costs for electrolysers may fall below USD 500/kW. They contribute to the LCOH falling as low as USD 3/kg for renewable hydrogen when coupled with renewable power costing USD 0.02/kWh (ESMAP, OECD, Global Infrastructure Facility, and Hydrogen Council, 2023[4]).

Figure 2.1. Breakdown of USD 3/kg LCOH of green hydrogen at low-cost location, 2023



Note: An LCOH of USD 3/kg is used for the estimation which is representative of "best-in-class" projects. This breakdown assumes a co-located renewable power plant and electrolyser. Transmission cost of electricity is excluded. Electrolyser efficiency is assumed to be 57%; the system requires 15 litres of water/kg of hydrogen. Water production requires 2 kWh/m3 and is supplied from a desalination plant with a capital cost of USD 3 litres/day. The assumed capital cost of equipment is USD 2,400/kW for offshore wind, USD 800/kW for onshore wind, USD 400/kW for solar PV, and USD 750/kW for electrolysers with capacity factors of 50 %, 40%, and 25%. A discount rate of 10% and a lifetime of 20 years are assumed, yielding an annuity of 11.4%.
Source: (ESMAP, OECD, Global Infrastructure Facility, and Hydrogen Council, 2023[4])

[11] The Levelised Cost of Hydrogen (LCOH) is a metric that factors in all costs related to hydrogen production, including capital, operating, maintenance, fuel, and other expenses, across its expected lifetime. These costs are divided by the total hydrogen output, typically measured in kilograms or another relevant unit.

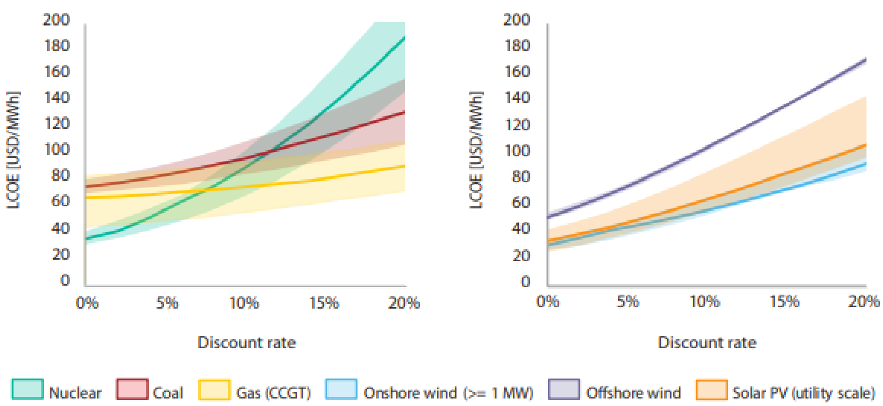
It is notable that recent reductions in the capital costs of electrolysers were made through research and development (R&D) in the absence of significant market penetration. The cost of a new technology is dependent on factors beyond its operational characteristics such as how it compares to other technologies in the market. When a new technology is first introduced, it is uncertain, and investing in it could be risky. Adoption is slow, but as the market learns more and the technology performance rate improves, sometimes through active R&D investment to bring down the initial cost, it gains acceptance and demand grows. With more firms entering the market, there are gradual improvements and costs go down. Eventually, as the market matures, costs decrease further. During the early phases of market development, when capital costs for electrolysers are relatively high, the capacity factor of electrolysers will remain a critical factor affecting LCOH. Electrolyser operation is effective when operated with capacity factors above 50% (ESMAP, OECD, Global Infrastructure Facility, and Hydrogen Council, 2023[4]).

The production and supply cost of electricity is another critical factor in determining the overall LCOH of electrolysers. Currently, renewable electricity can be generated on a utility scale for as low as USD 30/MWh in various desert and coastal locations in the Middle East, Mexico, Chile and the United States, particularly for solar PV and onshore wind projects (Gielen et al., 2020[24]).

Capital costs have a higher share in the LCOE of renewable energy projects due to higher upfront costs with little OPEX share once operational compared to fossil fuels (Bachner, Mayer and Steininger, 2019[25]),[12] For instance, investment costs account for between 50% and 80% of the LCOE for renewable energy projects. This makes LCOE more sensitive towards the cost of capital. According to the IEA, for a discount rate of 10%, LCOE ranges from as low as USD 42 /MWh to as high as USD 212 /MWh. However, when the discount rate is reduced to 3%, the LCOE decreases significantly to a range of USD 22-104/MWh (see Figure 2.2).

Figure 2.2. Impact of WACC on the levelised cost of electricity in different technologies

Sensitivity Analysis Result: LCOE as a function of the discount rate (left: non-renewable/ right: renewables)



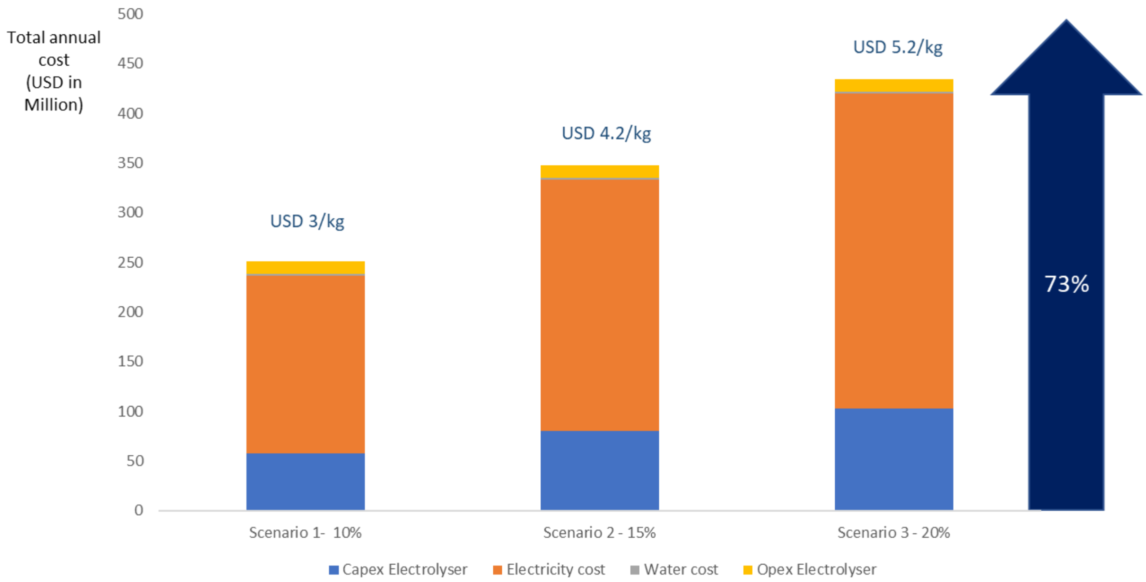
LCOE (USD /MWH)	10% WACC S1		7% WACC S2		3% WACC S3		**% Change (S1 to S3)**	
Value	Upper Band	Lower Band	Upper Band	Lower Band	Upper Band	Lower Band	**Upper Band**	**Lower Band**
Utility scale PV	212	42	172	34	104	22	**-50.9**	**-47.6**
Wind offshore	237	58	200	49	157	37	**-33.8**	**-36.2**
Wind onshore	172	36	140	29	126	24	**-26.7**	**-33.3**

Source: Authors' adaptation from (IEA, 2020[26])

[12] Renewable LCOE is highly cost related while fossil fuels are more susceptible to input costs (e.g. gas or coal).

Cost of capital impact on LCOH shows similar implications as for renewable energy projects. This is primarily because LCOH is susceptible given that renewable power LCOE accounts for around 30%-50% of LCOH of green hydrogen production (ESMAP, OECD, Global Infrastructure Facility, and Hydrogen Council, 2023[4]). As an illustration, holding all other production cost factors constant (same assumptions as in Figure 2.1.), an increase in the cost of capital (*or* WACC) from 10% to 20% can lead to a substantial increase of up to 73% in LCOH (Figure 2.3).

Figure 2.3. Impact of WACC on LCOH (in USD/kg hydrogen) and total annual cost (USD million)



Note: Baseline scope (scenario 1) is based on the World Bank's assumption for base case for 2030 to achieve USD 3/kg, applying the same assumption as in Figure 2.1. For Scenario 2 and 3, only WACC changed.
Source: Authors, Data adapted from (ESMAP, OECD, Global Infrastructure Facility, and Hydrogen Council, 2023[4])

Despite its significant implications on green hydrogen costs, understanding of the cost of capital for green hydrogen is scarce and fragmented. The limited data availability on the costs and pricing of green hydrogen means it is necessary to provide guidance for policymaking and investment choices. As discussed in the previous section, there are very few projects that have reached final investment decision or that are in operation. As a result, data on the project level cost of capital is scarce and confidential for commercial purposes. This is further complicated by the fact that the green hydrogen cost differential is contingent upon the costs of clean alternatives and traditional production methods. In particular, determining a cost cap[13] for green hydrogen remains uncertain because its cost determinants deviate from those of conventional hydrogen. Consequently, this cost gap differential is susceptible to fluctuation and can exhibit regional variations (ESMAP, OECD, Global Infrastructure Facility, and Hydrogen Council, 2023[4]).

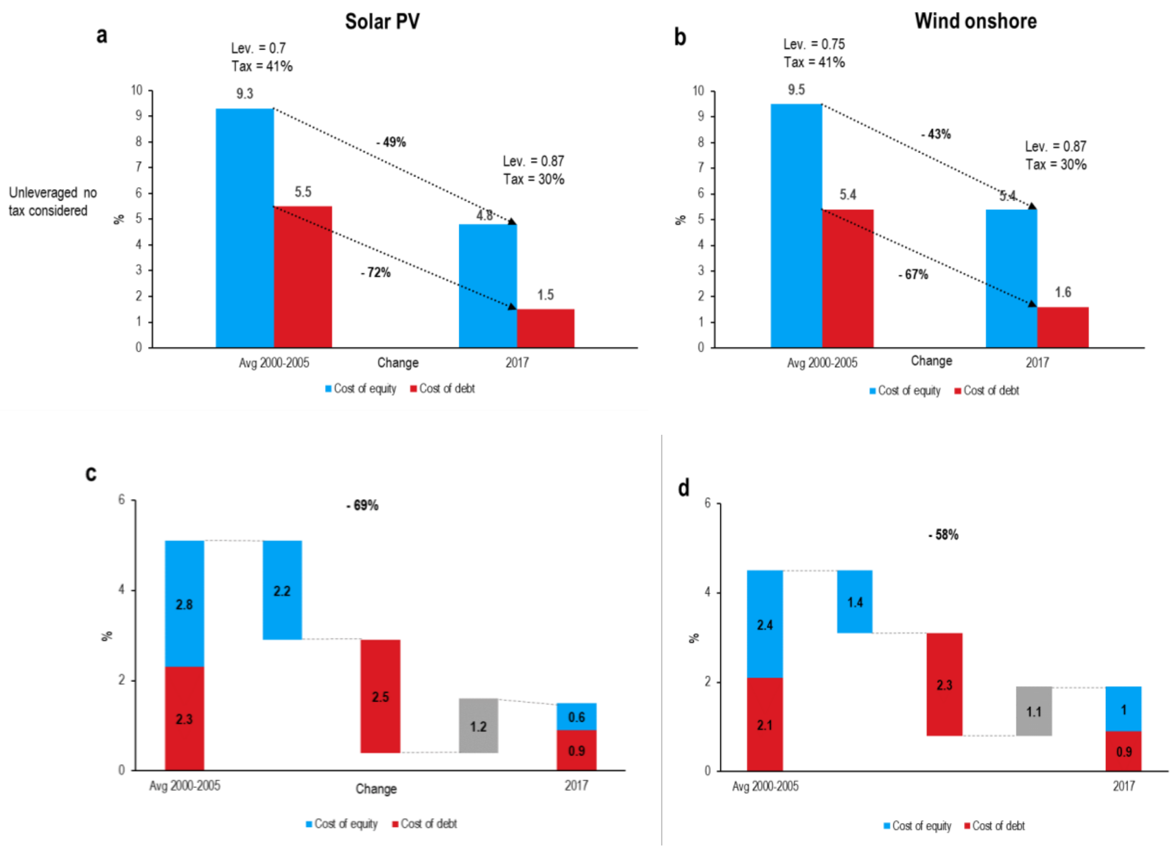
The learning rate in the context of low carbon technologies refers to the rate at which the cost of the technology, such as solar panels or wind turbines, decreases as their produced or installed capacity doubles. For instance, the potential learning rates for fuel cells and electrolysers are comparable to those observed in solar PV, ranging between 16% and 21% based on the data going back over 60 years in some

[13] In the context of green hydrogen, "cost cap" is a predetermined cost target that represents the affordability needed for competitiveness with other energy sources. It serves as a financial boundary or ceiling, signifying the level of affordability necessary for green hydrogen to compete effectively with other energy sources or hydrogen production methods. Attaining a cost cap is frequently a pivotal goal in advancing and expanding green hydrogen technologies.

studies (IRENA, 2020[27]), However, these rates are notably lower than the 36% learning rates witnessed in solar PV between 2010 to 2019. Taking the lower end of the learning rate for electrolysers into consideration, one could argue that green hydrogen technologies would achieve a slower pace in cost reduction than solar PV has achieved, as demonstrated in Figure 2.4.

The cost of capital for renewable energy technologies globally has declined over the period between 2000 and 2017 (Figure 2.4). During this period, the cost of debt experienced a more significant decrease compared to the cost of equity, which is also influenced by factors such as leverage, corporate tax rates (a decrease from 41% to 30%) (Egli, Steffen and Schmidt, 2018[15]) as well as low interest rates. For both technologies, leverage increased, with debt financing surpassing 80% of the total investment in 2017.

Figure 2.4. Changes and dynamics of RE technologies' cost of capital



Note: a,b is unleveraged and c,d is leveraged cost of capital. The tax effect was due to a decrease in the corporate tax rate that led to a smaller cost reduction from tax-deductible debt interest payments.
Source: adapted from (Egli, Steffen and Schmidt, 2018[15])

Achieving reductions in LCOH hinges on two pivotal factors: a decrease in unit capital costs of electrolysers and renewable energy technologies, and a reduction in the cost of capital. According to (ESMAP, OECD, Global Infrastructure Facility, and Hydrogen Council, 2023[4]), today's global average LCOH for green hydrogen is estimated to be around USD 5/kg hydrogen. Understanding the intricate interplay between the cost of capital and the dynamics of green hydrogen projects is crucial in the pursuit of achieving economically viable competitiveness of green hydrogen. When looking at initial cost reductions, the primary focus lies on reducing unit capital costs. However, to achieve substantially lower hydrogen costs, it is crucial to also address high cost of capital. Implementing risk-reduction measures that lower investor risks could substantially reduce cost of capital (Đukan and Kitzing, 2023[28]), thereby potentially reaching an LCOH of USD 3/kg hydrogen in ideal locations by 2030.

3 Green Hydrogen Project Landscape and Financing Risk

Chapter 3 provides a concise overview of the financing landscape for green hydrogen and delves into the risk factors of green hydrogen projects that impact the cost of capital within this context.

Green hydrogen is not yet a viable asset

The growing market toward the investment opportunities in green hydrogen projects globally is well reflected in capital markets. The outperformance of environmentally friendly assets against others has enhanced investors' confidence in green hydrogen related assets. For instance, amongst listed assets, the MSCI ACWI ESG Leader Index[14] showed a 5.5% annualised return[15] since 2007, outperforming the MSCI World Index by 50 basis points. In addition, while traditional funds saw outflows of USD 565 billion by 2022, sustainable funds witnessed net positive inflows of USD 115 billion in 2022, signalling strong asset owner demand for sustainable products and strategies (Morgan Stanley, 2023[29]).

Infrastructure investments[16] typically outperformed other alternative assets[17] on a marked-to-market basis in 2022 (Boston Consulting Group, 2023[30]). Despite a 16% average decline in similar asset class valuations caused by a 250 basis points increase in interest rates, infrastructure assets were better protected from inflation, offsetting nearly 50% of the negative impact. As inflation rose, infrastructure investment groups' cash flows increased, resulting in a 3% average valuation uplift. Overall, infrastructure investments remained an attractive asset class delivering both cash yields and valuation growth (Sachs et al., 2019[31]). This makes green hydrogen a potential investment opportunity.

However, green hydrogen is not yet regarded as a viable asset by a significant number of investors as its risk-return profile is not yet fully comprehended. As a result, the capital influx from private sector is still limited, even though the transition for decarbonising the economy requires vast investments (OECD/The World Bank/UN Environment, 2018[32]).

[14] The MSCI ACWI ESG Leaders Index is a market-cap weighted index derived from the MSCI ACWI Index (Parent index), focusing on companies selected based on Environmental, Social, and Governance (ESG) criteria. Exclusions include specific business activities and constituents with ESG ratings or controversies. It mirrors sector weights of the Parent Index and covers Large and Mid-cap firms across 23 Developed and 24 Emerging Markets. The index aims for 50% free float-adjusted market cap coverage per Global Industry Classification Standard (GICS) sector, with selection based on ESG ratings, trends and industry-adjusted ESG scores. Source: MSCI.

[15] The annual returns generated for the investor by the investment.

[16] Defined to include public utilities such as telecommunications, power, transportation, and water and sanitation (OECD, 2007[65]).

[17] Alternative assets typically refer to investments that fall outside of the traditional asset classes commonly accessed by most investors, such as stocks, bonds, or cash investments. Due to their alternative nature, these investments may be less liquid than their traditional counterparts and may require a longer investment period before any material value is realised. Source: (Prequin, 2023[68]).

Green hydrogen financing overview

Most energy infrastructure assets, including both fossil fuel and renewable energy projects, are financed through corporate balance sheets, despite a growing utilisation of project finance in the renewable sector. In terms of financing structure trends [18], project financing has been declining since 2013, while balance sheet financing has shown growth in recent years. In established renewable energy markets, project finance should be the standard, or at the very least, there should be limited recourse project finance. As renewable energy projects expand into emerging and developing countries where initial projects are often financed through corporate balance sheets, these practices could potentially influence these statistics. In 2015, project finance for renewable projects surpassed the 50% mark, marking an exception. However, in 2019, project finance accounted for 35% of renewable energy asset finance, compared to 16% in 2004 (UN Environment, 2020[33]).

Corporate guarantees are commonly utilised for some final investment decisions (FIDs) or near-FID green hydrogen projects, where a company with a robust balance sheet serves as the sponsor and guarantor, risking its balance sheet instead of project finance structures. For instance, fertiliser companies (e.g. Yara, Balance Agri-Nutrients), shipping operators (e.g. Maersk), oil & gas players (e.g. Shell, OMV, Sinopec), and Industrial Gases Companies (e.g. Air Products) are playing a key role as successful projects to achieve FID. Development financial institutions and national development banks may provide additional debt financing at a preferred interest rate to bridge the funding gap.

While corporate guarantees can contribute to the financing structure in the early-stage green hydrogen market, it is not sustainable or appropriate for large-scale projects. As green hydrogen becomes more commercially viable and the market stabilises, non-recourse loans (project finance) are expected to grow, particularly for large-scale green hydrogen projects. This is also because project finance loans are less risky for developers and sponsors than corporate finance loans with similar ratings (Esty and Sesia, 2002[34]), which makes them the more suitable financing structure for projects like green hydrogen.

Risk profile of green hydrogen

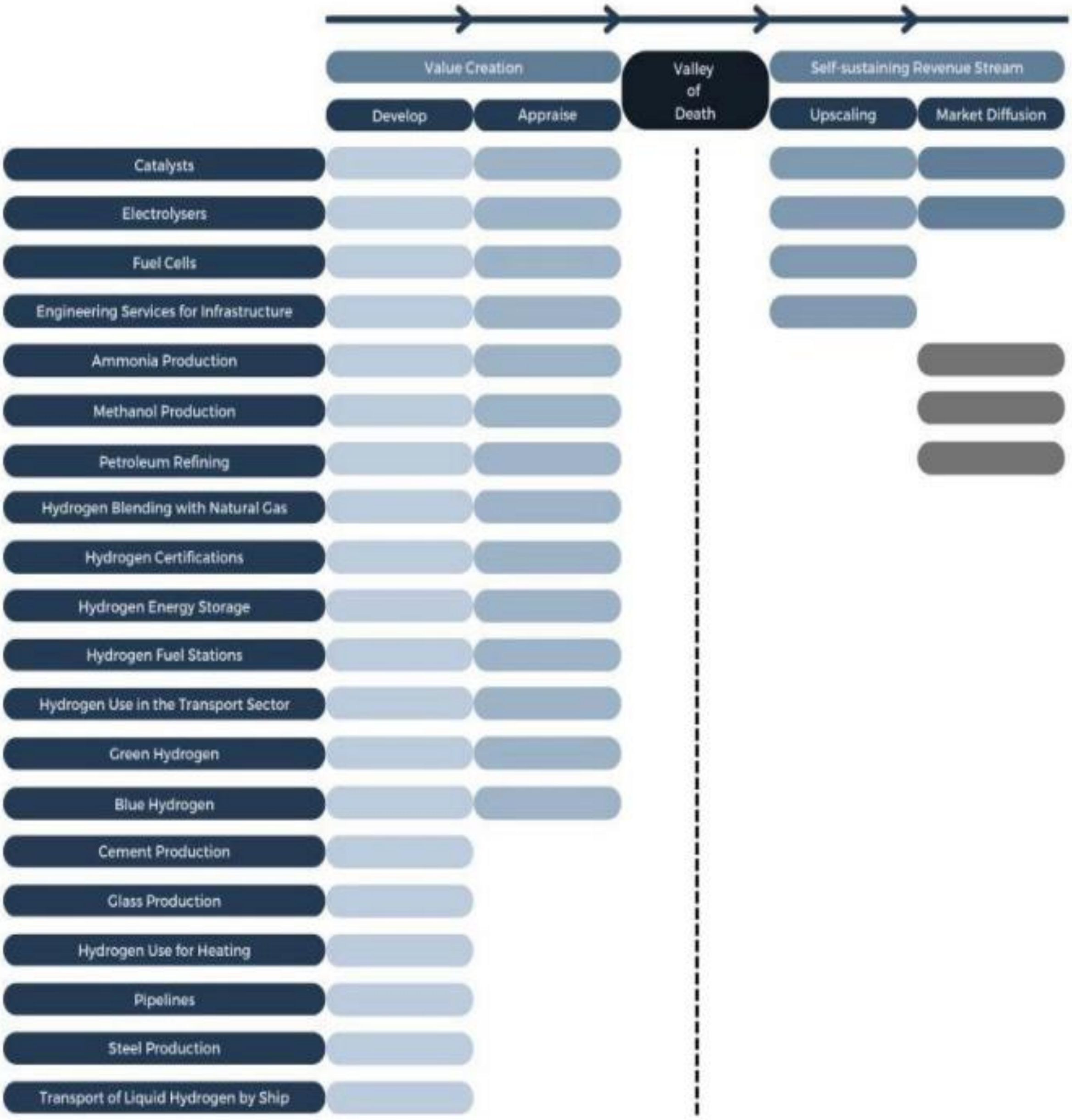
Currently, the risk profile of green hydrogen is unknown or high due to the nascent hydrogen market status. Consequently, the financing profile of green hydrogen projects *resembles* that of venture capital investments (Figure 3.2)[19] rather than senior debt (Renssen, 2021[35]).

According to (Küfeoğlu, 2023[36]), most hydrogen technologies have not yet reached beyond the valley of death stage (see Figure 3.1). Early-stage technologies are often confronted with a significant hurdle known as the “Commercialisation Valley of Death.” This phase occurs between the pilot/demonstration and commercialisation stages of technological development and represents a gap in funding between venture capital investments and later-stage project finance and debt/equity investors (Jenkins and Mansur, 2011[37]).

[18] Regarding financing structure two prominent structures exist, corporate finance and project finance. Firstly, in the realm of corporate finance, the sponsoring company obtains capital by leveraging its own balance sheets. This entails that the company's debt capacity and borrowing costs are determined based on its overall profile, and the associated assets serve as collateral in the event of default. (ii) Secondly, on the other hand, project finance involves the arrangement of funds through a special purpose vehicle (SPV), an independent legal entity established for each specific project. In this structure, the project's assets and cash flows are primarily used as security.

[19] The approach has limited application as a venture capital-style model often involves taking higher risk bets than highly capital-intensive infrastructure projects such as green hydrogen. The comparison is drawn from the perspectives of market and technology maturity.

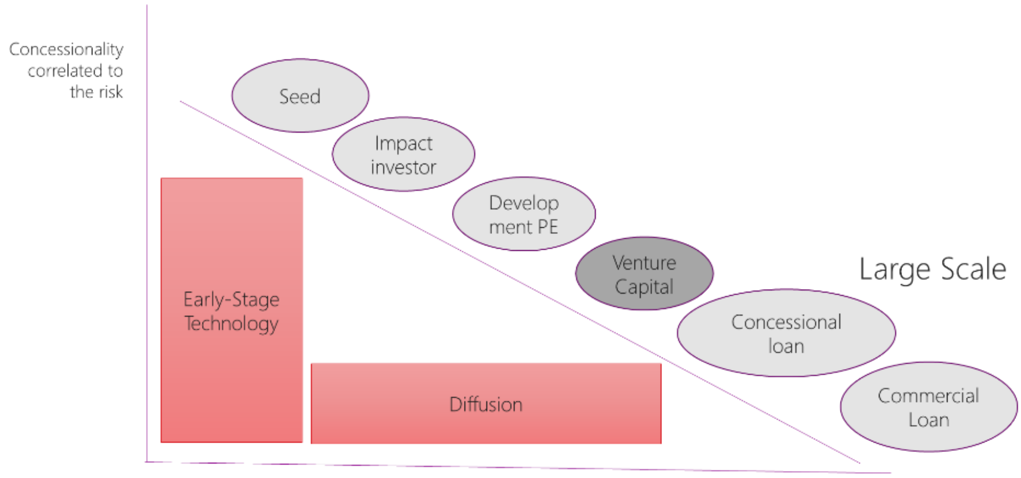
Figure 3.1. Market Phases of Hydrogen Businesses



Source: (Küfeoğlu, 2023[36]).

Note: Technologies with bars at the Development and Appraisal stage are at a low level of maturity, and commercialisation has not yet been achieved. A darker colour indicates the technology's maturity level. This figure illustrates that the majority of green hydrogen production technologies have not yet reached the commercialization stage.

Figure 3.2. Types of financing instrument per technology maturity level



Source: Author adapted from (Green Climate Fund, 2023[38])

A lack of historical data is a major factor that hinders effective risk assessment for front-loaded capital structured projects such as green hydrogen. According to (Fitch, 2023[39]), the credit risk profile of thermal power assets is considered similiar to that of green hydrogen when considering factors like operating risk, supply risk and revenue risk. However, it is important to note that this comparison requires further discussion and evaluation. This is primarily due to the fact that, in contrast to thermal power and certain renewable energy technologies such as solar and wind, there exists a significantly limited track record and demand profile in the case of green hydrogen.

Credit ratings' overestimation of credit risk is another factor associated with clean energy projects such as green hydrogen, as it leads to excessive risk aversion and increases the required returns. For example, rating agencies have assigned BB or lower ratings to wind and solar project bonds (S&P Global Ratings, 2022[40]), making it challenging for these projects to attract investors and resulting in high-interest rates for the raised funds. It is worth noting that the credit spreads of project finance with longer maturity are typically lower in comparison to the use of credit ratings which assign higher spreads to compensate lenders for a longer risk exposure duration (Sorge and Gadanecz, 2004[41]). These specific issues, combined with existing infrastructure risks, further elevate actual and perceived risks for green hydrogen, leading conventional credit rating methods to constrain financing from both banks and capital markets.

Risk factors impacting cost of capital

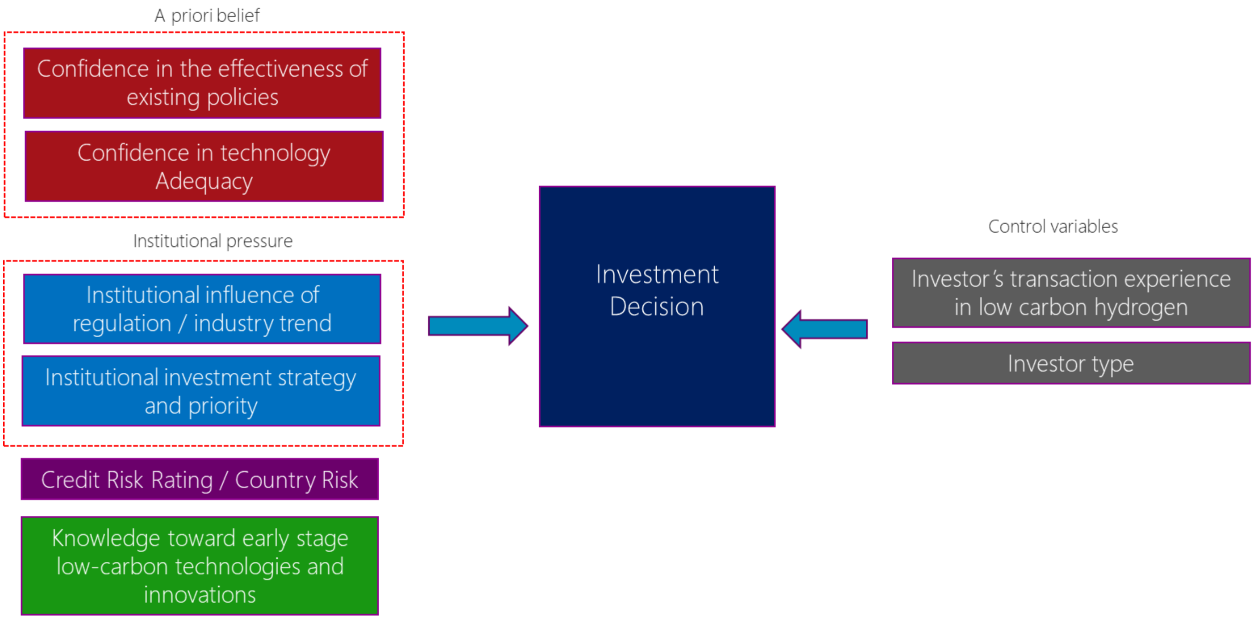
The most desirable approach is to structure a project that involves entering a long-term, fixed-price offtake contract with a public or quasi-public utility to make green hydrogen project bankable. The key risk that needs to be considered in the context of cost of capital are perceived risk, political and regulatory risk, country risk, offtake risk, technology risk, design, construction and completion risk, and supply risk, which will be discussed below.

Perceived risk

The cost of capital is correlated to the investors' perceptions of risk (Pratt and Grabowski, 2014[42]) (Bachner, Mayer and Steininger, 2019[25]). The risks associated with green hydrogen are paramount in impacting the cost of capital. There are various factors that influence investor's perception of risk (see Figure 3.3). Note that the magnitude of each factor on perceived risk can be different based on the financing structure of the project (e.g. corporate finance versus limited or non-recourse finance), investor type as well as investor's transaction experience in green hydrogen. In particular:

- A priori belief usually concerns the outlook or elements of the relevant markets that meet certain criteria, such as the trustworthiness of current policies or the state of technology development and adoption (Binswanger, Garbely and Oechslin, 2023[43]).
- Institutional pressure is also another key determinant of an organisation/investor's strategy and actions (Aharonson and Bort, 2015[44]), such as regulation (e.g. net zero industry act) or industry trend (e.g. corporate governance).
- In addition, the credit rating of the asset (based on historical performance), inherited country level risk and green hydrogen specific risk (actual risk, such as country risk, offtake risk, technology risk, design, construction and completion risk, and supply risk are discussed further in details in below) are important factors.

Figure 3.3. Factors influencing investor's perceived risk



Source: Authors adapted from (Masini and Menichetti, 2012[20]), (Lee, 2019[45])

Political and regulatory risk

Political risks in green hydrogen projects encompass legal and political changes that jeopardise financial viability, including alterations to laws, expropriation, conflict, currency restrictions and contract breaches. These risks are accentuated in the emerging hydrogen sector, heavily reliant on regulatory incentives like tax breaks, subsidies and price guarantees. Risks persist in projects that earn revenue in local currencies, potentially facing obstacles in currency conversion and capital transfer. Green hydrogen projects in countries with political instability or project governance or structuring challenges can pose significant risk, particularly as green hydrogen projects require a high level of investment and long tenor of return. Here, political risk insurance, for example through export credit agencies, becomes pivotal. Protecting against governance and legal disruptions throughout projects' lifecycle will be important as conventional insurance markets may be inadequate due to high-risk premiums.

Another risk factor is the regulatory risk such as the permit process. Green hydrogen initiatives necessitate obtaining various licenses and approvals, encompassing land rights, social and environmental permits, and construction licenses. If the country lacks the institutional capabilities and technical expertise, it can significantly extend the development timeline for low-carbon hydrogen projects. For instance, in the case of the Faro del Sur e-fuels project in Chile's Magallanes region, HIF and Enel Green Power decided to withdraw their environmental impact declaration due to the limited availability of essential baseline environmental information. This withdrawal not only affected the project's planned schedule but could also heighten the perceived permitting risks for both developers and financiers (ESMAP, OECD, Global Infrastructure Facility, and Hydrogen Council, 2023[4]).

In addition, as international trade of green hydrogen could account for a substantial share of its total consumption in the coming years, regulatory tools such as certification mechanisms are of paramount importance to facilitate such trades. Certification is particularly important for export to countries with strict environmental standards and regulations (e.g. Carbon Border Adjustment Mechanism (CBAM)). It is imperative that policymakers and regulators champion the international harmonisation of relevant definitions and certifications.

Country risk

Country credit risk, often referred to as sovereign borrowers' credit risk, is another factor that exerts a substantial influence on elevating the risk, particularly in emerging and developing countries. It serves as a crucial tool for informing investors about the risk profile of sovereign borrowers, effectively mitigating information asymmetries and empowering lenders to make more astute decisions concerning potential risks (UNDP, 2023[46]). The impact of country credit ratings on capital costs cannot be overlooked. As country credit rating gets lower, borrowers are compelled to bear higher interest rates for capital, resulting in an elevated cost of capital (Chodnicka, Piotr and Niew, 2015[47]). This correlation is well illustrated in Table 3.1., which shows the close connection between country credit ratings and risk premiums. Consequently, these risk premiums translated into higher capital costs associated with green hydrogen projects.

Table 3.1. Country Credit Rating and WACC for selected renewable energy technologies

	Country Credit Rating and Risk Premium				After-tax WACC IRENA Assumption (%)	
Country	Moody	Rating based default spread	Total Equity Premium	Country Risk Premium	Solar PV (On Shore)	Onshore wind
Chile	A1	0.59%	5.89%	0.69%	3.50%	4.50%
Egypt	B2	4.60%	10.63%	5.43%	8.80%	8.80%
United Kingdom	Aa2	0.41%	5.69%	0.49%	2%	2.60%
India	Baa2	1.59%	7.08%	1.88%	5.90%	5.90%
Mauritius	Baa1	1.34%	6.77%	1.57%	4.60%	6%

Note: US government 10-year treasury bond (4.18%) currency all in USD (no frontier market included).
Source: Authors (data from IRENA, Moody's, Damodaran)

Offtake risk

Offtake risk is substantial particularly for new green hydrogen assets at the early stage and, therefore, debt investors will require contracts that encompass all possible risks. The contracting party must have sound credit and be willing to agree on long-term offtake agreements. Power price risk is another factor to consider, as Power Purchase Agreement (PPA) contracts that last an average of 10 years will not cover the entire life of a green hydrogen project. For instance, in the case of NEOM, offtake risk has been mitigated by the 30-year offtake agreement signed by Air Products (see Annex B). This is also the case for the Yuri project which secured a 20-year offtake agreement between Yuri and Yara to mitigate the risk of not having an established spot market for green hydrogen.

Design, construction, and completion risk

Green hydrogen projects are intricate, involving various stakeholders in a complex supply chain. Specifically, vertically-integrated green hydrogen projects, which incorporate renewable power for electrolysers and support infrastructure for mid- and downstream processes, pose challenges due to the limited transaction experience of sponsors and financiers in this field. Moreover, accurately estimating project design costs is difficult when there is insufficient data for investment appraisal (ESMAP, OECD, Global Infrastructure Facility, and Hydrogen Council, 2023[4]).

Construction and completion risk of green hydrogen projects have been heightened due to the relatively small balance sheets of some primary technology suppliers being unable to keep pace with the market entrance of significant corporations (e.g. Bank of America, BNP Paribas, Schroders Capital, Deutsche Bank, Barclays, BP, Shell etc.), and the announcements of project partnerships. Consequently, lenders may demand significant maintenance reserves and manufacturer warranties may require the backing of insurance or other financial instruments to offer credit support. This is also due to the complexity of green hydrogen projects and the associated high level of construction and completion risks.

Construction and completion risk pertains to the possibility of a project not meeting its budget and schedule expectations (ESMAP, OECD, Global Infrastructure Facility, and Hydrogen Council, 2023[4]). These risks are heightened compared to similar energy projects like offshore wind or gas ventures, primarily due to the involvement of multiple contractors and the deployment of various technologies (such as renewable power, electrolysers, etc.). Inadequate construction and completion of project components can lead to cost overruns, delays and deviations from technical specifications, all of which can impact financing costs. Providing such security may entail high costs for pioneering projects.

Due to the cautious and risk-averse nature of EPC contracts, costs may be higher as there are few entities with experience in implementing green hydrogen projects. While a fully wrapped EPC contract may be optimal to avoid interface risk during construction, a disaggregated EPC contract per each value chain may be more appropriate for green hydrogen projects (Patonia and Poudineh, 2022[48]). For example, the Yuri project, which will be one of the first green hydrogen projects globally to be incorporated into the ammonia value chain in Karratha, Western Australia (FID in 2022), the management of technology and construction risks has been effectively addressed by choosing highly experienced technologists and reputable engineering and construction firms, namely Technip Energies and Monford Group. Furthermore, establishing a strong partnership with a globally recognised infrastructure player like Mitsui, responsible for asset operation, serves as an additional measure to reduce these risks over the medium and long term (see Annex B).

In addition, it is preferable to have a well-qualified equity player with a proven track record of successfully completing high-level engineering risk projects involved in green hydrogen projects. In the NEOM Green Hydrogen Project in Oxagon, Saudi Arabia (FID 2023), one of the significant factors that facilitated the attainment of FID was the alignment of equity providers with other critical project risks. These equity providers, including entities like Air Products and ACWA Power, took on additional responsibilities such as technology risks and ensuring project completion. Similarly, for the CWP AMAN project in Mauritania (see Annex B), in June 2023, CWP announced a strategic investment from Copenhagen Infrastructure Partners (CIP), which acquired a 26.6% stake in CWP's green hydrogen development platform to further develop and invest in the project's successful implementation.

Technology risk

Electrolysers are a critical technology to produce green hydrogen from renewables. However, due to its limited deployment, the technology's performance, durability, and asset lifetime, it still needs to be tested. The absence of information on performance increases the cost of finance. In addition, the asset lifetime of electrolysers will raise risks related to the interplay of electrolyser degradation and the replacement cycle (ESMAP, OECD, Global Infrastructure Facility, and Hydrogen Council, 2023[4]).

It will be crucial to ensure the proper functioning of electrolysis technology meets planned outputs and returns on investment. Presently, manufacturers provide contracts that cover the replacement of faulty components at their expense and set a warranty reserve. However, considering the technology performance is yet to be tested, there is a risk that actual warranty costs might surpass this reserve. If the manufacturer cannot fulfil the warranty due to financial insolvency, it disrupts a project developer's cash flow by jeopardising the project's balance sheet, liquidity, solvency, and financial viability.

Supply risk

Supply risks is relevant to key inputs for green hydrogen production, water, and renewable power. The requirement for both water and power are a fundamental aspect of green hydrogen projects, introducing intricacies into project design, construction and operation. Supplies of both water and power may well be separate from the project company and sold to it by utilities or other third parties, thereby raising risks related to price, volume and duration of the contracts for these inputs (ESMAP, OECD, Global Infrastructure Facility, and Hydrogen Council, 2023[4]).

Investors in renewable hydrogen projects are deeply concerned about mitigating power price volatility and ensuring a reliable electricity supply, both of which significantly impact the project's LOCH. Currently, many projects opt to generate their electricity internally to manage this risk, albeit at a higher cost. When considering third-party electricity supply, assessing the creditworthiness of the electricity provider is crucial. Furthermore, factors like the terms of power purchase agreements (PPA) and hydrogen purchase agreements (HPA) are pivotal to ensure duration of the contract covers asset's entire life cycle (e.g. if the PPA is contracted to be 10 years, HPA contract duration should be synced with the PPA to ensure price stability). In regions where electrolysers rely on grid connections, wheeling charge of grid should be address.

Water stress in some emerging and developing countries (e.g. Egypt) is a key risk for green hydrogen projects, especially as water tends to be scarce where solar energy sources are abundant and photovoltaic technologies have high-capacity factors (ESMAP, OECD, Global Infrastructure Facility, and Hydrogen Council, 2023[4]). As such, to mitigate water supply risk, the project can benefit by being located near coasts with a water desalination facility. In the case of water supplied by a third party, financiers will look at the pricing, duration, and technical requirements of water contracts to reduce price volatility and volume risks.

4 Cost of Capital for green hydrogen projects and associated perceived risks

Chapter 4 employs the two dual methodologies developed for the purpose of this paper to assess the cost of capital for green hydrogen projects and the related risks.

- As a first step, financial data from the market is collected and used as a proxy for project-level data for green hydrogen to estimate the cost of capital for green hydrogen projects (detail methodology available in Annex A).
- Subsequently, a survey was conducted to gain insights into the primary risk factors that contribute to high cost of capital. These survey findings have been validated through the case studies developed for the purpose of this working paper and they are provided in Annex A.

The determination of cost of capital (*or* WACC) for green hydrogen projects depends on various factors, including the project's location, size, financing structure and technological aspects. Given the higher risk and uncertainty associated with green hydrogen technology, cost of capital for such projects is typically expected to be higher than those for traditional fossil fuel projects.

Cost of Capital Estimation

Overview

- In calculating the cost of equity, the market value of equity is used, determined by multiplying the current stock price by the outstanding shares based on the historical capital structure. The equity's weightage is then found by dividing the market value of equity by the total market value of debt and equity. The equity risk premium is computed as the difference between the average stock market return and the risk free rate. Beta values are sourced from financial data providers, but for companies with limited operating history, industry averages calculated by sources like Damodaran may be used.
- To compute the cost of debt, we use the market value of the company's total debt, which includes both long-term and short-term debt from the balance sheet. This cost is then determined by dividing the finance cost by the total debt, and we factor in the effective tax rate to arrive at the post-tax cost of debt.
- Detailed information regarding the selection criteria for companies and the collection of financial data can be found in Annex A.

Cost of Equity

The Capital Asset Pricing Model (CAPM) serves as a useful tool in estimating the cost of equity. While numerous studies have demonstrated the effectiveness of the multi-factor CAPM known as the Fama-French model,[20] which incorporated firm size and book-to-market value (FAMA and FRENCH, 1995[49]), a contrasting perspective has been presented by (JAGANNATHAN and WANG, 1996[50]) who found that Fama-French factors lost statistical significance in different contexts. Consequently, (JAGANNATHAN and WANG, 1996[50]) advocated relying on the traditional CAPM for prospective cost of capital estimates. Thus, considering the lack of pre-existing data to validate the outcomes or parameters of the factors, the research has applied single-factor CAPM.

Box 4.1. Capital Asset Pricing Model (CAPM)

$$r_e = r_f + \beta\,(r_m - r_f)$$

Where:
r_e = the expected cost of equity capital for a company
r_f = the risk-free rate of return
β = the share' beta
r_m = the return on the market portfolio
(r_m - r_f) = the expected premium offered by the market portfolio over and above the risk-free rate

For the calculation of the expected cost of equity, first the market value of equity is used instead of the book value for calculation. This is achieved by multiplying the current stock price with the outstanding number of shares which are available from a company's historical capital structure. The weightage of equity is found by dividing the market value of equity by the total of the market value of debt and equity. The equity risk premium is computed as the difference between the average stock market return and the risk free rate. The average stock market return is calculated by tracking the points of the stock market index from the specified source at each year-end throughout five years (if applicable), followed by calculating the average of the growth or decline. For Beta, levered beta was obtained from a financial data source (e.g. Yahoo Finance). On the risk free rate of return, the US government 10-year treasury bond (4.18%) was used.

Box 4.2. Steps to unlever and relever the beta for CAPM

Step 1: unlever the levered beta

$$\beta_u = \beta_l\,(1 + \frac{D}{D+E})/(1 - \frac{D}{D+E})$$

Step 2: relever the unlevered beta

$$\beta_r = \beta_u\,(1 + \frac{D^*}{D^*+E^*})/(1 - \frac{D^*}{D^*+E^*})$$

The beta for each company were sourced from third party data providers. However, in the case of companies that do not have readily available levered beta due to their limited operating years in business, the research used the industry average calculated by Damodaran.[21] For example, (Werner and Scholtens, 2016[51]) used a broad measure of industry beta to calculate the cost of equity using CAPM. The calculation took an additional step to calculate unlevered beta to eliminate the impact of financial leverage on a single company's return volatility.

[20] This is the method that is used mainly by hedge funds and institutional investors.

[21] Bio and Mission Statement (nyu.edu).

Cost of Debt

The market value of debt is derived from the book value of debt at the closing date, encompassing both long-term and short-term debt figures obtained from the company's balance sheet. The weightage of debt is calculated by dividing the market value of debt by the total market value of debt and equity. The cost of debt is computed by dividing the finance cost of the latest year or the average finance cost of two years by the total debt. The effective tax rate is determined by dividing the tax expense by the income before tax, or alternatively, the average tax rate of previous years can be used. Lastly, the post-tax cost of debt is obtained by multiplying the cost of debt by (1– tax rate/shield) from the income statement.

Results of the Cost of Capital Estimation

The selected sample companies align with predefined criteria. Most of these companies are located in Europe or North America and exhibit the potential to expand operations globally. This is due to the business pattern difference between the regions. While numerous early-stage companies involved in green hydrogen equipment manufacturing or engineering services are based in Europe, a significant portion of these businesses are led or invested by oil and gas companies or industrial conglomerates in Asia. This observation is likely influenced by the policy environment and incentives related to green hydrogen and low-carbon technologies in the respective regions, which eventually impacts financing costs and access to capital.

The capital structure of the sample companies is primarily financed by equity investors, resulting in a low gearing rate. The prevalence of equity financing suggests a cautious approach towards debt, which may be driven by the unique circumstances and characteristics of the hydrogen industry and the companies operating within it.

Table 4.1. Result of cost of capital calculation

Category (%)	B1- End User (Benchmark)	B2-Renewable (Benchmark)	Company I	Company P	Company S
Debt Price	3.5	3	7.40	4	2.2
Equity Price	4.2	11.6	10.90	24.3	12.8
Gearing	2.0	27.8	1	11.4	6.6
WACC	4.2	9.9	10.85	22.3	12.1

Category	Company A	Company F	Company G	Company N	Company H
Debt Price	6.48	16.5	1.48	5	0.41
Equity Price	24.7	6.4	50.7	18.6	10.9
Gearing	1.5	0.4	65	9.9	2.9
WACC	24.1	6.4	20.3	16.2	10.5

Note: Convertible bonds are not reflected on equity (information not available). Risk premium US T Bond (4.18% sourced from US Treasury). The one company used industry Beta due to the absence of calculated Beta.

As discussed in the previous section, companies seeking access to capital face the challenge of needing historical data on their performance to establish credibility. Without a strong track record in delivering hydrogen projects or producing hydrogen, raising capital through debt can be particularly difficult. In such cases, strategic equity investors or large corporations[22] with an in-depth understanding of green hydrogen operations and a long-term investment horizon can step in to fill the financing gap. This pattern was reminiscent of the early stages of renewable energy, until favourable policy incentives and accumulated transaction experience led to a decrease in capital costs and an increased emergence of project finance.

The cost of capital is significantly influenced by both leverage and the corporate tax rate. When a company bears the initial losses of a project, having higher leverage suggests lower risk. For example, well-established renewable energy technologies in certain developed countries utilised a heavily leveraged capital structure, with over 80% of financing sourced from debt in 2017. While enjoying a significant corporate tax rate decrease from 41% to 30%, this led to relatively higher debt costs since interest rate payments are deductible from taxable revenues (Egli, Steffen and Schmidt, 2018[15]). This also was found in this paper's analysis.

The WACC for the selected companies falls within the range of 6.4% to 24%, with debt costs ranging from 1.5% to 16.5%, and equity costs ranging from 6.45% to 50.7%. The most significant outlier in this analysis is Company G, which exhibits an unusually low debt cost of 1.48% and an exceptionally high equity cost of 50.7%. This is attributed to several factors, including a highly leveraged ratio and extremely high cash volatility. The heavy debt repayment burden constrains their cash flow while not enough sales are generated with high volatility, contributing to the exceptionally high WACC value for the company. This becomes particularly evident when comparing Company P with a renewable energy company, Company B2, which has a leverage ratio of 27.8%. Despite Company B2 being more leveraged, its WACC and equity cost are lower than that of Company P.[23] This suggests that Company P is more exposed to market risks due to the higher perceived risk associated with its operations.

A lot of sample companies are similiarly characterised by fragile margins, as their profitability before interest, taxes, depreciation and amortisation are relatively low. This weak profitability is posing challenges for companies, leading to concerns about their overall performance. Moreover, many companies are at a high valuation level due to the high expecation towards green hydrogen while experiencing instability or a decline in anticipated sales volumes for the current fiscal year compared to the previous period. Furthermore, the company's sales projections for the coming years have also been varied reflecting the nascent green hydrogen market and price risk, suggesting a high cash flow volaitility. However, having a low gearing rate is partially helping these companies to maintain a relatively moderate WACC range despite high cash volatility and perceived risk.

[22] For instance, Shell, Hyundai and Weichai Power were one of the biggest low carbon hydrogen technologies or equipment early-stage investors. Source: (Pitchbook, 2022[69]).

[23] They are listed in the same market.

Figure 4.1. Hydrogen ETX Historical Volatility

Note: HYDR launched July 2021 with a high expectation toward the growing green hydrogen market. Annual total return in 2022 was negative 47.24%. The opening price in 2021 was USD 24.5 compared to USD 10.4 as of August 2023, which shows a negative 54-57% volatility throughout the year. The annualised fund NAV has been negative 40.17% since inception. The volatility of HYDR may also be influenced by market and geopolitical factors like rising interest rates, economic forecasts and the Russia-Ukraine conflict's impact on commodity prices.
Source: Yahoo Finance

It is noticeable that some companies registered in countries with favourable hydrogen policy, where the tax rate is 0%, were able to mitigate their negative cash flow. When a company is not taxed, it is because the company has not generated, or generated a negative, cash flow or it could be due to the case of a favourable tax treatment. In the case of sample Company H, it was due to the favourable tax treatment towards clean technology, which highlights the significance of tax treatments as a crucial factor for early-stage technologies like green hydrogen. For instance, compared to conventional renewable energy companies which demonstrated 9.9% WACC, the WACC of most green hydrogen companies, excluding Company H which experienced a favourable tax treatment, were higher. The difference is bigger if it is compared with hydrogen end-users (e.g. steel manufacturers with consumption of green steel), which was 4.2%. This gaps also implies a high level of perceived risk of green hydrogen business amongst investors and markets.

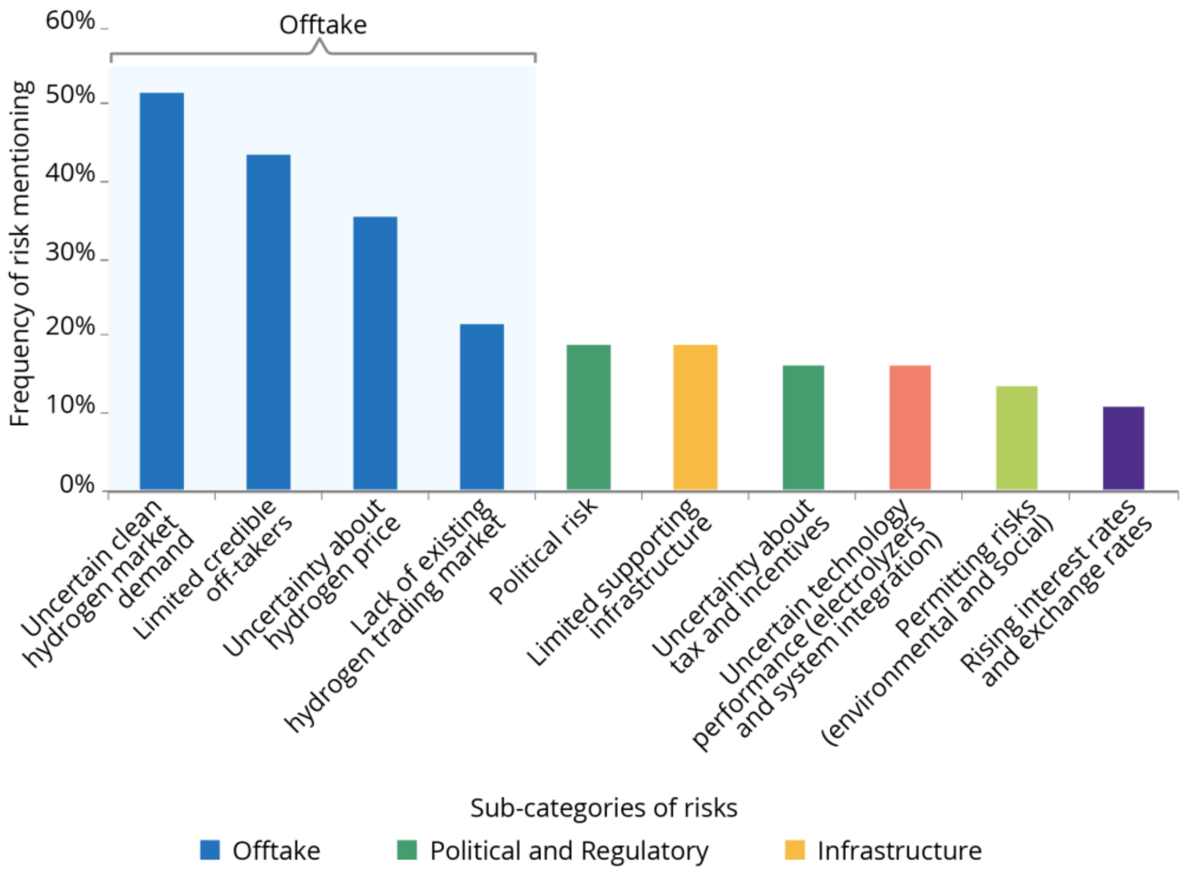
The growth prospects of the green hydrogen market have attracted the attention of investors, with expectations that it will follow a trajectory like renewable energy. As a result, there is a growing emphasis on corporate investors to align their governance practices with investments in low carbon technologies, including green hydrogen. However, the high level of cost of capital indicates that investors are exercising caution and closely monitoring the market, awaiting regulatory clarity before committing substantial investments.

As discussed in Chapter 2, to decrease the current green hydrogen production cost from USD 5 to 3/kg, the current high level of cost of capital needs to be reduced significantly. This is possible if appropriate financial and policy risk mitigation mechanisms are deployed to tackle the risk factors identified in Chapter 3. For instance, primary risk should be given to strategies that address cash flow risks, which encompass factors like production risks and price risks. While grants are valuable at the early stage, primary risk mitigation should focus on strategies in stabilising cash flows derived from green hydrogen projects, as the establishment of a robust market and the credibility of offtakers are intertwined with projected cash flows. To gain a comprehensive understanding of the key risks that require prioritisation, a survey was carried out.

Results – Key perceived risk factors associated with green hydrogen projects based on surveys and case studies

Segmenting responses based on years of experience also fails to reveal the predominant risks within the projects (see Annex C for survey results). Respondents with 1-3 years of experience tend to identify uncertainty in hydrogen pricing and market demand as the primary risk, albeit without a strong consensus. Meanwhile, those with 4-10 years of experience lean towards political risk and interest or exchange rate risks, though this view also lacks unanimity. This situation can largely be attributed to the market's relative maturity and the lack of transaction experience necessary for building a cohesive consensus, leading to a state of perplexity. Based on the survey respond, key risks are identified in Figure 4.2.

Figure 4.2. Key risks identified through survey

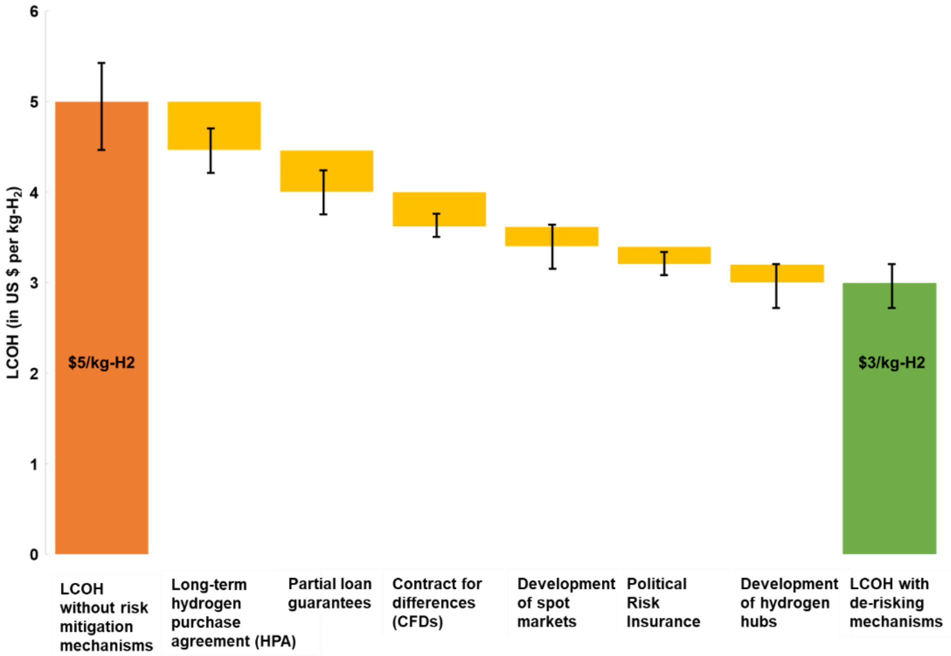


Source: (ESMAP, OECD, Global Infrastructure Facility, and Hydrogen Council, 2023[4]).

Concerning the most significant barriers hindering project finance deployment for green hydrogen, most respondents pinpoint uncertainty in market demand and hydrogen pricing, alongside a scarcity of reliable offtakers. Many of these prominent risks align with the availability of tools to address them in the market. For instance, although several financiers and developers acknowledge that country credit risk stands as a major concern leading to heightened financing costs for green hydrogen projects, it garners relatively low ranking due to its potential mitigation through sovereign guarantees. In contrast, risks like uncertainty in hydrogen pricing and market demand arise predominantly from the nascent nature of the hydrogen industry, lacking existing or applicable mitigation solutions. As such, if all risks are valued with the same price, their potential to effect to increase the cost of capital should be counterbalanced by deploying the above-mentioned risk mitigation instruments and/or direct policy interventions.

The implementation of financial and policy de-risking mechanisms have the potential to bridge the cost of producing hydrogen from USD 5 to USD 3/kg. For instance, the selected applicable mitigation instruments counterbalance the risks and allows developers to have access to lower cost of capital: 1) long-term Hydrogen Purchase Agreements: 2) partial loan guarantee; 3) reserve accounts; 4) purchase obligation, 5) political risk insurance; and 6) development of hydrogen hubs (Figure 4.3).

Figure 4.3. Financial and policy de-risking mechanisms lowering the cost of producing hydrogen from USD 5 to 3/kg (Illustrative)



Note: The risk cost for each factor was determined by translating the weight of survey responses into a proportional cost, aiming to reach USD 3/kg from the current global average price USD 5/kg.
Source: Authors' calculations

Regarding the survey's second component, which aims to evaluate whether key risk factors might differ across countries, particularly with regard to country-specific risks, the variance in the magnitude of each risk factor hinges on the unique risk profile of each country. For example, in the case of Country A (Europe, a developed market), offtaker risk assumes notable significance compared to Country B (Asia) and Country C (Africa), even though other contributing factors exhibit moderate similarities. Remarkably, political risk has notably surged in importance for Country B and Country C (both developing markets), accompanied by a corresponding increase in concerns regarding regulations. Furthermore, the state of enabling infrastructure and the extent of technology diffusion within each country's context contribute to shaping perceptions of technology risk.

The final segment of the survey delved into the market's inclination towards a risk premium for the capital cost associated with financing green hydrogen projects. Risk premium measures the willingness-to-pay to receive the expected value with certainty, rather than face the risk (OECD, 2018[52]). Against the risk associated with green hydrogen, lenders and investors will demand higher risk premium. The risk premium directly affects the weighted average cost of capital and the cost of the product or service delivered—in this case green hydrogen. This risk premium could be understood in terms of four dimensions: Beta, representing market-related risk; liquidity risk; size risk; and country risk. In terms of risk premium for green hydrogen, it could be considered under country risk (CRP) or liquidity risk:

- Within the spectrum of credit risk ratings spanning from AAA to A, the risk premium falls within the range of 100 to 200 bps.
- In the case of BBB- and B ratings, the risk premium widens, spanning from approximately 200 to 500 bps.

At the calculation level, this could be regarded as an "additional risk," which is incorporated either into the computation of debt or equity costs. To illustrate, if the initial cost of capital was set at 12% and we apply an extra risk premium of 5%, the overall cost of capital would elevate to 17%. This financial calculation takes into account key elements such as a 50% gearing ratio, a 20% tax rate, a 23% equity cost, a 13% debt cost before tax, and a specific country risk premium (CRP) of 2.5%.

It is challenging to discern the risk premium associated with clean energy, including green hydrogen, making it difficult to draw precise conclusions regarding its accuracy. Nevertheless, it becomes evident that there is a strong connection between the risk premium and a country's rating, suggesting that the cost of capital for green hydrogen will be influenced by the project's geographical location, thereby necessitating additional risk mitigation measures.

Lessons from case studies on enabling conditions and fiancing insturments

For the purpose of this working paper, five new case studies were developed (Table 4.2).

Table 4.2. List of case studies

Company	Country	Green hydrogen application
ENGIE/Yara	Australia	Ammonia
NEL	Norway	Electrolyser (Equipment)
NEOM	Saudi Arabia	Ammonia
CWP	Mauritania	Ammonia & Direct Reduced Iron (DRI)
ACWA	Uzbekistan	Ammonia

Summary

- To mitigate risks, developers are focusing on hydrogen derivatives, using megawatt-scale projects initially, and exploring long-term offtake agreements or market-based solutions. Most projects aim to export to North America and Europe, driven by decarbonisation mandates and support packages. These projects often emphasize environmental and social benefits to gain political and social support.
- To lower offtake risk, business models are based on hydrogen derivatives as final products (e.g. low-carbon ammonia for fertilisers, low-carbon steel, or cement) as well as strategic allocation of resources in terms of MW instead of GW until the market matures. The long-term offtake agreements with defined volumes and prices are one of the effective ways to tackle offtake risks.
- Public-private partnerships are emerging as potential facilitators for project decision-making and execution, with various models explored, involving state-owned entities and public institutions in private sector-led initiatives often backed by public funds or sovereign wealth funds.
- Developers predominantly opt for strategic alliances and partnerships across the hydrogen value chain, involving renewable energy project developers, equipment manufacturers, utilities and

large-scale energy consumers, enhancing market validation, offtaker alignment and risk mitigation for financiers.

- Concessional funding and blended finance attract investors in riskier markets, using pilot projects as proof-of-concept. Aligning interests between equity holders and offtakers, and involving key stakeholders, proves effective in lowering project risks and gaining investor confidence.

Business models

- The appetite of project developers to develop low-carbon, renewable hydrogen and derivatives businesses is increasing at global scale, with many new project announcements during Q2 2022 and Q1 2023. However, several challenges are still preventing many of these projects from reaching Final Investment Decision (FID). Some of the most relevant challenges are the large amount of capital needed to develop and execute the project, with an evident need of high-risk capital for early-stage development activities, and different market risks associated with a young, nascent hydrogen market, such as volume and price uncertainty.
- To lower offtake risk, many project developers are focusing on business models which include hydrogen derivatives as final products (e.g. low-carbon ammonia for fertilisers, low-carbon steel, or cement) as well as strategic allocation of resources in terms of MW instead of GW until the market matures. These products can be smoothly incorporated into current industry or transport business practices in the short term, without the need to establish a hydrogen market which is in the early stages of development. Low-carbon ammonia, steel, and cement are showing increasing demand even without reaching market price parity, mainly due to corporate mandates from private sector early adopters, which are eager to pay a premium for low-carbon alternatives.
- Specifically for the green hydrogen market, long-term offtake agreements with defined volumes and prices are one of the effective ways to tackle market risks. However, other market-based alternatives are being developed such as contract-for-differences. Nevertheless, these tools still need to be complemented by other incentives such as subsidies or concessional financing.
- Due to their scale and location, most projects are being developed to export their products to foreign markets, especially to North America and Europe. Decarbonisation mandates (revenue support that can bridge the green premium between the green cost of production and the fossil fuel equivalent such as the Inflation Reduction Act in the USA, and the European Green Deal) are leading to implementation of financial support packages for low-carbon product supply and demand, and therefore are positioning these two regions as early adopters of renewable hydrogen and derivatives.
- Environmental and social aspects of projects such as local value-add through industrial development, national infrastructure development, and increased access to affordable, are present in most project’s business cases. In some cases, the economic development dimension is a key factor to gain the required political and social support of the project.

Project governance

- Usually, projects are structured through specific-purpose investment vehicles (SPV’s) through which all project activities are led (project development, equity and debt structuring), and which will ultimately own the asset. This structure is the most utilised by both private and state-owned companies, in this and other industries.
- Even though project structures are usually under private corporate law, public-private partnerships could become enablers or catalysers for project FID and execution. Different ways of public-private partnerships are being explored in early-stage renewable hydrogen projects, such as state-owned companies and public institutions participating in private sector-led projects. These activities

usually include the participation of public funds, sometimes through sovereign wealth funds (SWF) or development financial institutions (DFI) to support private investments.

- A strong engagement with the public sector and local communities are usually included in projects' governance strategies, as large-scale projects usually rely or depend on national and subnational regulations to reach feasibility (e.g. regulation for energy generation, infrastructure development, hydrogen generation and sale, and land use).
- Strategic alliances and partnerships between different players along the hydrogen value chain seem to be the most preferred strategy for developers. Different stakeholders, such as renewable energy project developers, equipment manufacturers, utility and energy companies and large-scale energy consumers, tend to have participation during the project design and feasibility stages. This collaborative approach benefits project developers (which validates the market viability of the project), offtakers (which make sure to fit the project with their needs), and financiers (as a de-risking mechanism).

Enabling market conditions and de-risking investment

- Most of the projects showing strong advancement in their development process are ultra-large scale, in the range of several pilot projects to few GWs of renewable energy and electrolysis installed capacity. Sites with abundant renewable energy resource, especially if there is complementary resource between different renewable technologies, such as solar PV and wind, and access to large portions of land are key characteristics to achieve low-cost, high-volume hydrogen production, and are considered competitive advantages in the long term.
- Availability and access to basic infrastructure, such as electricity grids and transportation systems (maritime, railroad) are also valuable characteristics to decrease project capital needs and increase economic feasibility.
- The development of ultra-large-scale projects is being helped by the evolution of electrolyser technology and manufacturing capabilities. GW-scale hydrolyser manufacturing facilities are being planned and built around the world, as electrolyser size for hydrogen production is moving from MWs to hundreds of MWs. While more manufacturing is helping electrolyser costs to decrease, production capacity would need to continue to scale up to keep pace with demand and avoid adoption bottlenecks.
- Project-specific risks, such as currency and political instability, are present in projects being developed in emerging markets and developing economies (EMDEs). Several projects are being developed in EMDEs, and therefore countries with politically stable economies, tax schemes and currencies are preferred. Projects located in countries with a strong industrial sector and developed human capital also decreases risk perception. Aligning project goals with national structural goals in EMDEs can be determinant to risk mitigation.

Financing

- Offtake risk is particularly relevant in a project financing structure, especially to secure non-recourse project financing, which has been a widely used mechanism in other capital-intensive industries. However, the difficulty to secure long-term sale and purchase agreements, which is a fundamental tool for project financing, is making many project developers to utilise equity-only capital structures, especially during early stages of the development. Larger developers are usually able to use their own equity funds, while smaller developers utilise joint ventures to raise the capital needed.
- The role of DFIs, multilateral development banks (MDBs) and export credit agencies (ECAs) has been paramount to lower guarantee requirements and financing costs. Usually, national DFIs and

ECAs are eager to bear higher risks if the project is aligned with the institution’s mission (boosting technology exports, developing industries and markets, etc).

- Structuring fundraising into multiple financing rounds is also utilised to adequately involve different kind of investors (utility companies, infrastructure developers, and private equity groups). While there is an increasing interest from private equity firms, historically more risk averse, to participate in early- or mid-stage hydrogen developments, a higher participation of different kinds of capital sources will be needed to execute more projects, increase experience from financial institutions in climate-related financing, and establish a more mature hydrogen market.
- The utilisation of concessional funding and blended finance structures has been an effective tool to engage investors and financiers with different risk profiles, especially in less mature markets with high perceived risk. Pilot projects are effective tools as to build knowledge on technology performance, business model, and proof-of-concept. Pilot projects are effective tools as to build knowledge on technology performance, business model, and proof-of-concept. Philanthropic and development capital, as well as government contributions and tax incentives, play a substantial role to deploy pilot projects and unlock follow-on funding for large-scale commercial projects.
- Aligning interests between equity holders and offtakers, especially through participation of offtakers in the project’s equity structure (similar to early stage of LNG industry where big trading houses take equity proportionate to their offtake of gas), is proven to be a good practice to increase the success rate of the project, and to lower risk perception of financiers and investors. Aligning other project stakeholders, such as EPC contractors, electricity suppliers, and equipment manufacturers could have similar effects in lowering project risks.
- For example, Yuri project, the management of technology and construction risks has been effectively addressed by choosing highly experienced technologists and reputable engineering and construction firms, namely Technip Energies and Monford Group. Furthermore, establishing a strong partnership with a globally recognised infrastructure player like Mitsui, responsible for asset operation, serves as an additional measure to reduce these risks over the medium and long term (Annex B).

5 Policy Implications

Chapter 5 examines how the substantial risks and high capital costs discussed in Chapters 3 and 4 influence the policy discourse on green hydrogen.

Strategic policy formulation for cost of capital reduction

Establishing an operational green hydrogen market requires significant more effort, making it imperative to establish enabling conditions through, for example, national roadmaps and strategies, regulatory frameworks, supportive policy packages and R&D support that can expedite market creation and development. These should take into account that contrary to the conventional belief that the establishment of hydrogen markets primarily hinges on technological challenges, as illustrated in Figure 2.3 (increase in the cost of capital from 10% to 20% results in a 73% rise in LCOH), cost of capital is equally an important factor to cost competitiveness.

The presence of enabling conditions plays a pivotal role in achieving a low cost of capital. Enabling conditions are essential to reduce the short- and long-term cost gaps, facilitate stakeholder co-ordination, decrease the need for project vertical integration, share risks and costs, and facilitate financing structures. (ESMAP, OECD, Global Infrastructure Facility, and Hydrogen Council, 2023[4]). Presently, green hydrogen projects adopt a vertically integrated approach, involving significant capital requirements (e.g. the announced average investment of projects of approximately USD 600 million).

Policies to create enabling environment for green hydrogen investment

Currently, following recent policies have been announced across some OECD countries and emerging and developing economies to scale up green hydrogen production:

- India has devised an extensive scheme to foster the proliferation of low carbon hydrogen and mitigate carbon dioxide emissions, positioning itself as a prominent exporter in this burgeoning sector. Incentives of no less than 10% of production costs, amounting to around USD 2 billion, will be granted to low carbon hydrogen fuel producers under the program. Notably, the government will offer incentives of at least USD 0.36 per kilogram for low carbon hydrogen production, which currently incurs a cost of about USD 3.63 per kilogram when generated through renewable energy sources rather than fossil fuel-derived electricity (IBEF, 2023[53]). These incentives will be awarded through a competitive bidding process and will gradually decline annually. The scheme aims to enable the establishment of 3.6 million tonnes of hydrogen production capacity over the next three years. Moreover, the government plans to release requests for proposals in multiple phases for both electrolysers and low carbon hydrogen supply, allowing for market exploration, technology adoption, and cost optimisation.
- The United States Inflation Reduction Act (IRA) provides tax credits for renewable electricity and new provisions for low carbon hydrogen. Renewable electricity plants and low carbon hydrogen facilities starting operation in 2023 can benefit from a production tax credit of USD 2.6 cents per kWh and up to USD 3 per kg of hydrogen, respectively, for the initial 10 years of their operational lifespan (typically up to 30 years) (Zhou, 2023[54]). The full tax credit of USD 0.60 cents per kg of

hydrogen (multiplied by five if labour and wage standards are met) is available for hydrogen where greenhouse gas emissions are less than 0.45kg CO_2e/kg hydrogen. Hydrogen produced with 0.45-1.5kg of emissions would receive 33.4% of the credit; with 25% for 1.5-2.5kg of CO_2e; and 20% for 2.5-4kg (GH2, 2022[55]).

- Canada's Clean Hydrogen Investment Tax Credit (CHITC) has been introduced to provide reimbursement to developers of green and blue hydrogen, covering up to 40% of their taxes on the purchase and installation of eligible equipment. However, the level of support granted will vary based on the anticipated lifecycle of greenhouse gas emissions of the projects. Under the CHITC, projects that exhibit a CO_2e emissions intensity of less than 0.75kg per kg of hydrogen produced will be eligible for the full 40% reimbursement rate. Projects with an emissions intensity between 0.75kg CO_2e/kgH_2 and 2kg CO_2e/kgH_2 will receive a 25% rebate, while those with an emissions intensity ranging from 2kg CO_2e/kgH_2 to 4kg CO_2e/kgH_2 will qualify for a 15% rebate. Projects with emissions higher than 4kg CO_2e/kgH_2 will not be eligible for the tax credit (Whitton and Sheldrick, 2023[56]).

Although the ongoing efforts to establish policy measures for incentivising green hydrogen production are encouraging, their effective implementation necessitates a collaborative approach among nations and hydrogen stakeholders. The current set of announced policy measures faces several challenges. There exists a lack of uniformity in defining green hydrogen, as criteria and assessment processes differ across countries, an important observation arising from the OECD's webinar on "Certification for facilitating international trade of green hydrogen.[24]" Additionally, it will be important to avoid competing incentives from financial support from public resources. Lastly, the existing policies demonstrate a short-term focus, whereas the successful realisation of green hydrogen requires sustained political commitment in the long run.

Tailoring right measures to mitigate high priority risks

Different types of risks emerge at distinct stages in project development and green hydrogen production. Policy and public support are crucial to tackle these immediate risks, particularly for many emerging markets as they are facing challenges posed by underdeveloped and nascent capital markets. These risks should be addressed separately, each with its own set of solutions. For instance, through the survey, key risk factors were identified by financiers and developers that participate in the hydrogen economy (Table 5.1) and each risk requires tailored risk mitigating policy mechanisms. As elaborated in this working paper, in the absence of initial public financial intervention, the perceived risk associated with green hydrogen would remain high thereby resulting in a heightened cost of capital.

[24] Certification for facilitating international trade of green hydrogen webinar - OECD.

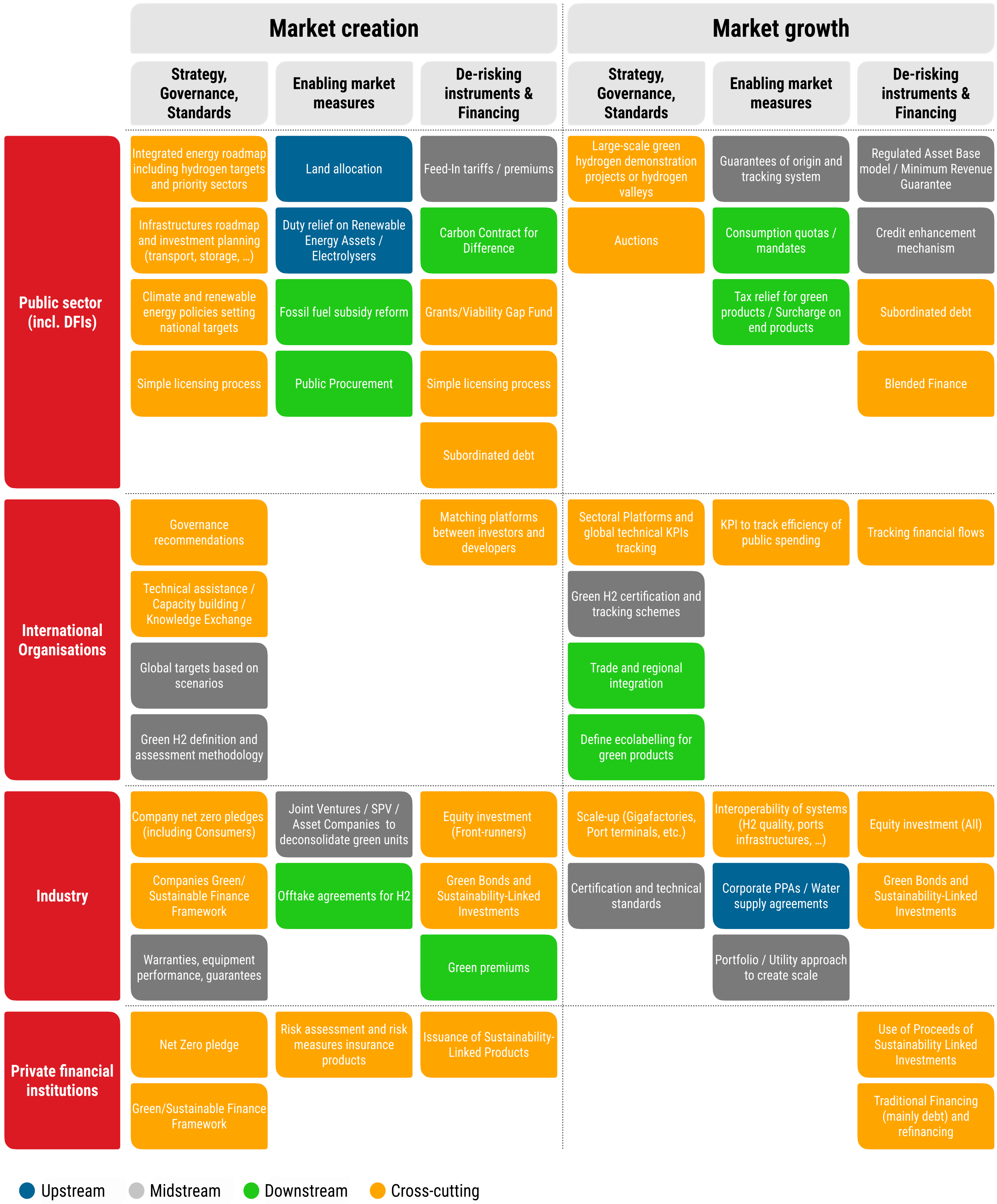
Table 5.1. Survey Result: Key risk factors and potential financial/policy de-risking mechanisms

Risk factors	Weighted	Examples of financial and/or policy De-risking mechanisms
Uncertain market demand	27%	Purchase obligations, public procurement.
Limited credible offtakers	23%	Long-term hydrogen purchase agreement (HPA), Partial risk/credit guarantees, export credit guarantees, and government guarantees especially for EMDEs
Uncertainty about hydrogen price	19%	Long-term hydrogen purchase agreement (HPA) and partial loan guarantee
Lack of existing hydrogen trading market	11%	Long-term hydrogen purchase agreement (HPA), De-risking through Guarantees of Origin could also strengthen market credibility
Political risk (Expropriation, Breach of Contracts, War, Currency Inconvertibility and Transfer Restriction)	10%	Political risk insurance, Partial risk/credit guarantees
Limited supporting infrastructure	10%	Hydrogen hubs
Total	**100%**	

Note: Given that the survey specifically focused on vertically integrated projects, it is important to note that renewable energy power supply and price risk are inherently intertwined with offtaker risk and hydrogen pricing.
Source: Authors, adapted from (ESMAP, OECD, Global Infrastructure Facility, and Hydrogen Council, 2023[4]).

As (Cordonnier and Saygin, 2022[5]) discussed, targeted support (policies and actions) could be in different forms (see Figure 5.1). Subsidies, tax credits and grants can alleviate the high capital that is a burden to investors until the market reaches maturity to attract higher private capital volume.

Figure 5.1. Policies and actions to facilitate market creation and growth



Source: (Cordonnier and Saygin, 2022[5])

Policy solutions for different market maturity level

For green hydrogen, policy support can be prioritised and designed to reflect different phases of the market as below;

- **Phase 1 (early stage):** In this initial phase, characterised by smaller investments before the FID, investors are seeking returns of 2-3 times their capital over a span of three years, often involving estimated WACC of around 20% or more. These investments carry a high degree of risk as they are typically equity-financed and rely on the potential of the management team, development sites, and the anticipation of forthcoming binding contracts. Moreover, they hinge on the expectation that conducive policy measures will emerge to facilitate the FID. Major capital expenditures are usually withheld until projects are sufficiently de-risked, often contingent on securing offtake agreements. At this stage, policy support can consider mechanisms like enforcing industry decarbonisation regulations, public procurement (e.g. H2Global Double Auction), revenue stream support (e.g. IRA), and offering upfront capital grants to alleviate initial high capital expenditure (CAPEX) requirements and create further demands.
- **Phase 2 (mature stage):** Transitioning to the second phase involving FID for substantial projects, investors aim for a more moderate WACC ranging from 10% to 20%. However, this phase necessitates a level of certainty regarding offtake volumes and pricing, typically linked to regulatory support or feed-in tariffs, to bridge the “green premium”—the gap between the green production cost and fossil fuel price parity. It is improbable that substantial investments will be made until these factors are firmly established. Once in place, the WACC aligns with the expectations for infrastructure projects with a range of 10-20%. At this stage, carbon pricing or levying taxes to mitigate the expenses associated with its production, and use, as the green hydrogen market becomes more matured.

Optimising the allocation of scare public resources

Currently, most green hydrogen projects receive FID through upfront capital grants (e.g. capital grants provided by Australian Renewable Energy Agency (ARENA) in the case of the ENGIE/YARA project in Australia, details in Annex B) provided by the government or in the form of corporate financing from strategic investors, which may be suitable for early-stage pilots where project finance structures are not applicable.

The capital grant is a free source of capital which is targeted to achieve policy objectives (e.g. deployment of green hydrogen for decarbonisation), and it can contribute to decrease the cost of capital and increase return on equity. However, it can also pose a potential risk of causing market distortion (Koh, Karamchandani and Katz, 2012[57]), deterring active private sector participation in some cases. For instance, grants are valuable during transitions, incentivising change and showcasing sustainability should have set timeframes and outcome indicators (Arvanitis, 2013[58]). However, long-term solutions should be involved to create an environment that attracts private investment. As such, capital support from government for policy goals, either in the form of grants or subsidies, should be designed in a similar manner to that stated in (OECD, 2022[59]) (European Commission, 2009[60]):

- Grants should not replace sustainable solutions but should target short-term development goals unattainable through regulations and markets alone.
- Harness sustainable private funding and facilitate a process of regulatory reform or encourage beneficiary behaviour change.
- Not compromise the long-term commercial viability of projects.

As such, supporting revenue stream mechanisms like feed-in tariffs over the operational lifetime of projects is effective as private investors provide more effective modes of public assistance compared to non-recurring capital grants. These combined efforts can pave the way for a more cost-effective and sustainable future for green hydrogen adoption. This can be achieved through the creation of revenue streams facilitated by public co-financing or direct investments. In the event that policymakers opt for subsidies, such as co-financing capital or operating expenditures, the funding for these initiatives should align with the anticipated scale of the hydrogen market expansion (Odenweller et al., 2022[61]).

In addition, auctions offer a robust solution to address hydrogen-related risks like price fluctuations and uncertain market demand. They reveal prices, optimizing resource allocation and risk mitigation. European countries have embraced this approach, exemplified by Germany's H2Global initiative, utilising double auctions for long-term supply and short-term demand contracts, bridging supply and demand price gaps with government grants. Double auctions provide a flexible market framework to match supply and demand amid varying price levels and subsidy availability. Yet, they come with complexities, project preparation requirements, contract duration concerns, and the need to navigate uncertainties related to competitive fuel prices, such as natural gas fluctuations.

6 Discussion and conclusions

According to the findings of this working paper, capital seekers for green hydrogen projects face challenges to mobilise required capital in the absence of a strong track record. However, strategic equity investors or large corporations with low-carbon technology project expertise building on their experiences from engineering projects (renewable energy, oil extraction etc.) may bridge the green hydrogen investment gap. Major barrier in terms of accelerating the green hydrogen deployment is that current LCOH is not cost competitive. Achieving reductions in LCOH from the current green hydrogen production cost from USD 5 to USD 3/kg hinges on tackling the high cost of capital.

However, as project-level financial data are often confidential and not available for the public, it becomes one of major barriers in understanding current level of cost of capital for low carbon technology projects such as green hydrogen projects. In addition, for green hydrogen, the data scarcity is exacerbated as very few projects have reached FID.

Strengths and limitations of data and methodology

This working paper approached solving the data problem in two steps. In the first approach to estimate the project-specific cost of capital, financial market proxy data for off-balance-sheet SPVs was utilised, akin to the approach taken when evaluating early-stage business models. The assumption was early stage green hydrogen companies receive investments from high risk tolerant investors, like private equity and venture capital limited partners. This mirrors the common practice of estimating project costs based on market data from publicly traded firms in the same industry. In addition, all the chosen companies were early stage firms, which should make their risk levels comparable to non-public firms with similar characteristics in the green hydrogen sector. Finally a range of sources were used to collect financial data.

Methdology could be strengthed as more companies as more companies participate in the green hydrogen value chain. Furthermore, it can be challenging to ascertain whether the revenue is a direct result of the strategic return, which refers to the additional benefits or gains achieved within the framework of the organisation's strategic planning, such as increased market share or enhanced competitive advantage. This difficulty arises from the absence of historical data that would allow a clear distinction between strategic returns and revenue generated solely from the specific business line, such as green hydrogen. In addition, the results may not accurately reflect the returns expected from projects once they've undergone risk mitigation. The venture capital style model often involves taking higher risk bets than highly capital intensive infrastructure project such as green hydrogen.

These limitations stem from the absence of well-established policy frameworks in the current market context and the dataset is predominantly private project composition. Additionally, market dynamics influenced by investor speculation can introduce volatility to pricing. Consequently, relying solely on the Capital Asset Pricing Model (CAPM) may not precisely capture the nuanced financial factors considered by investors in their decision-making process.

Summary of findings

The WACC for the selected companies ranged from 6.4% to 24%. The majority of companies face high perceived risk and cash flow volatility but maintain relatively moderate WACC. Tax treatment plays a significant role for low WACC values, which means companies in countries offering favourable policies can show better financial performance. This underscores the importance of favourable policy measures that could help to stabilise cash flow of the projects caused by price risk and market immaturity at the early stage of green hydrogen market development.

Mirroring how the advancement and stabilisation of major renewable technologies like solar PV and onshore wind have achieved cost reduction in the majority of the market,[25] equity financing will continue to play a significant role, especially for jumpstarting less mature technologies and funding ventures in regions with elevated risk or limited access to credit. However, as the market becomes more mature, the broad availability of affordable debt will be pivotal for executing capital intensive projects like green hydrogen. Securing substantial debt funding will be viable if lenders can foresee consistent and dependable cash flows over extended periods, aided by mechanisms like power purchase agreements (PPAs) and government policies such as Feed-in Tariffs (FiTs) in renewable energy projects.

In the second approach where an investor's survey was conducted, key priority risks that contribute to investor's perceived risks toward green hydrogen as well as associated risk premium were identified. The survey revealed the top six key risks identified as follows: 1) uncertain market demand; 2) a shortage of credible offtakers; 3) the absence of a solid hydrogen price; 4) lack of existing trading market; 5) political risks; and 6) insufficient enabling infrastructure. The implementation of financial and policy de-risking mechanisms that matches these factors will help to bridge the cost of producing hydrogen from USD 5 to USD 3/kg.

The findings from the survey were also complemented by key findings from the case studies (detailed in Annex B):

- Offtaker risk is significant. To mitigate offtake risk, many developers are adopting business models that produce hydrogen derivatives like low-carbon ammonia, steel or cement as end products. The long-term offtake agreements with defined volumes and prices are one of the most effective ways to tackle market risks. However, other market-based alternatives are being developed such as contract-for-differences. Nevertheless, these tools still need to be complemented by other incentives such as subsidies or concessional financing.
- Strategic alliances and partnerships between credible players with strong expertise and track records along the hydrogen value chain seems to be the most preferred strategy for developers to mitigate technology and construction risk.
- Availability and access to basic infrastructure, such as electricity grids and transportation systems (maritime, railroad) are also valuable characteristics to decrease project capital needs and increase economic feasibility.
- Decarbonisation mandates (such as the Inflation Reduction Act in the USA, and the European Green Deal) are leading to implementation of financial support packages for low-carbon product supply and demand, and therefore are positioning these two regions as early adopters of renewable hydrogen and derivatives.
- The projects are structured through specific-purpose investment vehicles (SPV's) led by big industry companies through which all project activities are led (project development, equity and debt structuring), and which will ultimately own the asset. Even though project structures are

[25] It is crucial to acknowledge the varying experiences in RE between developed and mature economies, particularly in EMDEs.

usually under private corporate law, public-private partnerships could become enablers or catalysers for project FID and execution.

- Project-specific risks, such as currency and political instability, are present in projects being developed in emerging markets and developing economies (EMDE). Aligning project goals with national structural goals in EMDEs can be determinant to risk mitigation.

Comprehensive green hydrogen policy measures are essential for mitigating perceived risks and mobilising private investment. The choice of policy adopted by countries will dictate the required level of intervention, the types of policies implemented and the allocation patterns of public resources. In addition the policy design should consider market maturity phases.

In Phase 1 (early market stage), consisting of smaller investments with a high cost of capital, policy support could focus more on demand creation, regulatory clarification and revenue stream support.

In Phase 2, for matured projects at the FID stage, investors aim for a 10-20% WACC but require certainty in offtake volumes and pricing (e.g. feed-in-tariffs, carbon pricing and auctions).

While public support and policy should be designed to accelerate the market, they also carry the risk of distorting the market and discouraging private sector involvement. For instance, grants are valuable during transitions, incentivising change and demonstrating sustainability, but they should have defined timeframes and outcome indicators. As such, policy measures should consider long-term solutions to create an environment that attracts private investment.

Next steps

Green hydrogen serves as a versatile energy carrier with the potential to facilitate the decarbonisation of multiple end-use sectors. (Cordonnier and Saygin, 2022[5]) discussed taking a value chain approach to pinpoint key areas of focus for developing national hydrogen strategies, viable business models and applications. This working paper explored the factors that influence the elevated perception of risk, a factor closely tied to the high cost of capital in green hydrogen projects. Also, this working paper complemented the upcoming World Bank/OECD Hydrogen Financing Flagship report.

This paper discusses the impact of high capital costs and related risks surrounding green hydrogen policy discussions but doesn't explore financial solutions or enabling conditions (e.g. policy measures) in depth due to limited market-based solutions and tailored policies. As more emerging and developing countries undertake ambitious green hydrogen plans, there will be a need for further research. This research could have a particular focus on how effective financing tools work for successful projects and how de-risking measures can be structured while creating the right enabling conditions to reduce high cost of capital for green hydrogen project.

Annex A. Methodology

Methodology for cost of capital calculation

The analysis conducted in this working paper screens companies based on specific criteria, including industry classifications, geographic locations and business descriptions to ensure homogeneity of business line, portfolio and geography. Applied key selection criteria are as following:

- Business line of company related to green hydrogen value chain
- Company's size and operation focus
- Geographic coverage
- Revenue should be 100% from green hydrogen value chain
- Exclude government owned companies
- Two additional samples were selected beyond the above-mentioned categories (end user of green hydrogen, renewable energy project developer and equipment producer in order to make a comparison with the rest of the samples and methodology validation).

After controlling indicators of financial maturity, the assumption is that public and private equity are similar in beta risk (Sahlman and Scherlis, 2009[62]). This aligns with the standard practice of inferring cost of capital from market data in public corporations, where new project beta risk is assumed to be comparable to public firms in the same industry (Kerins, Smith and Smith, 2004[63]).

Selection bias may lead to underestimates of cost of capital for the green hydrogen value chain as publicly listed firms could be less risky than non-listed firms with similar characteristics (Easley and O'hara, 2004[64]). However, since the selected companies are all early-stage firms, the risk levels are expected to be comparable to non-public firms with similar characteristics in green hydrogen (Kerins, Smith and Smith, 2004[63]).

Table A A.1. Selected company profile

Category	B1- End User (Benchmark)	B2-Renewable (Benchmark)	Company I	Company P	Company S
Main operating region(s)	Europe, North America, China	Europe, North America and Asia	UK, Middle East	North America	China / India
Operation details (Hydrogen business)	Consumer of low carbon hydrogen for their industrial process in manufacturing sector	Renewable energy development and construction, and operation providers: mainly offshore, wind farm	Leading company listed in European stock market dedicated to hydrogen. Focus on electrolyser	hydrogen fuel cell turnkey solutions provider(dominated by hydrogen infrastructure and fuel cell system)	R&D focus for energy storage, electrolyser and engineering service integrated GH projects
Revenue generation from GH business line	N/A	N/A	100%	100%	100%

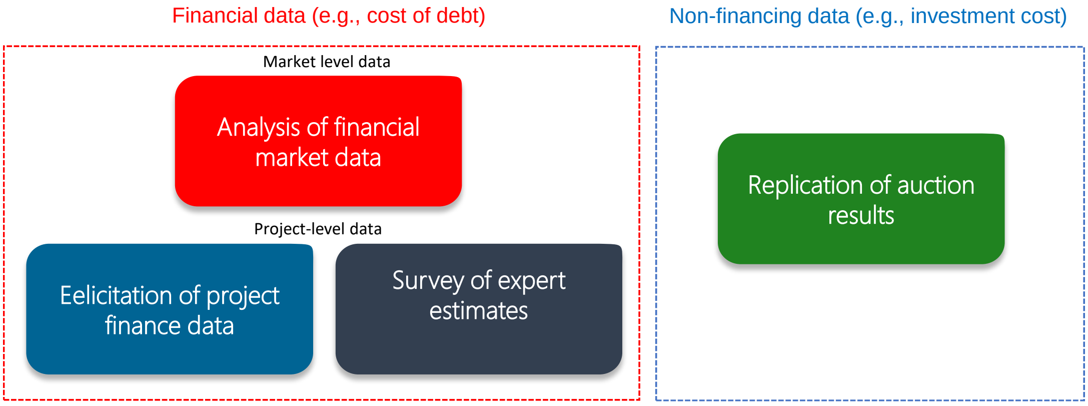
Category	Company A	Company F	Company G	Company N	Company H
Main operating region(s)	North America and Asia	North America	Europe	Europe, Asia, Middle East	Europe
Operation details (Hydrogen business)	Fuel cells producer and engineering service for integrated GH projects	Focus on low carbon hydrogen production and distribution and hydrogen-fuel-cell-powered light commercial demonstrator vehicles	R&D focus and raised A series. Electrolysers, Engineering service for integrated GH projects	R&D focus and commercialisation focusing on hydrogen fueling and electrolyser Raised capital through Private Placement	specialised in the mass production of turnkey hydrogen refueling stations
Revenue generation from GH business line	100%	100%	100%	100%	100%

Note: Details on companies' capital structure and some sensitive information could not be disclosed due to the narrow nature of the industry.

Financial data collection

The method of estimation utilised plays a crucial role in determining the level of the cost of capital. There are four distinct techniques (see Figure A A.1) to determine the WACC (Coleman, 2021[12]) (Zhou et al., 2023[11]). These approaches encompass extracting the WACC from existing financial market data, recreating it through modelling public auction outcomes, carrying out surveys of sectoral experts (Bruner et al., 1998[9]), and eliciting insights from private entities participating in transactions (Steffen, 2020[16]).

Figure A A.1. Methodologies that are typically applied to collect cost of capital for low carbon technology projects



Source: Authors adopted from (Steffen, 2020[16]), (Zhou et al., 2023[11])

In devising the methodology to assess the cost of capital for green hydrogen projects, essential considerations encompass factors such as the limited availability of data and the risk profile associated with such projects. As highlighted in the previous section, a significant challenge lies in the absence of accessible data concerning the cost of capital for green hydrogen. This deficiency can be attributed to both the scarcity of project pipelines and the confidentiality surrounding available data. Furthermore, it is worth noting that the risk profile of green hydrogen mirrors that of high-risk clean technologies and even resembles the risk associated with venture capital investments.

The collection of financial data is sourced from various platforms such as Yahoo Finance Marketscreener and Refinitiv. These private data provider platforms offer information on a company's balance sheet, income statement, cash flow, investment strategy and historical capital structure.

The research chose publicly available early stage firms which are green hydrogen businesses receiving investments from high risk toleranace investors (e.g. private equity, well-diversified limited partners of venture capital funds or boutique firms with a strategic investment position in clean technology). It bases analysis on aftermarket performance of a selected sample of public companies with extremely limited operating histories including firms with a high risk of failure, firms that had not yet generated large revenue and firms with a relatively small number of employees (Kerins, Smith and Smith, 2004[63]).

Survey for key risk factor identification

The survey targeted investors, financiers and developers actively engaged in the development of green hydrogen (The survey questions are available in Annex D). The selection of survey participants was meticulously carried out to ensure data quality and relevance. The following aspects were considered:

- profiles of investors/financiers
- geographical location of projects
- transaction experience
- business line within the green hydrogen value chain.

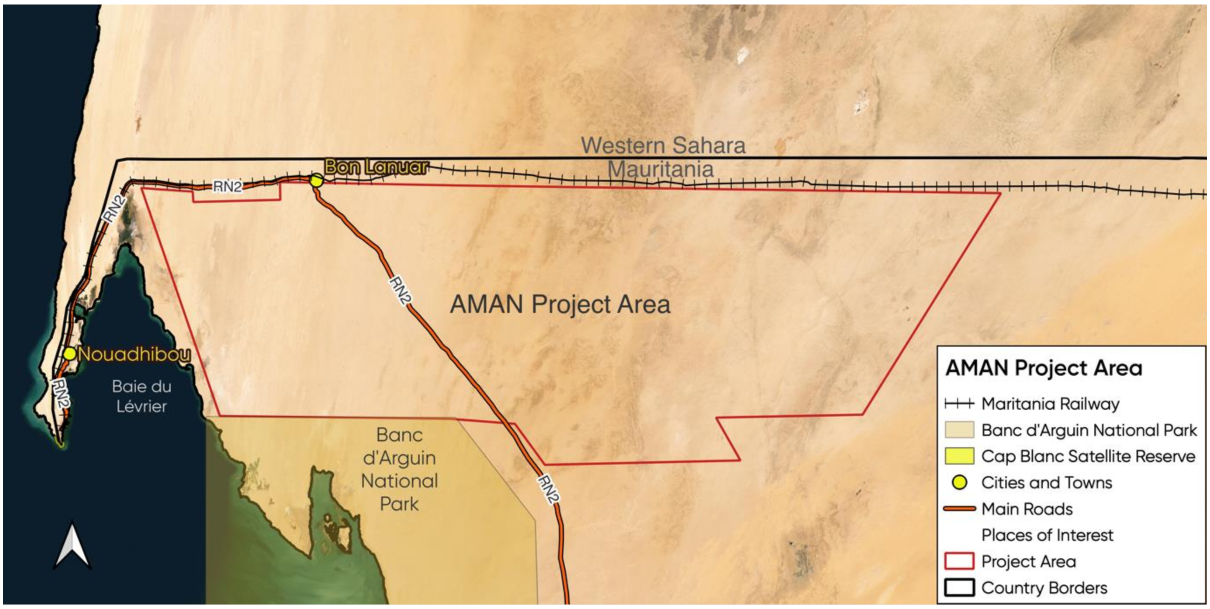
The survey comprised three main components, aimed at capturing the primary risks affecting the financing costs of low carbon hydrogen, a key barrier to its scalability:

- The initial component aimed to assess the influence of various perceived risk factors in the investment process for green hydrogen projects. Respondents were then requested to prioritise the three most significant risks that need mitigation. The risk factors in the survey were identified through preliminary interviews with developers, financiers and investors who had made financial investment decisions (FID) in low carbon hydrogen projects.

- The second component focused on gauging how the magnitude of each risk factor could change across different countries. Three countries, each from a different continent, were chosen. These countries demonstrated high-level policy support for green hydrogen development. Differences between these countries included infrastructure availability, capital costs reflecting country-specific risks, investment environments and local capital market development. The aim was to gain insights into how diverse macroeconomic factors impact the magnitude of risk factors in the investment decision process, ultimately influencing a project's financing costs.
- The third component sought to understand the additional risk premium associated with a country's risk rating and green hydrogen projects. Given the capital intensive nature of such projects, they are sensitive to financing costs, which are affected by sovereign credit ratings. Respondents were presented with four different country credit ratings (AAA, A, BBB- and B) and were asked to provide the required risk premium that would apply to cost of capital, reflecting their transaction experiences when financing green hydrogen projects.

Annex B. Case Studies

Case Study 1 – CWP Global: Project AMAN



Key indicators

Table A B.1. Project AMAN overview

Indicator	Company/Project
Value Chain step/Application	Green hydrogen/ammonia and green iron production (powered by dedicated renewable energy power generation
Country	Mauritania
Status	Feasibility
Production route & type of renewable	At full scale, planning 30 GW dedicated renewables (~18 GW onshore wind + ~12 GW solar PV) + ~15 GW electrolysis capacity for green H2 production Ammonia synthesis
Key project metrics (RE capacity/Electrolyser capacity/Ammonia Production etc.)	Renewable power capacity: ~30 GW (~5.5 GW for Stage 1) Electrolyser capacity: ~15 GW (~2.5 GW for Stage 1) Ammonia production volume: ~10 million tonnes per annum (mtpa)
Hydrogen production (kt/y)	~1,7 million tonnes H2/y (at full scale)
Start-up date	Stage 1: ~ 5.5 GW renewable power for 1 mtpa of green ammonia and 2.5 mtpa Direct Reduced Iron (DRI): Estimated 2029 Full-scale operations: Estimated 2037
Amount of investment (USD million)	USD 42 billion (at full scale); USD 5-10 billion (Stage 1)

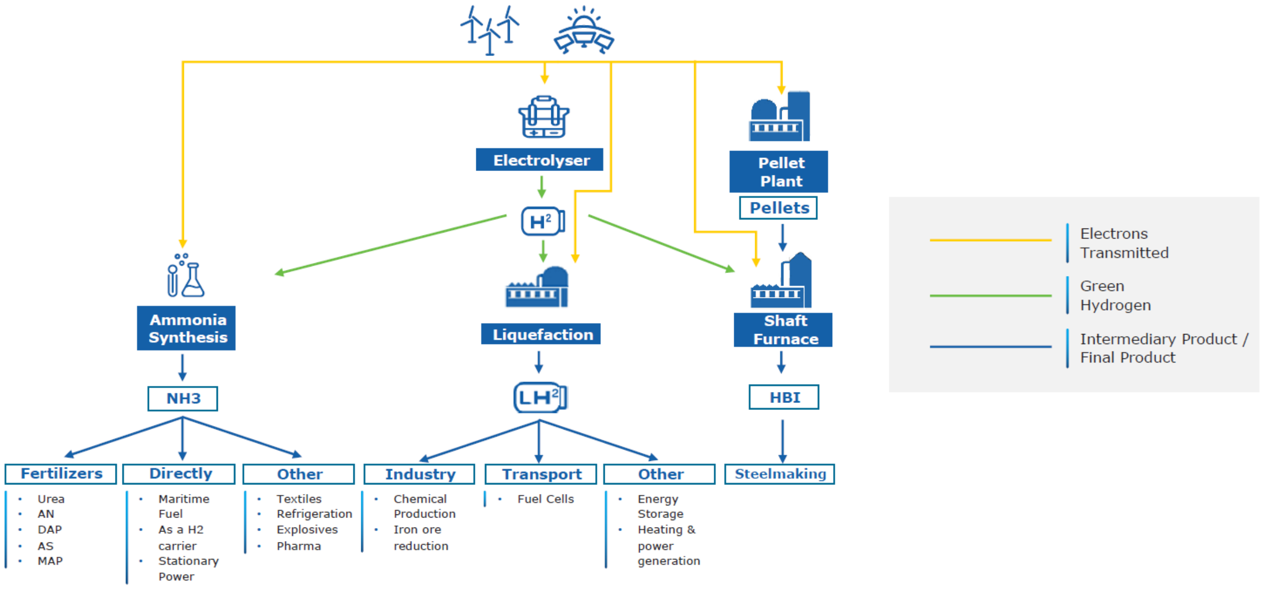
Basic description

Located in the regions of Dakhlet Nouadhibou and Inchiri, in Mauritania, the AMAN ultra-large-scale hydrogen hub project is being developed by CWP Global (CWP) on 850,000-hectares of public land in the country's north-west (see map above). The project aims, over a series of development stages, to install approximately 30 GW of renewable power generation facilities, an electrolyser capacity of ~15 GW and a green ammonia production capacity of up to 13 million tonnes annually.

AMAN is among the largest hydrogen hub projects under development in the North African Sahel region, and CWP is currently engaged in advanced feasibility studies for the project.

CWP is now progressing plans for **AMAN Stage 1** which foresees construction of about 5.5 GW of hybrid wind and solar power generation, commencing in 2027, with optionality for early offtake in the form of 1 mtpa of green ammonia and 2.5 mtpa of DRI, with exports envisaged from 2029. AMAN Stage 1 will of course be built with an eye to seamless integration of additional renewable power generation and production of green hydrogen and derivatives to eventually achieve the project's full 30 GW potential by around 2037, thereby maximising economies of scale and flow of benefits to the Mauritanian economy, as well as the project's contribution to the global decarbonisation effort.

Figure A B.1. Energy and material flow diagram for AMAN project in Mauritania



Source: CWP Global

CWP signed a memorandum of understanding with the Mauritanian government in 2021 and a framework agreement in 2022, including exclusive project development rights in the specified area. CWP is currently in the process of negotiating a final Host Government Agreement (HGA) with the Mauritanian government, including relevant economic terms, and continues to progress technical and economic feasibility studies in parallel. A key input to HGA negotiations is work by the Mauritanian government to finalise and seek parliamentary approval for a new Mauritanian hydrogen code, which will set the broad parameters for the development of the country's new green hydrogen industry.

Leveraging the experience of having built the largest portfolios of grid-connected renewables in both South-East Europe and Australia, CWP launched its ultra-large-scale hydrogen business with co-development of the landmark 26 GW Australian Renewable Energy Hub (AREH), located in the iron-ore-rich Pilbara region of Western Australia. The project was partially acquired and is now operated by BP in a joint venture development consortium comprised of BP, InterContinental Energy, CWP Global and Macquarie Capital/Green Investment Group (GIG).

Currently, CWP has six ultra-large-scale green hydrogen projects in different stages of development across three continents: Australia, Africa and Latin America.

Project rationale

The AMAN project vision is to be an early mover in the green hydrogen and derivatives industry in Africa and globally. CWP expects that green hydrogen and green ammonia will in the medium term play a fundamental role in the decarbonisation of heavy industry, such as steel and cement, long-range and heavy transport (aviation, maritime shipping), and agriculture (fertilisers).

According to the IEA, investment in the production of green hydrogen would need a significant scaling-up to meet both supply and demand targets aligned with the goals of the Paris Agreement, including 2030 GHG emission reduction targets and a net-zero global economy by 2050 at the latest. Green hydrogen supply is expected to grow exponentially from less than 1 mtpa in 2020 up to a range between 140 and 155 million mtpa by 2030, which is equivalent to 7 to 8 times the target of 20 mtpa green hydrogen use in the European Union by 2030.

The ultra-large scale of the AMAN project, together with the availability of world-class renewable energy resources and its co-location with a significant and high-quality iron ore basin positions CWP to produce green power, green hydrogen and ammonia, and low-carbon direct reduction iron at very competitive costs compared to other smaller-scale projects being developed globally.

Given the project´s ultra-large scale, the variety of potential offtake vectors, and the limited local demand, the AMAN project is primarily focused on major export markets, mainly in Europe, given its relative geographical proximity and growing demand. The project's expected delivery timeline will allow CWP to participate in the scaling-up of the European hydrogen and low-carbon steel markets, which is now accelerating with the help of clear and evolving EU policy settings. As noted above, the European Commission has set a goal to import 10 mtpa of renewable hydrogen (and derivatives, including green ammonia), by 2030, as part of an overall goal to use 20 mtpa by 2030. It also has a binding target to ensure that at least 42% of Europe´s industrial hydrogen use is produced from renewable energy.

Building a local and integrated green iron production hub is a potentially attractive component of the project, due to the presence of SNIM(Société Nationale Industrielle et Minière)'s Zouerat mine to the north-east of the AMAN project site – the latter has a northern boundary that runs very close and parallel to the railway line that brings Zouerat iron ore to its export terminal on the Nouadhibou peninsula. Green-energy-powered mining and an on-site DRI facility using locally produced green hydrogen would allow Mauritania to capture more local value-add, rather than exporting raw iron ore, which is the current business. This could provide a significant boost to Mauritania's economic activity and GDP, and potentially create thousands of new, highly-skilled jobs.

The AMAN project also includes production of desalinated fresh water, which could help to reduce northern Mauritania's water supply shortfall, which is expected to be 20 million m^3 (20 GL) per annum in 2030. As the AMAN project would have the potential to supply up to 30 GL in excess of 2030 water needs, the project will also have the capacity to supply fresh water for agriculture, leading to increased domestic cereal production up to 10%, improving local food supply and security - Mauritania currently relies on imports of cereals to meet food demand and is therefore susceptible to supply shocks.

Governance

CWP is an independent renewable energy and now Power-to-X (PtX) project developer, founded in 2006, with expertise across the full project lifecycle. CWP focuses on: (i) utility-scale, grid-connected renewables, mainly onshore wind and solar PV, where it has built the largest portfolios of such projects in both South-East Europe and Australia; and (ii) ultra-large-scale hydrogen hubs, where it is currently developing projects with a total of more than 220 GW in non-grid-connected renewable power generation. In June 2023, CWP announced a strategic investment by Copenhagen Infrastructure Partners (CIP), which acquired a 26,7% stake in part of CWP's green hydrogen business, with the aim to continue developing and investing in the implementation of CWP's projects.

The AMAN project is currently being developed by a project-specific SPV, named "H1RM-S.a.r. l (Mauritania)", which has been the sole developer of the project since its inception. In pursuit of a co-operative and collaborative platform for investment in, and development of the AMAN project, CWP has worked collaboratively with relevant ministries and other local stakeholders to establish several joint initiatives, including working groups like the Inter-ministerial Committee (ITC), at Cabinet level, and the Inter-Ministerial Technical Committee (IMTC), for more technical matters. Through the IMTC, CWP conducts regular meetings and workshops to engage with relevant government and other interested stakeholders about different aspects of project development work, usually divided by topic (for example, electrification, environment, legal and regulatory issues, financial and commercial considerations, etc.).

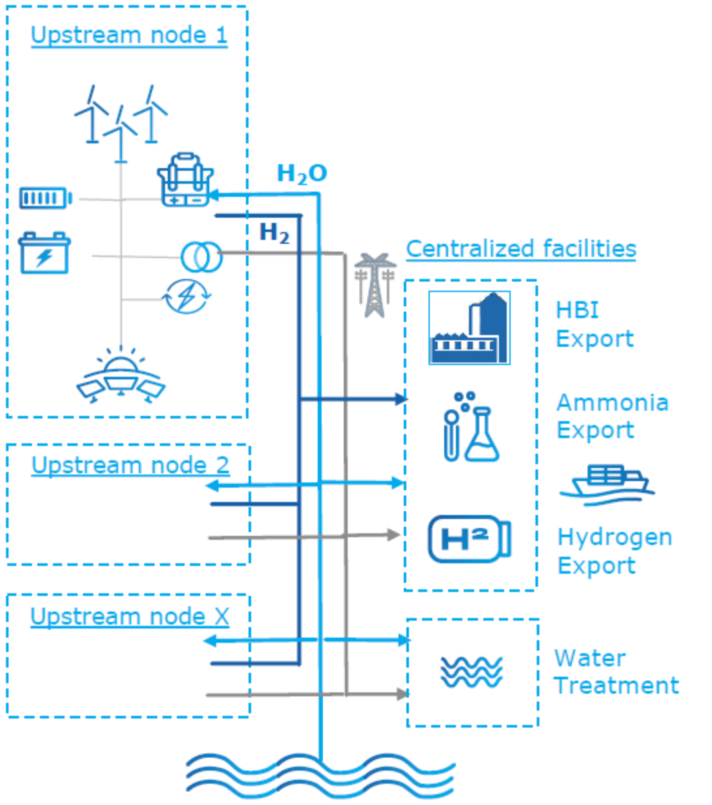
Business model

CWP is aiming to build a full-cycle, ultra-large-scale hydrogen and derivatives hub in north-west Mauritania, which includes several activities across the hydrogen value chain. CWP will, in a series of stages, construct a dedicated, on-site renewable energy generation hub, consisting at full scale of approximately 18 GW of onshore wind, and 12 GW of solar PV generation capacity. This will power an estimated 15 GW in electrolyser capacity to produce green hydrogen from desalinated water. The resulting green hydrogen will be used to produce green ammonia in dedicated synthesis ammonia reactors, and also to supply DRI plants to convert available iron ore into green iron pellets and/or hot-briquetted iron (HBI), largely for value-added export. As these green hydrogen-fuelled iron ore processing technologies produce very low or zero greenhouse gas emissions, it is possible to significantly reduce the resulting carbon footprint of the iron and steel end products.

At full scale, AMAN project capital expenditures (CAPEX) are currently estimated at approximately USD 42 billion over the project's first 10 years, including USD 18 billion for power generation, and USD 24 billion for downstream infrastructure (electrolysers, desalination equipment, ammonia synthesis equipment, etc). These estimates may increase with the addition of one or more DRI plants as part of the project. As noted above, Stage 1 of the project is designed to deploy approximately 5.5 GW of renewables generation capacity, with an estimated USD 5–10 billion in CAPEX, depending on the selection of production and offtake vectors for the project´s initial stage, and integrated planning for subsequent stages.

The overall project layout and physical structure is envisioned as several distributed upstream nodes of concentrated renewable power, which will generate electricity and feed localised electrolysers to produce green hydrogen, which is then transported via dedicated pipelines. This hydrogen will feed into downstream facilities, including air separation units, ammonia synthesis plants, storage facilities, and/or a DRI/HBI plant or plants, and hydrogen and ammonia export pipelines into bunkering facilities or ship-refuelling stations (see Figure A B.2 below).

Figure A B.2. Physical structure planned for CWP's AMAN project in Mauritania



Source: CWP Global

To secure offtake revenues, CWP is currently focused on potential participation in European markets for green ammonia and green iron, demand for which is rapidly increasing due to regional and national decarbonisation targets, green fuel incentive schemes and net-zero industry initiatives. As one example, the German government "H2Global" program, already underway with an initial EUR 900 million fund, aims to generate long-term offtake contracts by matching purchase and sale prices (done by Hintco, a state-owned intermediary company). The H2Global program already has a EUR 3.5 billion second phase plan committed, with funding from the German Government.

The main advantages for AMAN in seeking to position itself to secure export markets in Europe include its strategic and proximate geographical location, with access to West African shipping routes already used by the fuel and steel industries. The project site has access to railroad infrastructure, and the port of Nouadhibou is well positioned to facilitate an expansion of maritime shipping, with access to main European import hubs, such as the Port of Rotterdam, which is 4.700km away (seven days at sea).

Another key advantage is the availability of world-class wind and solar resources, which lead to low-cost renewable power generation, estimated at around 19-25 USD/MWh for solar and 22-29 USD/MWh for wind. Low-cost power is the main building block to achieving low-cost hydrogen production. The AMAN project is estimated to be able to achieve green hydrogen costs of between 1.7 and 2 USD/kgH2 by 2035, which is among the lowest-cost potential in the sector globally.

Demand for green iron and steel is also expected to increase rapidly within the next decade, according to McKinsey. First movers in the green steel industry are already entering into different agreements with offtakers and renewable energy developers and suppliers, such as the Salzgitter project, SALCOS, and ArcelorMittal's planned DRI plants in Gijón, Spain. The AMAN project could produce low-carbon iron at competitive costs when compared to other green iron projects globally. Some early studies indicate that AMAN green iron costs could out-compete similar production in other key geographies, for example at about a 10-15% lower price per ton than that produced in other Asian, European, and American locations.

Enabling market conditions and de-risking investment

As with many large-scale infrastructure projects, offtake risk is the most relevant financial risk for projects like AMAN. The ability of the project and its sponsors to secure long-term, fixed-price offtake agreements are critical to the success of the project. Producing (green) ammonia and iron above current market prices could delay final investment decisions as the market is in the early phases of estimating and addressing the "green premium", including through policy interventions and incentive schemes. Efforts to address the cost gap between traditional and low-carbon manufacturing (such as subsidies and tax incentives for decarbonisation activities and low-carbon products), will help to secure the economic and financial viability of the project.

Technology risks are also relevant for a project like AMAN, as the equipment utilised to generate electricity, hydrogen and final products require deployment of technological innovations, integration and new levels of complexity. Suppliers of electrolysers, ammonia synthesis plants and hot briquetted iron equipment would need to be carefully selected and integrated, and technical and financial guarantees would help to minimise risk perception for project financing.

Perceived country political risk may also be a significant challenge for achieving a final investment decision. In this regard, the AMAN project is very well positioned as an opportunity to boost Mauritanian industrialisation prospects and dynamise its economy, and the project therefore enjoys very strong support from the Mauritanian Government. According to a report prepared by Systemiq Ltd in 2021, the AMAN project could help Mauritania to increase its GDP by 60 - 100% by 2037.

Financing

According to CWP's project development strategy, equity fundraising for the AMAN project might include the incorporation of strategic partners along the supply chain (upstream, midstream, or downstream activities), including Multilateral Developments Banks (MDBs) and Development Finance Institutions (DFIs), as well as potential partnerships and investments from large energy sector players, private equity and infrastructure firms.

Case Study 2 – Nel: Herøya plant automation

Note: Nel's hydrolyser manufacturing facility in Herøya, Norway [Source: Nel ASA]

Key indicators

Table A B.2. Nel: Herøya plant automation overview

Indicator	Company/Project
Value Chain step/Application	Electrolyser manufacturing
Country	Norway
Status	In operation
Production route & type of renewable	N/A
Key project metrics (RE capacity/Electrolyser capacity/Ammonia Production etc.)	Electrolyser manufacturing capacity Line 1: 500 MW/y Line 2: +500 MW/y (for a total of 1GW/y)
Hydrogen production (kt/y)	N/A
Start-up date	Line 1: 2022 Line 2: Expected April 2024
Amount of investment (USD million)	USD 38.6 million (EUR 35 million)

Basic description

Nel is a pure play hydrogen technology company developing solutions to produce, store and distribute hydrogen from renewable energy. The company specialises in electrolyser[26] technology for the production of renewable hydrogen, and hydrogen fuelling equipment for road-going vehicles.

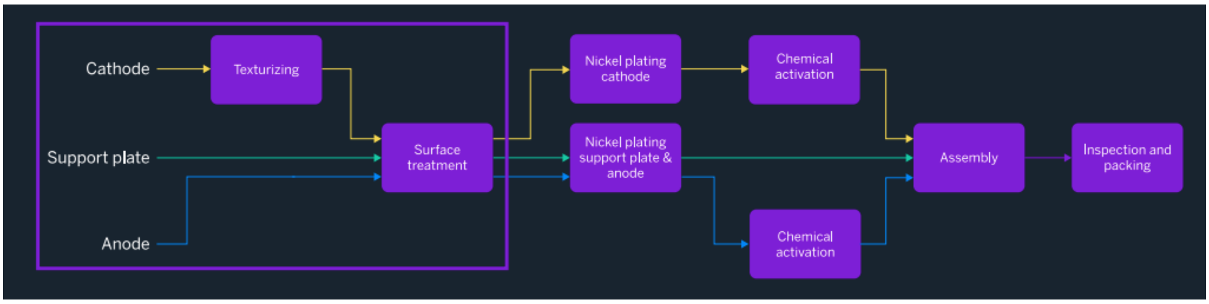
In April 2022, Nel inaugurated the world's first fully automated electrolyser manufacturing plant at Herøya (Norway). This plant consists of a state-of-the-art Alkaline Water Electrolyser (AWE)[27] manufacturing facility with an annual production capacity of 500 MW and room to expand up to 2 GW in the existing building. Electrolyser projects are expected to grow in size, from around 20 MW to the scale of hundreds of MWs or GWs. Large-scale electrolysis for green hydrogen production is a young market, but it is quickly ramping up and expected to dominate the market in the medium to long term.

In an effort to meet the global ambitions for renewable hydrogen, Nel initiated a continued expansion at Herøya. Nel has announced an additional 500 MW alkaline production line, expected to be operational from April 2024. Total CAPEX commitment for the equipment is of approximately EUR 35 million. Further capacity expansion will be closely aligned with commercial backlog. Nel has ordered building modifications at Herøya for two additional lines to prepare for further expansion.

[26] Electrolysis is the process to separate water molecules into hydrogen and oxygen. Green hydrogen production from water electrolysis is one of the most promising technologies to decarbonize various industries such as transportation, steel and ammonia production.

[27] AWE is a mature and safe technology and is currently used in many industrial applications. One of the main advantages of using AWE over other technologies is its ability to scale-up to megawatt range production capacities (Ursúa and Sanchis, 2012[70])). However, the process is very energy demanding with high capital investment, operation, and maintenance costs (Manabe et al., 2013[71]).

Figure A B.3. Part of manufacturing process of Herøya automated plant



Source: NEL ASA

Green hydrogen is intended to be a powerful tool for ensuring reliable renewable energy supply, and to scale-up the decarbonisation of the energy system, especially in hard-to-abate industries such as ammonia, methanol, refinery, steel, aviation and shipping, where direct electrification is more challenging. Given the current manufacturing capacity (6.6GW/y in 2021), electrolyser supply may become a bottleneck for these efforts. Investments for new manufacturing capacity and improved lead-times is becoming critical for this industry.

Project rationale

The fully automated production facility in Herøya, Norway, made Nel Electrolyser an early mover in the industrialisation of electrolyser production. To enable future growth and decrease cost through scale, volume and automation, Nel Electrolyser plans to further expand its production capacity in Europe and North America. Higher production volume is, according to the company, key to unlocking profitability and building trust with customers while accelerating development to meet market's growing demand. For Nel, increasing volume is important as it enables better resource utilisation and hence higher margins. For customers, it is of paramount importance to place orders with companies that can back up production and delivery schedules with real assets.

Besides focusing on growing its mass production capabilities, Nel intends to have the best technology in terms of total cost of ownership for the customer. To bring the cost of renewable hydrogen to fossil parity, CAPEX for a green hydrogen facility must be reduced by 40% of alkaline stack cost and 70% of PEM cost by 2026 of today's level. Consequently, Nel will continue to invest in research and development to improve the efficiency (OPEX) and cost (CAPEX) of its equipment.

In the longer term, it will be key to enable green hydrogen projects to become viable without the currently existing subsidies and financial incentives. For that, continuous efficiency and cost improvements in electrolyser manufacturing will be important as the market matures, in order to keep sustainable margins over time. It is expected that market trends will be similar to what happened with PV module manufacturing in the last decade.

Governance

Nel is a Norwegian public company, headquartered in Oslo, with a history tracing back to 1927. Nel has dedicated itself to serve different industries (fertiliser production, power, oil and gas) with hydrogen production technologies. More recently, Nel has focused on electrolyser manufacturing for green hydrogen production. Nel's shares are listed on the Oslo Stock Exchange under the ticker "NEL".

The electrolyser business has manufacturing facilities in Herøya, Norway, and in Wallingford, Connecticut, USA. The fuelling station manufacturing plant is in Herning, Denmark. Additionally, Nel has a sales and support network with global reach, including service organisations close to the main markets, including the US. West Coast, South Korea and Northern Europe.

Nel is engaged in numerous strategic alliances, both domestically and internationally, and is still actively pursuing new alliances with the goal to scale-up the entire hydrogen value chain effectively and rapidly, from engineering and procurement to installation, commissioning and aftersales. Some of Nel's' alliances include EPC partners, renewable technology providers and downstream technology partners (ammonia, ethanol, power).

As part of this strategy, Nel signed in November 2022 a joint development agreement with General Motors, a company with extensive experience in fuel cell technology development. The purpose of the collaboration is to accelerate the development of Nel's PEM (Proton Exchange Membrane) electrolyser technology.[28]

As a result of the above, Nel has taken the investment decision to improve the production line in Wallingford substantially, introducing automated stack assembly, sputtering, roll-to-roll, etc. This will increase PEM production capacity up to 500 MW, while at the same time reducing stack cost and improving stack efficiency. Nel also announced the plans of building an electrolyser gigafactory in the state of Michigan (where GM is located) with a production capacity of up to 4 GW, with an estimated investment of USD 400 million.

Business model

Nel has two main business divisions: Hydrogen Electrolyser (electrolyser manufacturing), and Hydrogen Fuelling (manufacturing of hydrogen fuelling stations for Fuel Cell Electric Vehicles – FCEV). Electrolyser is the largest segment in Nel and now constitutes 75% of Nel's total revenue in 2022, up from 58% in 2021. To date, Nel has delivered over 3 500 electrolyser solutions to over 80 countries, and more than 120 fuelling station solutions (delivered, or in progress to be delivered) to 14 countries.

In 2022, Nel's electrolyser order backlog more than doubled compared with 2021, including two record-size purchase orders in the USA, both of which will be delivered in 2023 and 2024:

- A manufacturing contract for 200MW from an undisclosed customer, with a total contract value of approximately EUR 45 million.
- A contract with Woodside Energy to deliver alkaline electrolyser equipment for NOK 600 million (EUR 51.75 million).

Additionally, Nel has received a 40 MW large-scale electrolyser order from Statkraft in Norway (value approx. NOK 120 million – EUR 10.35 million). These contracts have been essential milestones for Nel to make the final investment decision to expand and automate the Herøya plant.

The project pipelines for new large-scale green hydrogen projects are growing rapidly. Demand is expected to increase further driven by support mechanisms such as the US Inflation Reduction Act and the legislative and financial support packages proposed by the EU Commission. In this global context, Nel has narrowed its scope of supply from providing complete hydrogen plants worldwide to delivering larger-scale electrolyser stacks and gas separation modules to high-volume customers. The remaining scope is now delivered by strategic EPC (Engineering, Procurement and Construction) partners. According to Nel, this new focus on scope will enable the delivery of standardised solutions while reducing execution risk and improving margins for the equipment produced and sold.

Nel expects to sell and deliver its products primarily in Europe and North America over the next couple of years, until larger projects in other regions starts to materialise. In the longer term, many of the largest

[28] PEM electrolysis is considered a promising technique to produce high-purity and efficient green hydrogen. Large-scale PEM electrolysers are in general more efficient and have longer lifespans than alkaline electrolysers. However, they usually have larger CAPEX.

projects are likely to be in geographical areas with abundant renewable energy resources and lower electricity prices, such as Chile and Australia. Nel has a partnership strategy and a network of agents across the globe to service other geographical markets.

Enabling market conditions and de-risking investment

During the past two years, the hydrogen industry made the definitive transition from small to large-scale projects. According to Nel's research, orders for almost 5 GW[29] of electrolyser capacity were announced in 2022 only, while large-scale electrolyser projects will account for almost 90% of demand from 2025. Multiple factors contributed to this important transition: increased production targets and improved support schemes for renewable hydrogen projects, mainly in the USA and Europe; banks and financial institutions gained more experience and understanding of renewable hydrogen, making it easier for hydrogen producers to finance their business plans; and green hydrogen producers were able to secure attractive long term power purchase and offtake agreements with end customers.

The overall hydrogen market is expected to grow significantly, with hydrogen being used as a zero-emission fuel for mobility and as a way of decarbonising hard-to-decarbonise industrial sectors like the replacement of coal in the metal industry. Moreover, water electrolysis technology is expected to rapidly increase market share among hydrogen production technologies – today, 1% of the global supply of green hydrogen is generated via electrolysis. The other 99% is primarily produced from natural gas via steam methane reforming. Lower costs of renewable energy, a more mature electrolyser manufacturing industry, and increasing focus on decarbonisation are main drivers behind this growth.

As Nel operates in a fast-moving, emerging industry, market risks and uncertainties are one of the most relevant risks. There is significant uncertainty associated with the timing and pace of the growth expected in the hydrogen industry, which is also associated with other emerging (though more mature) markets, such as renewable energy for power generation and for transportation. Nevertheless, it is expected that the global focus on addressing climate change through decarbonisation is a megatrend that would define the energy sector in this half century.

As Nel is competing in a technology-intensive industry, technology risk is also very relevant for this project. There is associated risk to technological change, both inside the hydrogen industry as more efficient technologies may arise, and outside the hydrogen industry as other energy carriers or technologies may develop more quickly and efficiently. To partially mitigate this risk, Nel is continuously investing in research and development to cut down costs and improve the efficiency of electrolyser production and is investing in product development within several electrolyser emerging technologies, such as pressurized alkaline electrolysers and larger single cell stack PEM.

Supply chain risks are also particularly important for this industry as sourcing and availability of key components can impact lead times for equipment orders with a subsequent effect on deliveries of electrolysers to customers. However, one of the major advantages of Nel's alkaline electrolysers are that they do not dependent on any precious or rare earth metals/platinum group metals.

Finally, currency risks are relevant to maintain healthy financials. As a global company, Nel is exposed to currency fluctuations that might affect profitability. To partially mitigate this risk, since mid-2022 Nel has shifted away from fixed-price contracts, minimizing commodity and currency exposure, and reducing the overall contract risk.

[29] nelhydrogen.com/wp-content/uploads/2023/03/2022-Annual-Report.pdf.

Financing

Nel finances its activities mainly through private placements of new shares. In March 2023, Nel has raised USD 154.7 million through a private placement, intended to partially finance the expansion of the Herøya plant. Nel does not have a significant amount of interest-bearing, long-term debt to date.

Nel's main shareholders includes a considerable number of Norwegian and global institutional investors (such as BlackRock and Vanguard) and private investors, while there is also a large stake of small investors (through custodians) largely based in Continental Europe.

Nel has also been awarded different grants from the US government (Department of Energy, Department of Defence) to advance hydrogen technology. According to public sources, it is expected that Nel will continue to finance production capacity growth with corporate equity, mainly through private placements of shares.

Case Study 3 – ENOWA/NGHC (NEOM)

Key indicators

Table A B.3. ENOWA/NGHC (NEOM) overview

Indicator	Company/Project
Value Chain step/Application	Ammonia production from green hydrogen
Country	Saudi Arabia
Status	FID / Under Construction
Production route & type of renewable	Dedicated renewables (onshore wind + solar) Electrolysis Ammonia from green hydrogen
Key project metrics (RE capacity/Electrolyser capacity/Ammonia Production etc.)	Renewable power capacity: 4GW Electrolyser capacity: 2.2 GW Ammonia production volume: 1,2 million tonnes/year
Hydrogen production (kt/y)	~219 kton/y
Start-up date	2026
Amount of investment (USD million)	USD 8,4 billion

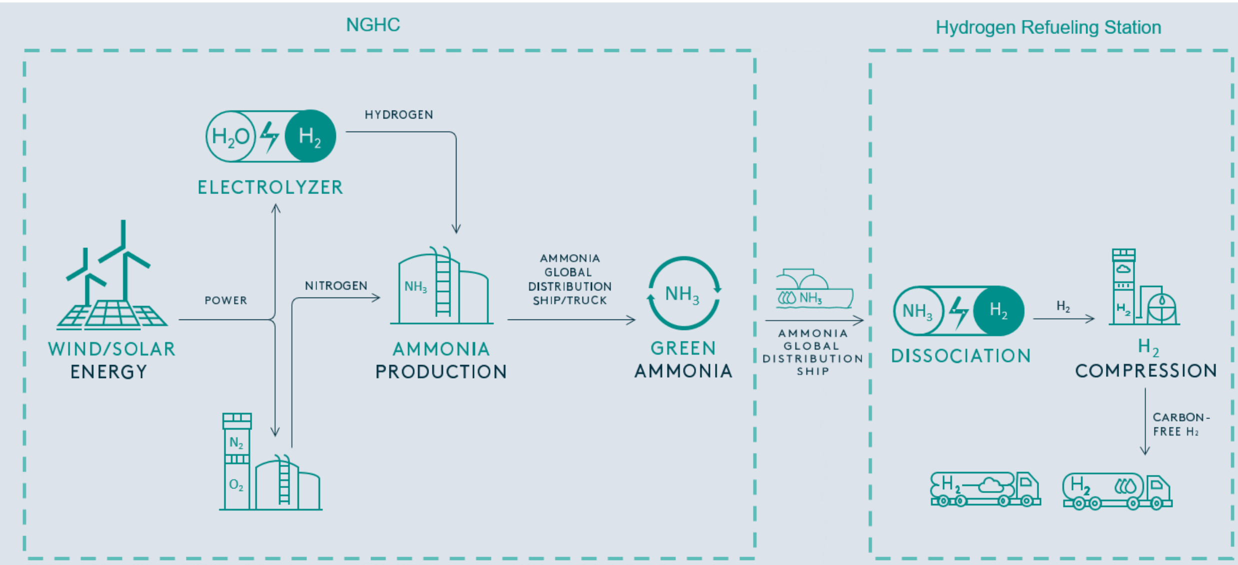
Basic description

NEOM Green Hydrogen Company (NGHC) is currently building the world's largest green hydrogen plant to produce green ammonia at scale in 2026. Located in Oxagon, in Saudi Arabia, the USD 8.4 billion plant includes 4 GW of renewable energy generation, and will produce up to 219 thousand tonnes of carbon-free hydrogen per year with electrolyser technology provided by ThyssenKrupp. Ammonia will be generated by Air Product's air separation technology and Baker Hughes will provide hydrogen compression units.

NGHC is an equal joint venture by ACWA Power (a private power generation developer and investor from Saudi Arabia), Air Products (a global provider of industrial gases and EPC contractor) and NEOM (a private company from Saudi Arabia building a USD 500 billion urbanistic project). The joint venture was formed as a vehicle to develop, build, own, operate and finance the project.

It is estimated that as a direct impact of the plant, up to 5 million tonnes of CO2 will be saved per year, helping Saudi Arabia to diversify and decarbonise energy production, as well as meet 2030's sustainable development goals.

Figure A B.4. NGHC production process



Source: Shearman & Sterling LLP, images by NEOM/AirProducts

According to Air Products, in early 2023 the construction phase has commenced with the first activities on the ground. To date, all groundworks have been completed, project engineering is complete, and all major subcontractors have been awarded. Additionally, the first industrial operating license was issued in January 2023 by Saudi Arabia's Ministry of Industry and Mineral Resources

Project rationale

This first-of-its-kind project aims to produce low-cost green hydrogen helped by economies of scale, enabled by the availability of large portions of land secured by the Saudi government, and access to low-cost debt and strategic equity capital. Besides scale, the project has several additional competitive advantages, the main one being the production of low-cost electricity, due to the availability of abundant and high-quality renewable resources such as wind and solar. The complementarity of these two resources on-site also plays an important role, which is a condition that the developer takes into account to seek for new project locations. Location is another competitive advantage, with access to European and Asian markets. Logistics play a relevant role in green hydrogen's cost structure, and NGHC will have access to a dedicated jetty for export in the Red Sea.

The early-mover advantage will position NGHC's partners as one of the largest and main providers of green hydrogen at scale by 2026 and being able to supply an increasing demand from the industry and transport sectors. Experienced business partners in industrial gas generation and commercialisation like Air Products and ACWA Power are also a competitive advantage of this project.

Air Products is a key player as offtaker, EPC contractor and equity partner of the project. Air Products has the strategic objective to maintain and boost its relevance in the industrial gases market in the upcoming years, with green hydrogen and ammonia gaining relevance in a global manufacturing sector with ambitious decarbonisation goals.

ACWA Power's long-term strategy is to use NGHC as a "blueprint project" to be replicated in several other locations around the globe. ACWA Power is currently developing ultra-large-scale projects in Oman, South Africa and Uzbekistan.

Governance

ACWA Power is a Saudi Arabian private company listed in Saudi Arabia's Tadawul stock exchange. ACWA Power is a developer, investor and operator of power generation and desalinated water plants with 77 assets in operation (USD 82.8 billion) in 12 countries. Saudi Arabia's sovereign wealth fund, the Public Investment Fund, is the biggest shareholder in ACWA Power, with a 44 per cent stake. It also has seven other stakeholders, including the Saudi Public Pension Agency.

Air Products (NYSE:APD) is a world-leading industrial gas company in operation for over 80 years focused on serving energy, environmental and emerging markets. The company has two growth pillars driven by sustainability. Air Products' base business provides essential industrial gases, related equipment, and applications expertise to customers in dozens of industries, including refining, chemicals, metals, electronics, manufacturing and food. Additionally, Air Products is the world leader in the supply of liquefied natural gas process technology and equipment, and globally provides turbomachinery, membrane systems and cryogenic containers. According to Air Product's financial statements, Air Products is the primary beneficiary of NGHC, which is formed as a Variable Interest Entity (VIE).[30]

NEOM is a state-owned company from Saudi Arabia, currently developing a USD 500 billion urbanistic project with the same name. NEOM will be home of more than one million people and is aimed to be a sustainable global city.

NGHC joint venture constitutes, in fact, a unique public-private partnership (PPP), formed by a utility company, an industrial company and a state-owned real estate/urban developer.

Business model

NGHC will produce green ammonia in an end-to-end process facility, covering all technologies in the value chain from renewable power generation and desalinated water to hydrogen and green ammonia production.

Due to the scale of the project and helped by favourable power and water resource availability, it is expected that NGHC will be able to produce green hydrogen at costs lower than 3 USD/kg, which makes the project highly competitive, and to produce green ammonia at around 700 USD/kg.

[30] A Variable Interest Entity (VIE) is a legal structure where an investor holds control, despite lacking a majority of voting rights. This control is established through contractual arrangements rather than direct ownership.

NGHC's main product, green ammonia, will be commercialised through an exclusive 30-year off-take agreement with Air Products and will be aimed to fulfil export markets, mainly in Europe. NGHC has also concluded an engineering, procurement and construction (EPC) agreement with Air Products as the nominated contractor and system integrator for the entire facility. This contract is valued at USD 6.7 billion.

The project was announced in 2020, and since then, the total project expenditures increased from USD 5 billion to USD 8.4 billion. Even if inflation has been the cause of a significant portion of the project cost increase (estimated in USD 500 million), other business decisions have been heavily impacted. NGHC has decided to internalise part of its supply chain to decrease future operational costs and dependence from external supply, such as transmission lines and other infrastructure costs. This represents an additional CAPEX of USD 1.2 billion.

According to Air Products, the remaining USD 1.8 billion in extra investments was caused by project financing costs, upfront fees, interest during construction, purchased spare parts and extra land costs. The two last items will also contribute to lower operational costs and NGHC was able to add these costs into project financing.

Enabling market conditions and de-risking investment

While the green hydrogen and derivatives markets (such as ammonia) is still under development, purchasers are seeking to secure supply agreements with providers that show robust, lower-risk projects, while minimising the "green premium" – the difference between low-carbon products versus traditional, carbon-intensive products.

Given the current status of the market, NGHC has solid de-risking instruments. The main unique characteristic of this project is the economic and interest alignment between the offtaker, investors and project contractors. One of the project's main advantages is that equity providers are also in charge of carrying other project risks, such as a technology risks (Air Products, ACWA Power) and project completion risks.

Offtake risk is, as in many other capital-intensive infrastructure projects, one of the main risks. In this case, the 30-year off-take agreement signed by Air Products mitigates this risk. Also, this long-term agreement allowed the partnering corporations to structure non-recourse, project financing debt, minimising guarantee and liquidity risks.

The integration of different technologies along the value chain is provided by industry majors, such as Thyssenkrupp (electrolysis), Topsoe (green ammonia), and Baker Hughes (hydrogen compression), which is another positive aspect of the project. Air Products also works as a technology provider (air separation) and as a main system integrator and EPC contractor.

Construction and timeline risks remain one of the most significant challenges for the project.

Country risk is also being partially mitigated by securing the participation of the Saudi government as equity investor (through NEOM), and as main provider of project financing. Saudi Arabia's interest in diversifying its energy exports and decreasing its carbon footprint aligns the project's interests with its home country's structural goals.

Financing

NGHC project has a total investment value of USD 8.4 billion and is being funded with a mix of 27% cash contributions and shareholder loans from the sponsors and approximately 73% with non- recourse project financing, according to Air Product's financial statements.

Financial closing for the NGHC Joint Venture was announced in May 2023, including a USD 6.1 billion non-recourse financing from 23 local, regional, and international banks and financial institutions. It is divided into a USD 5.8 billion senior debt and the remaining funding from mezzanine debt facilities. The Saudi government has played a fundamental role in the financing round, contributing more than 40% of the total financing. This includes USD 1.5 billion from the National Infrastructure Fund and USD 1.25 billion in the form of Saudi riyal-denominated financing from Saudi Industrial Development Fund.

Additionally, NGHC also announced that the non-recourse financing structured for the project has been certified by S&P Global (as the second party opinion provider) as adhering to green loan principles and is one of the largest project financings put in place under the green loan framework.

Case Study 4 – ENGIE/Yara

Key indicators

Table A B.4. ENGIE/Yara overview

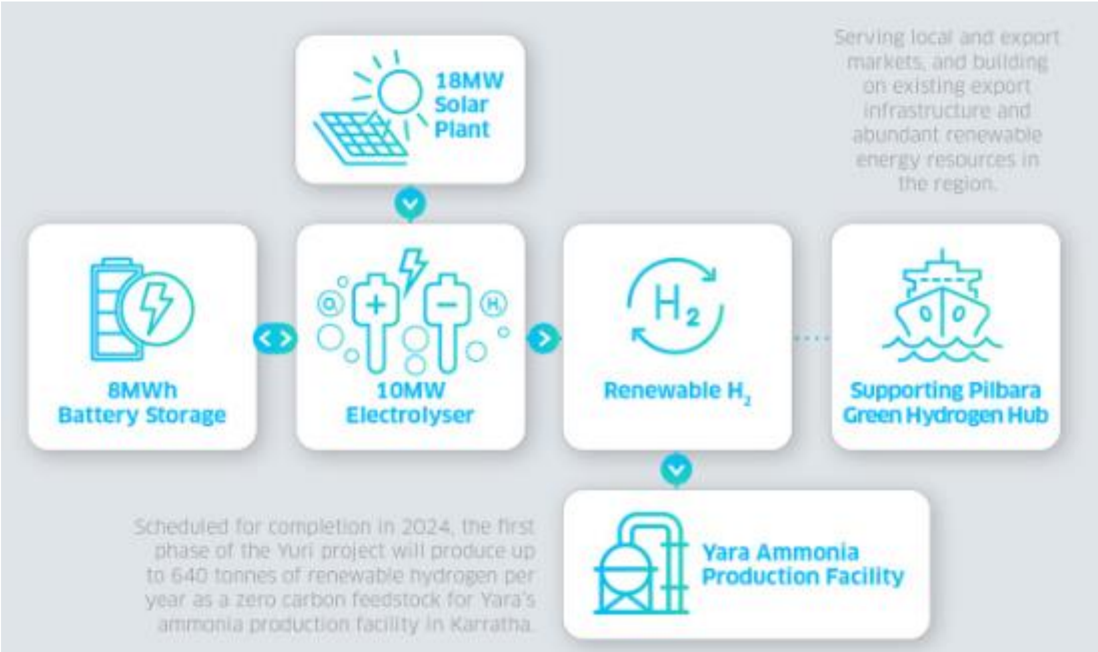
Indicator	Company/Project
Value Chain step/Application	Green hydrogen production (for ammonia synthesis)
Country	Australia
Status	Under construction
Production route & type of renewable	Dedicated renewables (Solar PV) + BESS + Electrolysis
Key project metrics (RE capacity/Electrolyser capacity/Ammonia Production etc.)	Renewable power capacity: 18 MW BESS capacity: 8MW/8MWh Electrolyser capacity: 10MW Est. green ammonia production: 3.7kton/y
Hydrogen production (kt/y)	Up to 640 tonnes H2 per year
Start-up date	May 2024
Amount of investment (USD million)	USD 57.1 million (AUD 87.1 million)

Basic description

ENGIE and Mitsui are currently developing an industrial-scale renewable hydrogen generation project to provide feedstock into Yara Pilbara Fertilisers' (Yara) existing ammonia operations. Located in Karratha, Western Australia, the Yuri Renewable Hydrogen project (Yuri) will be equipped with a 10 MW electrolyser powered by a dedicated 18-MW solar PV plant, with an 8 MW/8 MWh lithium-ion battery energy storage system (BESS) to manage electricity supply. The final investment decision was made in 2022, along with the financial closure and signature of investment agreements. Construction began in October 2022.

Scheduled for completion in mid-2024, the first phase of the Yuri project (called Yuri Phase 0) will produce up to 640 tonnes of renewable hydrogen per year. This zero-carbon hydrogen will be used as feedstock for Yara's ammonia production facility in Karratha, which is currently using carbon-intensive hydrogen produced with fossil fuels.

Figure A B.5. Production process



Source: ENGIE

Despite its considerable size, the Yuri project is conceived as a pilot plant, a demonstration phase of the projected Pilbara Green Hydrogen Hub, an ultra-large-scale project which is intended to serve both local and export markets, building on existing export infrastructure and abundant renewable energy resources in the region.

This project has received funding from the Australian government, through the Australian Renewable Energy Agency (ARENA), as well as from the Western Australia government, through the WA Renewable Hydrogen Fund.

Project rationale

The project's main objective is to demonstrate the business case for renewable hydrogen and develop the renewable ammonia industry in Australia and worldwide. This is why it has gained financial support from the public sector, which sees an opportunity to show Australia's potential for the nascent green hydrogen industry.

Moreover, fertiliser production is one of the predominant existing end uses for hydrogen, and one of the denominated hard-to-abate sectors to achieve deep decarbonisation. In this sense, pilot projects for fertiliser decarbonisation through green hydrogen could make a significant impact on the market adoption of green hydrogen, as well as the speeding-up of the maturity in the electrolyser technology, which is much needed to achieve cost-effective alternatives for industry decarbonisation.

Located in a commercial plant, the Yuri project will be of critical importance as a technology demonstration plant. Once commissioned, Yuri Renewable Hydrogen will be among the largest renewable-powered electrolysers in the world.

ENGIE is increasingly becoming a relevant player in the hydrogen industry, producing, and supplying zero-carbon hydrogen and diversifying its current energy generation portfolio. ENGIE's strategy is to operate across the entire value chain of renewable hydrogen, from carbon-free power generation to the three key end uses: mobility, industry and as an energy vector.

For the Australian government, the project will contribute to demonstrating the technical and commercial viability of the development, construction, and operation of green hydrogen plants in the country. Additionally, the project will also share knowledge and experience with other interested parties in the important areas of permitting processes and community engagement.

Governance

ENGIE is one of the largest global utility companies (HQ in France and listed in the Paris Stock Exchange as ENGI), operating in more than 30 countries with more than 96 thousand employees around the world. It is one of the largest independent power producers in the world, with more than 100 GW under operation. In Australia and New Zealand, ENGIE has formed a joint venture with the infrastructure major investor Mitsui & Co, and has 1 GW power capacity under operation, with additional business units in energy retail (Simply Energy) and trading (Global Energy Management & Sales).

Yara International is a global crop nutrition company, with operations in 60 countries and more than 17 thousand employees. Established in 1905 and headquartered in Oslo, Norway (listed in the Oslo stock exchange as YAR), Yara is the ammonia international market leader (excluding China) with a total annual production of 8.5 million tonnes NH3, with 26 plants around the world.

The Yuri project is structured under a special purpose vehicle (SPV) which will own and operate the asset, selling generated hydrogen to the Yara plant. Mitsui has agreed to invest up to 28% capital into the Yuri SPV, subject to milestone completion set in the investment agreement.

The project was supported by the Australian government through ARENA's Renewable Hydrogen Deployment Funding Round.

Business model

The Yuri project will be one of the first green hydrogen projects globally to be incorporated into the ammonia value chain and will include a dedicated off-grid renewable electricity generation facility with storage. The project will produce renewable hydrogen to partially substitute the hydrogen consumed at Yara, which is currently produced using Steam Methane Reforming technology at Yara's ammonia plant in Karratha, which has a current annual production capacity of 0.8 million tonnes.

Therefore, Yara will substitute the consumption of natural gas and purchase green energy to Yuri on-site. The hydrogen plant will be owned and operated by ENGIE and Mitsui. All hydrogen will be sold under a 20-year offtake agreement between Yuri and Yara, at an undisclosed Leverage Cost of Hydrogen (LCOH). While at this point there is no evidence that Yara will decrease operating costs with this feedstock replacement, decreasing the carbon footprint of ammonia sold could help Yara to attract new customers and potentially increase product prices, due to the increasing appetite of lower-carbon products in several markets, such as the EU, Asia and the USA.

In the long term, the production and operational experience gained by Yuri with this project could help Yara to completely decarbonise its ammonia production, while purchasing green hydrogen at more competitive costs. Additional competitive advantages of the project, compared with other green hydrogen projects worldwide, are the location, the excellent solar resource, and the available logistic routes to large customers.

The EPC contract for this project was awarded to Technip Energies, a French engineering and construction company, and Monford Group, an Australian construction company, specialising in the infrastructure, resources, and energy sectors. The hydrolyser will be provided by the Chinese company PERIC, an experienced provider of both alkaline and PEM hydrogen generators.

Enabling market conditions and de-risking investment

The green hydrogen market is in an early stage of development; however, diverse green hydrogen production projects are currently under way. Like Yuri, several final investment decisions have been made in the past year, and many new players are entering or exploring the space, including energy majors, infrastructure multinationals and companies across different sectors (automakers, oil, and gas companies, among others). Due to the hydrogen industry's stage of development, market risks are particularly relevant, offtake risk being one of the most predominant, due to uncertain technology costs, hydrogen production costs and market prices.

To mitigate existing market risk, local and national governments are providing grants and concessional financing to create more favourable market conditions for pilot projects. In the long term, pilot projects would decrease overall risk perception, becoming a proof-of-concept of innovative technologies and equipment, and validating economic and financial feasibility of business models.

Additionally, long-term offtake agreements are needed to mitigate the risk of not having an established spot market for green hydrogen. In this sense, the role of early adopters is key. Companies currently utilising hydrogen as by-products and with decarbonisation goals are taking first steps to partially replace the consumption of carbon-intensive hydrogen with its zero-carbon alternative.

Technology and construction risks are also critical for project demonstrations. The final CAPEX will be paramount to determine first LCOH values for the pilot project, and therefore deviations from original budgets could affect the long-term viability of the hydrogen hub and its technology. Technology selection is also key, as other early-stage technologies which are currently under development or demonstration could generate generation cost breakthroughs, making current investments obsolete. In this sense, the selection of experienced technologists and engineering and construction companies (Technip Energies and Monford Group) is key. Additionally, a solid partnership with an infrastructure global player such as Mitsui to operate the assets could decrease this risk in the medium and long term.

Country risks such as currency, availability of shipping infrastructure, and access to abundant, low-cost renewable energy resources are also relevant characteristics for developers when deciding project locations. Australia has been proven to be in one of the most wanted locations for developers, and one of the countries with most potential for low-cost, green hydrogen generation, according to the International Energy Agency (IEA).

Financing

The total investment of the Yuri project is USD 57.1 million (AUD 87.1 million). The project has not structured a financing scheme to date, and will be funded by Engie and Mitsui's equity and a USD 30.9 million (AUD 47.5 million) grant approved through ARENA's Renewable Hydrogen Deployment Funding Round. Additionally, the project has also received an AUD 2 million funding from the Renewable Hydrogen Fund as part of the Western Australian Government's Renewable Hydrogen Strategy.

The Australian Government had also supported the Yuri project in its early-stage development process. In 2019, ARENA supported Yara with an AUD ~1 million grant to investigate the feasibility of a renewable hydrogen and ammonia facility in the Pilbara. The positive outcomes of the feasibility studies conducted with ARENA's funding made possible the financial structure of the project.

Yuri SPV, an ENGIE's subsidiary created to develop the project, is the recipient of the equity and grant funding. Mitsui & Co. Ltd has agreed to acquire a 28% stake in the Yuri subsidiary, subject to satisfaction of certain conditions under its investment agreement.

Case Study 5 – ACWA Uzbekistan Hydrogen Project Phases 1 & 2

Key indicators

Table A B.5. ACWA Uzbekistan Hydrogen Project Phases 1 & 2 overview

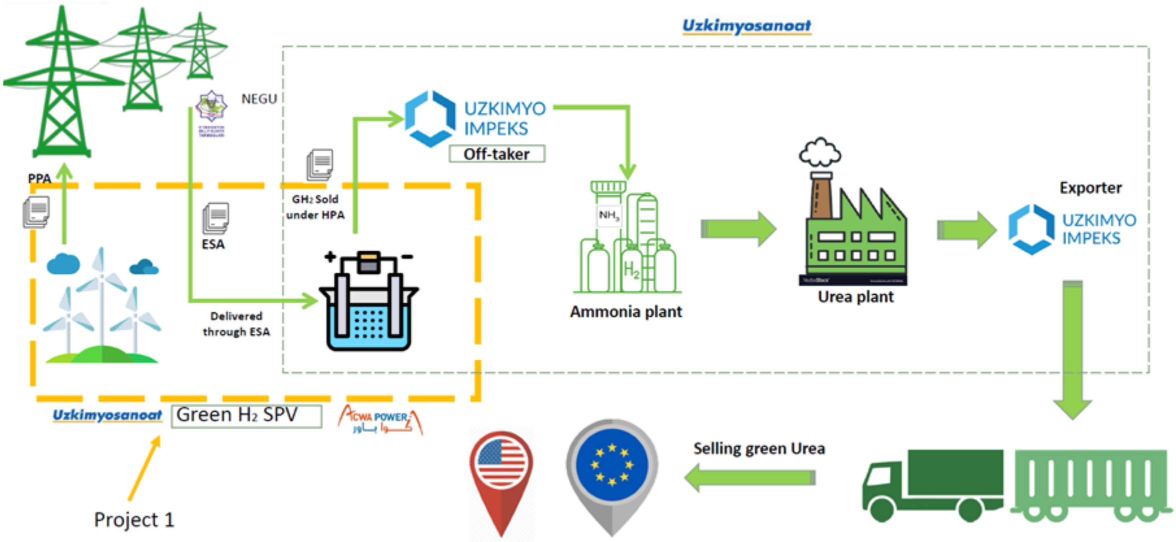
Indicator	Company/Project
Value Chain step/Application	Green hydrogen production through electrolysis Green ammonia production (in Phase 2)
Country	Uzbekistan
Status	Feasibility studies
Production route & type of renewable	Dedicated renewables (onshore wind) Electrolysis Green Ammonia and urea production (in Phase 2)
Key project metrics (RE capacity/Electrolyser capacity/Ammonia Production etc.)	Phase 1: Renewable power capacity: 52 MW Renewable power production: 175 GWh/y Electrolyser capacity: 20 MW
Hydrogen production (kt/y)	Phase 1: 3 kton/year (green hydrogen) Phase 2: 500 kpta (green ammonia)
Start-up date	Phase 1: Hydrogen power plant: Dec-2024 Wind power plant: May-2025
Amount of investment (USD million)	Phase 1: USD 85-100 million (estimated) Phase 2: USD 3.5-4.0 billion (estimated)

Basic description

ACWA Power is developing a zero-carbon hydrogen production project, to be used as an energy vector for ammonia production at the existing ammonia plant owned by Uzkimyoimpeks, an affiliate company of Uzkimyosanoat (UKS). Both the hydrogen production plant, which include a 20-MW electrolyser, and the ammonia production facility are located at CHIRCHIQ city, 45 km from Tashkent, in Uzbekistan. The project's main objective is to decarbonise ammonia production by substituting natural gas with locally sourced zero-carbon hydrogen.

The first phase has an estimated total investment of between USD 85-100 million. The electrolysis plant will be powered by a 52-MW wind energy power plant, located near existing BASH wind farm in the region of Bukhara, about 450 km away from the ammonia project. The wind power plant will be connected to the national grid and supplying power through a power purchase agreement (PPA). The electrolysis plant is expected to start commercial operations in December 2024, while the wind power plant will enter operations in November 2025. Phase 2 joint development agreement (JDA) is expected to be signed in November 2023.

Figure A B.6. Uzbekistan Project production process and end uses



Source: ACWA Power

This project will allow UKS to improve energy efficiency and decarbonise its ammonia production, while helping Uzbekistan to reduce energy security stress. Additionally, it will sustain and increase the country's presence in the international fertilisers market, while adding new revenue streams by exporting renewable urea to attractive markets.

Project rationale

This project will be one of several pioneering projects to deliver renewable hydrogen in Central Asia. Due to its relatively small size, the first phase of the project is being considered as a proof-of-concept plant for future development. With Phase 1 project, ACWA Power has the strategic objective to position Uzbekistan as a market complying with new carbon policies (CBAM).

Additionally, the first phase of the project will enable ACWA Power to start working on obtaining CMS 70 certification by TUV to export to EU market, while at the same time attracting additional hydrogen offtakers for Phase 2 of the project. Experience gained during the first phase of the project will also give ACWA Power and UKS the chance to reduce construction and implementation risks, as well as operational risks for next phases of the project.

One of the main advantages of the project is that it is being developed in association with one of the main ammonia producers in the country, which has enabled the lowering of market entry barriers for green hydrogen products, mainly low carbon fertilisers. Currently, one of the challenges faced by the low-carbon hydrogen market is to create demand from early adopters of the technology.

ACWA Power's long-term strategy is to keep building "blueprint projects" to be replicated in several other locations around the globe where the company has operations and new projects. ACWA Power is currently developing ultra-large-scale projects in Saudi Arabia (which is already under construction), and South Africa.

Lastly, with this project, ACWA Power will solidify its presence in Uzbekistan, where it has invested USD 7.5 billion since 2019, in six wind power plants (2.6 GW installed capacity), three PV plants (1.4GW), a combined-cycle natural gas plant (1.5GW) and three battery energy storage systems (BESS), totalling 2 475 MWh of storage.

Governance

ACWA Power is a Saudi Arabian private company listed in the Riadh Stock Exchange. ACWA Power is a developer, investor and operator of power generation and desalinated water plants with 77 assets in operation (USD 82.8 billion) in 12 countries. Saudi Arabia's sovereign wealth fund, the Public Investment Fund, is the biggest shareholder in ACWA Power, with a 44 per cent stake. It also has seven other stakeholders, including the Saudi Public Pension Agency.

ACWA Power has a pipeline of zero-carbon hydrogen and ammonia projects in different stages of development in Asia and Africa, including a utility-scale plant at NEOM, Saudi Arabia, which is under construction.

Uzkimyoimpeks LLC, a company owned by UKS, is a limited liability company dedicated to importing and mainly exporting chemical products from Uzbekistan to foreign markets. This company has been an important driver to expand the export potential of the country, as well as to implement the national Chemical Industry Development Program.

This project will be structured through a special purpose vehicle (SPV), the "ACWA POWER -UKS GH2 LLC", already registered and established in December 2022. This SPV is 80% owned by ACWA Power and 20% by UKS. The SPV will wholly own the wind power plant and the electrolysis facility.

Business model

ACWA Power and UKS will produce renewable hydrogen through an electrolysis facility co-located within the existing ammonia plant. The SPV has structured a 15-year hydrogen purchased agreement (HPA).

The electricity needed for the hydrogen production process will be generated through a 52-MW expansion of Bash wind project, already under operations and owned by ACWA Power. The project will be generating 175 GWh annually and injected to the grid. The electricity supply is structured through a 25-year Interface Power Purchase Agreement (PPA) with National Power Grid of Uzbekistan (NEGU), and 100% of electricity will be transmitted through NEGU's grid and injected at project site. For water desalination, due to low water consumption (4.4. cubic meters per hour), the project will be sourced from the pre-existing industrial complex that is currently drawing water from the canal (Phase 1).

Uzkimyoimpeks LLC will produce ammonia, which then will be transformed into low-carbon premium urea at the existing plant. This final product is prepared and shipped to export markets, where there is appetite for low- and zero-carbon chemical products such as Europe.

Enabling market conditions and de-risking investment

While the renewable hydrogen and derivatives markets is in its early stages of development, the first phase of the project shows a solid offtake structure through a 15-year purchase agreement with Uzkimyoimpeks LLC, which is located near the hydrogen production facility. An additional factor contributing to lowering offtake risk is that UKS has economic interest in both the project and the offtaker, which seems to lower any risk event such as breach of contract or early termination.

Electricity provision risk is mitigated through a long-term PPA. However, as the wind power plant will need the national electricity grid to evacuate and carry the electricity to the hydrogen production site, the electricity transmission capacity could be impacted.

For electrolyser, ACWA Power deployed alkaline water electrolysis, a technology selected exclusively based on comprehensive competitiveness criteria throughout the entire project's lifespan. The technology risk is mitigated by testing technology performance through rigorous in-house due diligence, comparative analysis and customer return of experience.

Uzbekistan is well-positioned as a supplier in the ammonium nitrates market to Europe, being the leading country in Central Asia in production volume of 1.7 Mtpa nitrogen-based fertiliser. This market presence gives this project a market advantage against other projects. Furthermore, this project will be one of the first green premium ammonia producers in 2024, with the significant advantage to be first mover in the European Market.

Country risk is also being partially mitigated by the participation of a state-owned company in the project structure. The project is aligned with the country's long-term development goals, such as increasing exports which may be positive for country risk mitigation in the future.

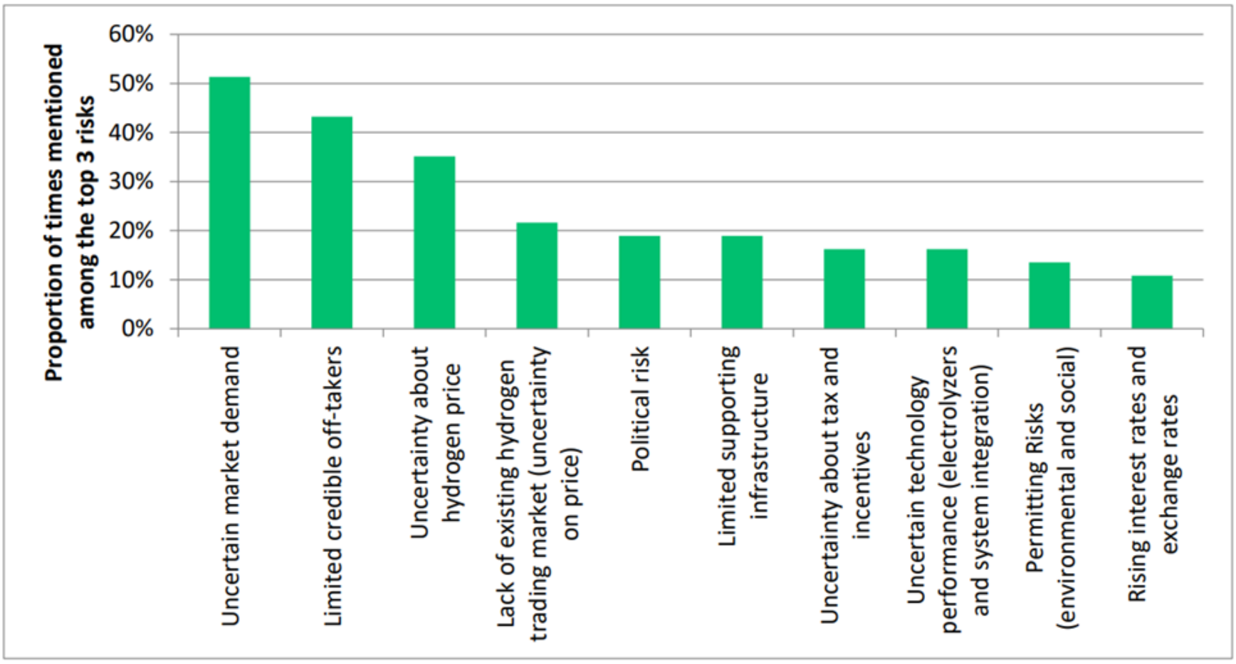
Financing

The Phase 1 project's financing structure will encompass both debt and equity components. In terms of financing conditions, the debt tranche is structured as a non-recourse/limited recourse facility with interest rates aligned with SWAP rates plus applicable margins, as is customary within the Uzbekistan financial landscape. This approach ensures a robust and balanced financial foundation for the project's successful implementation. The project also benefitted from financing from development finance institutions such as the EBRD.

Annex C. Survey Result

Section 1 – Key risk factors for green hydrogen projects

Figure A C.1. Key risks that, if mitigated, would enable low-carbon hydrogen projects to secure financing



Section 2 – Risk factors per country credit rating

The variation in the magnitude of each risk factor is contingent upon the country's specific risk profile. For instance, in the case of Germany, the offtaker risk holds notably more significance compared to the level in India and Egypt, even though the other contributing factors demonstrate moderate similarity. Notably, political risk has risen considerably in India and Egypt, accompanied by a correlated increase in regulatory concerns. Additionally, the state of enabling infrastructure and the level of technology diffusion within each country's context play a role in shaping the perception of technology risk.

Table A C.1. Perceived risk level in different country credit rating contexts

Risk category	Risk Level – country A	Risk Level – country B	Risk Level – country C
Political Risk	1	4	5
Macroeconomic Risk	2	3	5
Regulatory Risk	3	4	4
Supply Risk	3	3	4
Operation Risk	3	3	4
Technology Risk	2	3	3
Offtake Risk	5	5	5

Section 3 – Risk premium per different country credit rating

Figure A C.2. Risk premium for country credit rating AAA country

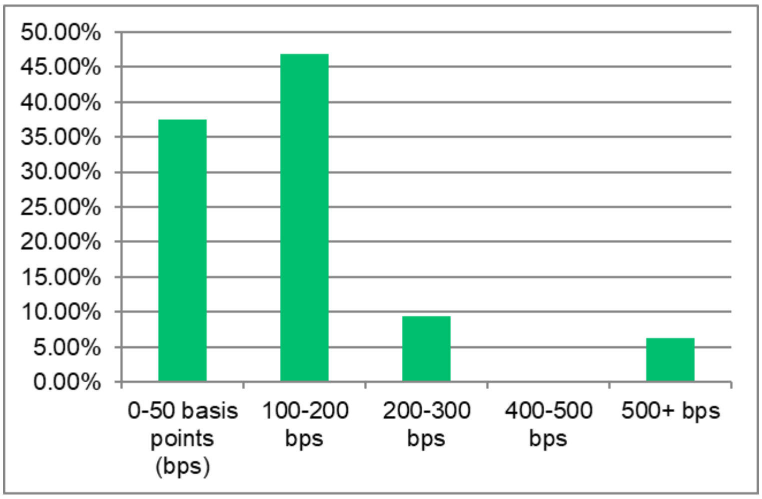


Figure A C.3. Risk premium for country credit rating A country

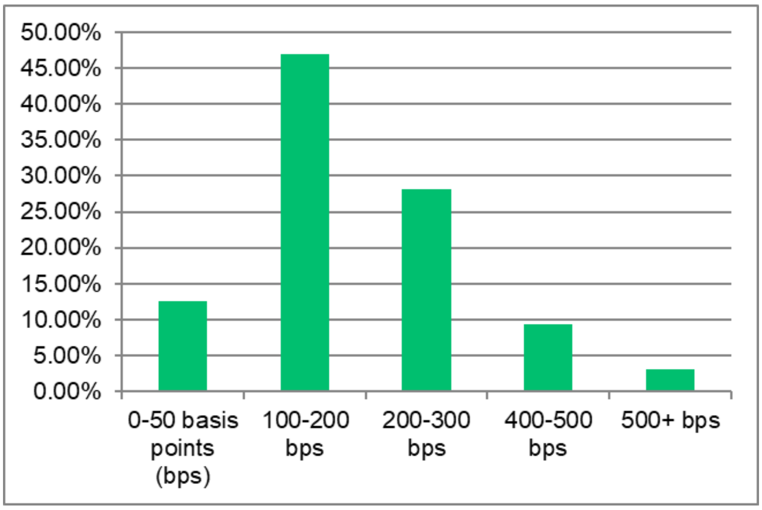


Figure A C.4. Risk premium for country credit rating BBB- country

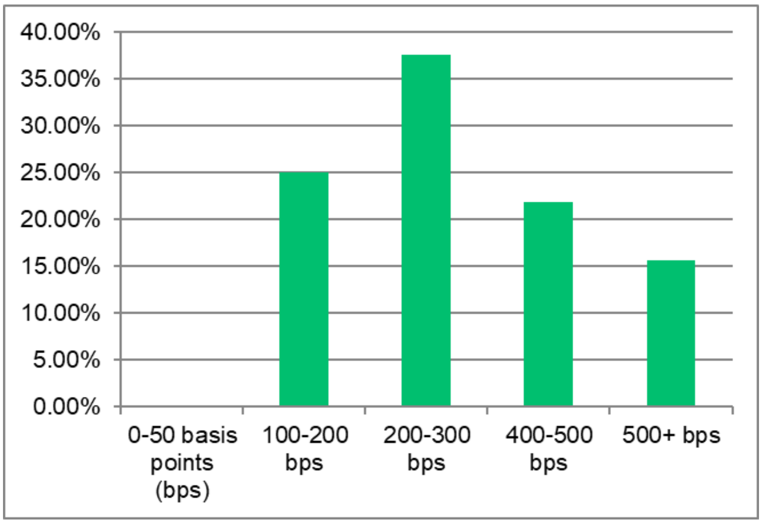
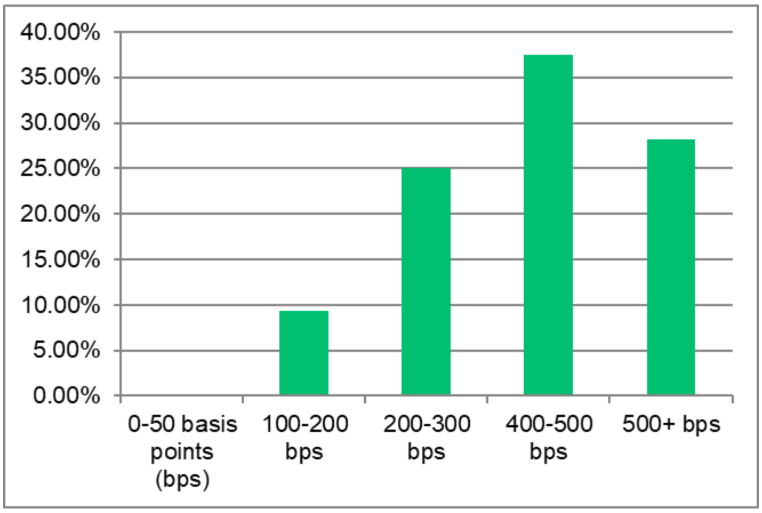


Figure A C.5. Risk premium for country credit rating B country



Section 4 – Respondent's profile

Figure A C.6. Experience in clean hydrogen

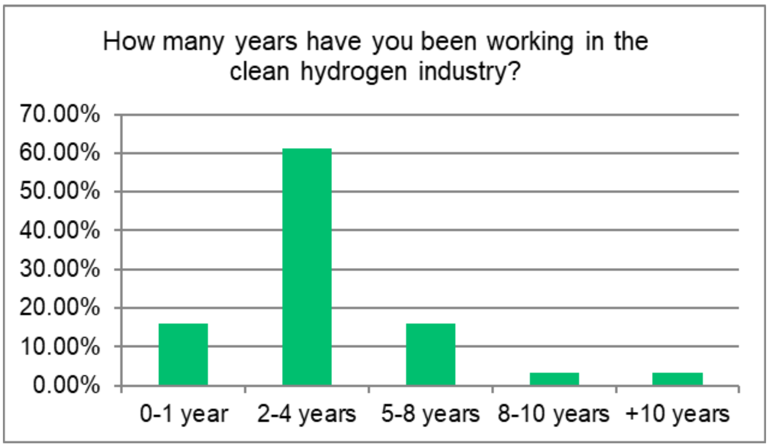


Figure A C.7. Regional focus for clean hydrogen projects

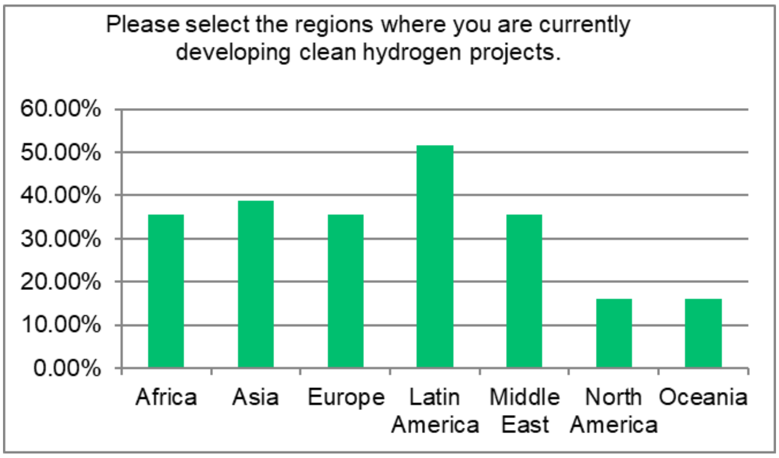


Figure A C.3. Clean hydrogen transaction experience

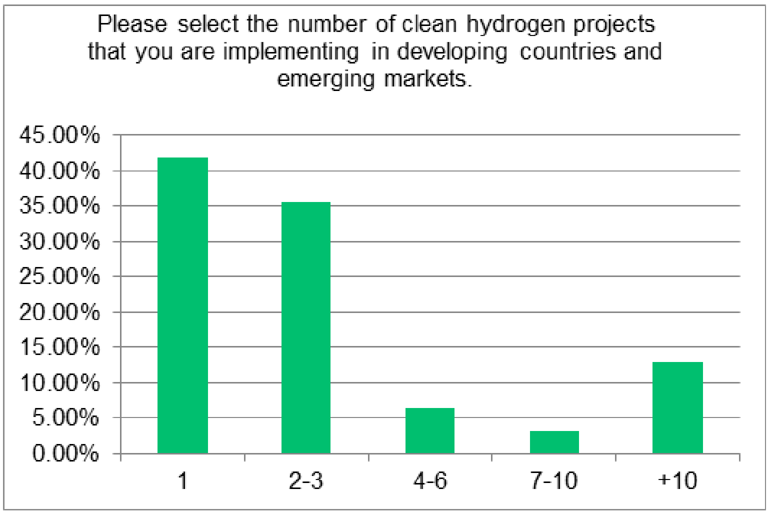
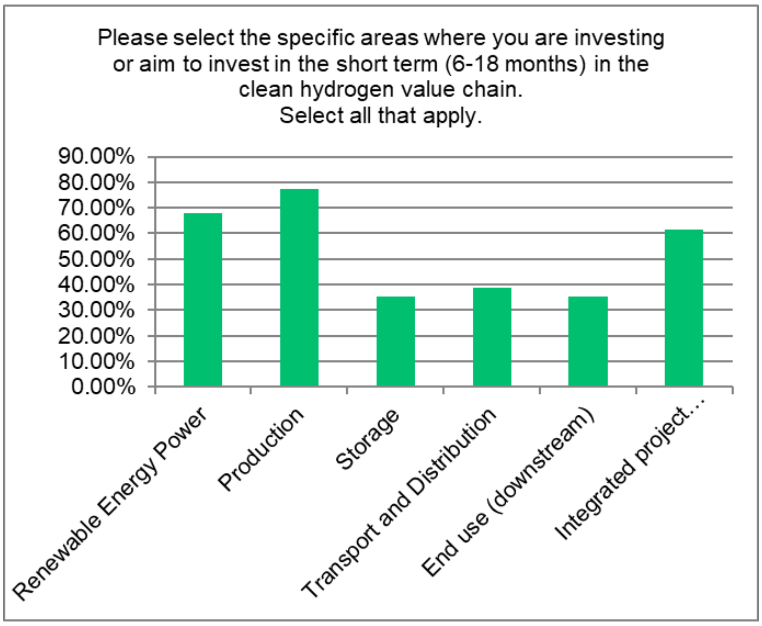


Figure A C.9. Investment focus in the clean hydrogen value chain



Annex D. Survey

PERCEIVED AND ACTUAL RISKS IN THE CLEAN HYDROGEN INDUSTRY

SECTION 1:
Risks affecting clean hydrogen financing
(General Market Perception)

1. Rate each of the following risks affecting the availability of finance and preventing clean hydrogen projects from achieving Final Investment Decision

Rate from 1 to 5, whereby 1 = is a minor risk and 5 = is a critical risk

Rising interest rates and exchange rates	1 minor
Country credit rating	1 minor
Political risk (Expropriation, Breach of Contracts, War, Currency Inconvertibility and Transfer Restriction)	1 minor
Size of ticket (high initial investment required)	1 minor
Long tenor of return	1 minor
Engineering Procurement and Construction (EPC) - Cost and time overrun	1 minor
Lack of guarantee from EPC company	
Permitting Risks (environmental and social)	1 minor
Land availability	
Uncertainty about hydrogen price	1 minor
Lack of clean hydrogen definition	1 minor
Uncertainty about taxes and incentives	1 minor
Uncertain market demand	1 minor
High cost of renewables	1 minor
Limited credible off-takers	1 minor
Uncertain technology performance (electrolyzers and system integration)	1 minor
Limited supporting infrastructure	1 minor
Lack of existing hydrogen trading market (uncertainty on price)	1 minor
Lack of trained/skilled local workers and technicians	1 minor

2. Select the top three key risks that, if mitigated, would enable clean hydrogen to secure financing on a non-recourse or limited-recourse project financing

Select only 3 answers.

Rising interest rates and exchange rates	☐
Country credit rating	☐
Political risk (Expropriation, Breach of Contracts, War, Currency Inconvertibility and Transfer Restriction)	☐
Size of ticket (high initial investment required)	☐
Long tenor of return	☐
Engineering Procurement and Construction (EPC) - Cost and time overrun	☐
Lack of guarantee from EPC company	☐
Permitting Risks (environmental and social)	☐
Land availability	☐
Uncertainty about hydrogen price	☐
Lack of clean hydrogen definition	☐
Uncertainty about taxes and incentives	☐
Uncertain market demand	☐
High cost of renewables	☐
Limited credible off-takers	☐
Uncertain technology performance (electrolyzers and system integration)	☐
Limited supporting infrastructure	☐
Lack of existing hydrogen trading market (uncertainty on price)	☐
Lack of trained/skilled local workers and technicians	☐

SECTION 2:
Clean Hydrogen Financing Risks
Project-level Perception

For the next series of questions, please rate the likelihood of these risks impacting clean hydrogen projects and their effect on the cost of finance.

Political and Macroeconomic Risks:
Risk associated with political events that adversely impact the value of investments (e.g. war, civil disturbance, currency inconvertibility, breach of contract, expropriation, non-honoring of obligations).

Regulatory Risks:
Risk associated with changes in legal or regulatory policies with adverse impacts on project design, construction or operation (e.g. incentive programs, tax regime, certification, permitting process, environmental regulation, etc.)

Supply Risk:
Risk associated with uncertainties around the availability, price of renewable energy, and duration of PPA (PPA contracts may not cover the entire lifespan of clean hydrogen project).

Operation Risk:
Ensure Engineering Procurement and Construction (EPC) and Operations and Maintenance (O&M) contractor's financial solvency and credibility in delivering similar projects or maintenance reserves, and manufacturer warranties.

Technology Risk:
Risk associated with the underperformance of nascent technology or with the available supporting infrastructure or technical capacity for their construction and/or operation.

Offtake Risk:
Risk associated with the limited demand, absence of buyers and the inexistence of wholesale markets for clean hydrogen.

3. You are investing in a clean hydrogen project - 5 gigawatts (GW) wind and solar energy capacity vertically integrated with 3 GW electrolyzer capacity, capable of producing around 300 kilotonnes of green hydrogen in **Germany**:
Please rate the likelihood of these risks to happen and their severity on the cost of finance.

1 =Low impact, 5 = High impact

Political Risk	1 Low impac
Macroeconomic Risk	1 Low impac
Regulatory Risk	1 Low impac
Supply Risk	1 Low impac
Operation Risk	1 Low impac
Technology Risk	1 Low impac
Offtake Risk	1 Low impac

4. You are investing in a clean hydrogen project - 5 gigawatts (GW) wind and solar energy capacity vertically integrated with 3 GW electrolyzer capacity, capable of producing around 300 kilotonnes of green hydrogen in **India**:
Please rate the likelihood of these risks to happen and their severity on the cost of finance

1 =Low impact, 5 = High impact

Political Risk	1 Low impac
Macroeconomic Risk	1 Low impac
Regulatory Risk	1 Low impac
Supply Risk	1 Low impac
Operation Risk	1 Low impac
Technology Risk	1 Low impac
Offtake Risk	1 Low impac

5. You are investing in a clean hydrogen project - 5 gigawatts (GW) wind and solar energy capacity vertically integrated with 3 GW electrolyzer capacity, capable of producing around 300 kilotonnes of green hydrogen in **Egypt**:
Please rate the likelihood of these risks to happen and their severity on the cost of finance

1 =Low impact, 5 = High impact

Political Risk	1 Low impac
Macroeconomic Risk	1 Low impac
Regulatory Risk	1 Low impac
Supply Risk	1 Low impac
Operation Risk	1 Low impac
Technology Risk	1 Low impac
Offtake Risk	1 Low impac

6. When you consider investments for clean hydrogen projects, please estimate a range of the premium that would apply to the cost of capital in countries with AAA credit ratings:

Select 1 answer

◯ 0-50 (bps) ◯ 100-200 bps ◯ 200-300 bps ◯ 400-500 bps ◯ 500+ bps

7. When you consider investments for clean hydrogen projects, please estimate a range of the premium that would apply to the cost of capital in countries with A credit ratings:

Select 1 answer

◯ 0-50 (bps) ◯ 100-200 bps ◯ 200-300 bps ◯ 400-500 bps ◯ 500+ bps

8. When you consider investments for clean hydrogen projects, please estimate a range of the premium that would apply to the cost of capital in countries with BBB- credit ratings:

Select 1 answer

◯ 0-50 (bps) ◯ 100-200 bps ◯ 200-300 bps ◯ 400-500 bps ◯ 500+ bps

9. When you consider investments for clean hydrogen projects, please estimate a range of the premium that would apply to the cost of capital in countries with B credit ratings:

Select 1 answer

◯ 0-50 (bps) ◯ 100-200 bps ◯ 200-300 bps ◯ 400-500 bps ◯ 500+ bps

10. How many years have you been working in the clean hydrogen industry?

Select 1 answer

◯ 0-1 year ◯ 2-4 years ◯ 5-8 years ◯ 8-10 years ◯ +10 years

11. Please select the regions where you are currently developing clean hydrogen projects.

Select all that apply

☐ Africa
☐ Asia
☐ Europe
☐ Latin America
☐ Middle East
☐ North America
☐ Oceania

12. Please select the number of clean hydrogen projects that you are implementing in developing countries and emerging markets.

◯ 1 ◯ 2-3 ◯ 4-6 ◯ 7-10 ◯ +10

13. Please select the specific areas where you are investing or aim to invest in the short term (6-18 months) in the clean hydrogen value chain.

Select all that apply

☐ Renewable Energy Power
☐ Production
☐ Storage
☐ Transport and Distribution
☐ End use (downstream)
☐ Integrated project structure (end to end)

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