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Sector Analysis – Ghana

Green hydrogen for the C&I sector

Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH

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Inhalt

Abbreviations/Acronyms

AC Alternating Current
AEL Alkaline electrolysis
AEM Anion exchange membrane
AHK German Chambers of Commerce Abroad
AHP African Hydrogen Partnership Trade Association
ASU Air Separation Unit
bar Metric unit of pressure
barg Absolute pressure and gauge pressure
BMWK German Federal Ministry of Economics and Climate Action
CAPEX Capital Expenditures
CH_3OH Methanol
CO Carbon monoxide
CO_2 Carbon dioxide
DAP Diammonium phosphate
DC Direct Current
EFTA European Free Trade Association (Iceland, Liechtenstein, Norway, Switzerland)
EIB European Investment Bank
ESMAP Energy Sector Management Assistance Program
EU European Union
EU ETS European Union Emissions Trading System
FIT Feed-in-Tariff
GHG Greenhouse Gases
GIPC Ghana Investment Promotion Centre
GIS Geographic information system
GIZ Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH
GW Gigawatt
H_2 Hydrogen
H2-PDP Project Development Programme for Green Hydrogen Projects
H2Uppp International Hydrogen Ramp-up Programme
IPP Independent Power Producer
IPSMP Integrated Power System Master Plan
KfW Kreditanstalt für Wiederaufbau)
kWh Kilowatt hour
LCoA Levelized Cost of Ammonia
LCoH Levelized Cost of Hydrogen
LOHC Liquid organic hydrogen carriers
LPG Liquefied petroleum gas
LPGMC Liquefied petroleum gas marketing companies
MMBtu Million British thermal units
Mt Million tons
MTHP Maximum Technical H2 Potential
MW Mega Watt
N_2 Nitrogen
NH_3 Ammonia
NPA National Petroleum Authority
OPEX Operational expenditures
PDP Project Development Programme
PEM Proton Exchange Membrane
PPA Power Purchase Agreement
PPP Public-Private Partnership
PtX Power-to-X
PURC Public Utilities Regulatory Commission
PV Photovoltaics
REMP Renewable Energy Master Plan
RES Renewable energy sources
SEFA Sustainable Energy Fund for Africa
SLT Special load tariff
SME Small and medium-sized enterprises
SNEP Strategic National Energy Plan
SOEC Solid Oxide Electrolysis Cell
TIC Total installed cost
tons Unit of weight, equivalent to 2000 pounds (0.907 metric ton)
tpa Tons per annum
tpd Tons per day
UAE United Arab Emirates
VAT Value Added Tax
WACOG Weighted Average Cost of Gas
WAGP West African Gas Pipeline
WASCAL West African Science Service Centre on Climate Change and Adapted Land Use

List of Figures

List of Tables

Currency Units

EUR Euro
USD United States Dollar
GHS Ghanaian Cedi

EUR 1 = GHS 13.0117 (Central Bank of Ghana, 2022)
Conversion 8/11/2022: EUR 1 = GHS 13.0117 (Central Bank of Ghana, 2022)

The German Energy Solutions Initiative

Energy solutions – made in Germany

Launched in 2002 by the German Federal Ministry for Economic Affairs and Climate Action (BMWK), the German Energy Solutions Initiative is primarily aimed at small and medium-sized enterprises (SMEs) and supports suppliers of climate-friendly energy solutions in finding new markets abroad. The initiative is active in around 140 countries and aims to disseminate German and European energy technologies more extensively across the globe.

The initiative includes the Project Development Programme (PDP) which is carried out by the Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH and promotes climate-friendly energy solutions in selected emerging and developing countries in sub-Saharan Africa, South and Southeast Asia and the Middle East. Since 2007, the PDP has been supporting the energy transition in its cooperation countries by developing concrete renewable energy and energy efficiency projects. The focus was recently expanded to include green hydrogen projects through the Project Development Programme for Green Hydrogen Projects (H2-PDP), as the German Energy Solutions Initiative is increasingly promoting green hydrogen as a crucial energy carrier for achieving a climate-neutral economy.

Project Development Programme for Green Hydrogen Projects (H2-PDP)

Green hydrogen (H2) is needed to reduce the industry carbon footprint. At present, however, countries such as Ghana, Kenya, Jordan and Vietnam primarily use 'grey hydrogen' derived from fossil fuels. The sustainability of a product and its carbon footprint will play a greater role in determining its competitiveness in future, so it is worthwhile for companies to switch from grey to green hydrogen at an early stage. This solution is hardly cost-effective at the moment, but it is expected to become more competitive with the ramping up of this new market. Moreover, German and European technology suppliers and project developers are not currently particularly active in the selected countries. The market is still being established.

The objective of the project is to enable Ghana, Kenya, Jordan and Vietnam to progressively produce green hydrogen at competitive prices. In order to achieve this, the project identifies local companies that are able to switch from producing or consuming grey hydrogen to producing green hydrogen within a short period. It advises them on plant design, financial models and how they can cover the funding gap when compared with grey hydrogen. With a view to accelerating the transition to green hydrogen, the project facilitates access to funding instruments such as the public-private partnership (PPP) under the International Hydrogen Ramp-up Programme (H2Uppp), international funds and to suitable technology partners from Germany and elsewhere.

The project analyses industry segments that would be suitable for pilot projects and facilitates contact with German/European companies. Additional training sessions raise awareness among local hydrogen consumers, producers and project developers with the involvement of German solution providers. Local companies gain access to suppliers, who are made aware of specific opportunities. Due to their pioneering role, they may profit from financial support measures for pilot projects.

The project is thus supporting the energy transition in the partner countries. At the same time, German and European companies can benefit from this approach as it supports the better understanding of markets and the study project opportunities whilst strategic contacts are also acquired in developing countries and emerging economies.

The series of sector analyses available explore the green hydrogen market potential of Ghana, Kenya, Jordan, and Vietnam and can be downloaded from GIZ's H2-PDP project website: Changing from grey to green hydrogen production – giz.de

Executive Summary

Why start a hydrogen business in Ghana?

The objective of this sector analysis is to outline the perspective of German and European business on the hydrogen (H2) market in Ghana and provide simplified cost estimations and orientations for starting a new business in the country. This report is intended for companies looking to partner with local companies in Ghana that use hydrogen as the main feedstock for their industrial processes. The country offers many opportunities for international investors such as a strategic location in proximity to primary transport routes, developed infrastructure, tax incentives and vast renewable resources.

Starting a business in Ghana has several benefits, including building new partnerships with Ghanaian companies and developing decarbonised solutions for the industry that can either be used locally or easily exported abroad due to the country's favourable location.

On the other hand, the current fossil fuel imports make the country's economy vulnerable to price fluctuations, and the government is motivated to support developers who will contribute to building Ghana's energy independence. Locally produced green hydrogen is an attractive alternative to reduce the country's current imports of fossil-based hydrogen and its derivatives. Additionally, technology costs are expected to decline since the market is in the early development stage.

Green hydrogen and ammonia opportunities

Green hydrogen and its derivatives offer multiple benefits such as decarbonisation, energy storage, renewable energy integration, energy security and economic opportunities. These technologies can play an essential role in the transition to a sustainable and low-carbon economy. The analysis explains in detail green hydrogen and green ammonia production processes, input product requirements and associated costs. In addition, a brief outlook is provided describing the supply and demand of hydrogen, ammonia and methanol by analysing the current industry sector in Ghana which uses grey hydrogen and the import and export balance for these three commodities.

Zusammenfassung

Warum sollte man ein Wasserstoffprojekt in Ghana starten?

Diese Sektoranalyse skizziert, welche Perspektiven der Wasserstoffmarkt in Ghana deutschen und europäischen Unternehmen bietet. Sie liefert vereinfachte Kostenschätzungen für die Herstellung von grünem Wasserstoff mit Hilfe von Photovoltaik (PV) und Orientierungshilfen für die Gründung eines Unternehmens in Ghana. Dieser Bericht wendet sich an deutsche und europäische Firmen mit Interesse an einer Partnerschaft mit ghanaischen Unternehmen, die Wasserstoff als Hauptrohstoff für ihre industriellen Prozesse nutzen. Ghana bietet internationalen Investor*innen gute Voraussetzungen wie zum Beispiel eine strategische, verkehrstechnisch günstige Lage, eine entwickelte Infrastruktur, steuerliche Anreize und umfangreiche erneuerbare Ressourcen.

Eine Projektgründung in Ghana ermöglicht den Aufbau von Partnerschaften zu lokalen Unternehmen und die Entwicklung kohlenstoffarmer Lösungen für die Industrie, welche entweder vor Ort genutzt oder aufgrund der günstigen Lage Ghanas problemlos ins Ausland exportiert werden können.

Ghanas Regierung ist motiviert, Entwickler*innen zu unterstützen, die zur Energieunabhängigkeit des Landes beitragen, denn die Importe fossiler Brennstoffe sind Preisschwankungen unterworfen und belasten die Wirtschaft. Lokal produzierter grüner Wasserstoff ist eine attraktive Alternative, um die Importe von grauem Wasserstoff und seinen chemischen Derivaten zu reduzieren. Künftig dürften zudem die Technologiekosten für grünen Wasserstoff sinken, da der noch junge Markt sich weiterentwickelt.

Chancen für grünen Wasserstoff und Ammoniak

Grüner Wasserstoff und seine chemischen Derivate bieten zahlreiche Vorteile, darunter die Dekarbonisierung von Prozessen und Produkten, Energiespeicherung, Integration erneuerbarer Energien, Energiesicherheit und neue wirtschaftliche Chancen. Diese Technologien können eine wesentliche Rolle beim Übergang zu einer nachhaltigen und kohlenstoffarmen Wirtschaft spielen. Die Analyse erläutert im Detail die Verfahren zur Herstellung von grünem Wasserstoff und grünem Ammoniak, die Anforderungen an die Ausgangsprodukte und die damit verbundenen Kosten. Darüber hinaus bietet sie für Wasserstoff, Ammoniak und Methanol einen kurzen Ausblick auf Angebot und Nachfrage, indem sie den Industriesektor in Ghana analysiert, der aktuell grauen Wasserstoff verwendet. Zudem werden die Import- und Exportbilanz für die drei Rohstoffe analysiert.

Benefiting from Ghanaian solar energy sources to produce green hydrogen for industry

Ghana possesses abundant renewable energy resources, including solar, wind, hydro and biomass, which could be used to produce renewable hydrogen. A specific focus is placed on renewable hydrogen produced from solar resources, with cost details presented in the case studies. Interviews with local manufacturers in Ghana supplemented by informal discussions and a detailed sector analysis were conducted to gauge their potential interest in converting to producing their own green hydrogen. Business cases were developed based on the interviews and represent typical sector scenarios for replacing grey hydrogen with green hydrogen. The business cases focused on current grey hydrogen consumers, where hydrogen is either a production feedstock or an element in the current manufacturing process. The analysis estimated the system cost, sizing and cost of the electrolyser system and solar photovoltaics (PV) plant, as well as the levelized cost of hydrogen (LCoH) as per the local solar resource. Two business cases are presented for illustrative purposes, where green hydrogen is used for green ammonia and food production.

Ghana offers a diverse range of incentives to attract a foreign capital

Its strategic location in West Africa, extensive road and port infrastructure, mild weather and proximity to major shipping routes make Ghana an excellent place for hydrogen business development and transportation of its derivatives. In addition, Ghana provides dedicated incentives to help attract foreign capital. The Ghana Investment Promotion Centre (GIPC) Act and the Free Zone Act are the key legislative documents which create a transparent and favourable investment environment for external capital through multiple supporting frameworks: such as custom duty exemptions, a 10-year tax holiday for free zone developers, free transferability of dividends and profits, personal remittance for expatriate personnel and the ability of both foreign and local investors to own 100% of the shares.

Nutzung der ghanaischen Solarenergie zur Herstellung von grünem Wasserstoff für die Industrie

Ghana ist reich an erneuerbaren Energieressourcen, darunter Solar-, Wind- und Wasserkraft sowie Biomasse, die zur Herstellung von erneuerbarem Wasserstoff genutzt werden können. Ein Schwerpunkt liegt auf erneuerbarem Wasserstoff, der mithilfe von Solarenergie gewonnen wird. Die entsprechenden Kosten werden in den Fallstudien dargestellt. Interviews mit lokalen Hersteller*innen, informelle Gespräche und eine detaillierte Sektoranalyse geben Aufschluss über das Interesse an der Produktion von grünem Wasserstoff. Auf der Grundlage der Interviews wurden Geschäftsszenarien entwickelt. Sie stellen typische Branchenszenarien für den Ersatz von grauem durch grünen Wasserstoff dar. Die Szenarien konzentrierten sich auf die derzeitigen Verbraucher*innen von grauem Wasserstoff, bei denen Wasserstoff entweder ein Produktionsrohstoff oder ein Element im Herstellungsprozess ist. Die Analyse liefert eine Einschätzung der Systemkosten, der Kosten für das Elektrolyseursystem und die Photovoltaikanlage sowie die nivellierten Wasserstoffkosten (LCoH) in Abhängigkeit der lokalen Solarressourcen. Zwei Fallbeispiele machen die Nutzung von grünem Wasserstoff für die Herstellung von grünem Ammoniak und Lebensmitteln anschaulich.

Ghana bietet eine Vielzahl von Anreizen, um ausländisches Kapital anzuziehen

Die strategische Lage in Westafrika, die gute Straßen- und Hafeninfrastruktur, das milde Klima und die Nähe zu den wichtigsten Schifffahrtsrouten machen Ghana zu einem hervorragenden Standort für die Entwicklung von Wasserstoffgeschäften und den Transport der chemischen Derivate. Darüber hinaus bietet Ghana spezielle Anreize, um ausländisches Kapital anzulocken. Der Ghana Investment Promotion Centre (GIPC) Act und der Free Zone Act sind die wichtigsten Gesetzestexte, die ein transparentes und günstiges Investitionsumfeld für ausländisches Kapital schaffen. Sie sichern Rahmenbedingungen wie zum Beispiel die Befreiung von Zollgebühren, eine zehnjährige Steuerbefreiung für Entwickler*innen von Freizonen, die freie Übertragbarkeit von Dividenden und Gewinnen, persönliche Überweisungen für ausländische Mitarbeitende und die Möglichkeit für ausländische und einheimische Investor*innen, 100 Prozent der Anteile zu besitzen.

Linking climate policies with financial incentives

Ghana's energy and climate policies aim to promote the use of renewable energy sources and reduce greenhouse gas emissions. The country has set targets to increase the share of renewable energy in its energy mix and has adopted a National Climate Change Policy to guide its efforts to mitigate and adapt to climate change. Moreover, the Renewable Energy Master Plan (REMP), launched in 2019, aims to guide the development of Ghana's renewable energy sector and includes provisions for the development of hydrogen technologies.

There is no specific financing for hydrogen investments in Ghana, but the government encourages project developers, green hydrogen producers, public-private partnerships with local and international partners to implement strategically important pilot hydrogen demonstration projects. A list of official government agencies to contact for companies interested in prospective business opportunities in Ghana has been included in the report.

Verknüpfung von Klimapolitik und finanziellen Anreizen

Ghanas Energie- und Klimapolitik zielt darauf ab, die Nutzung erneuerbarer Energiequellen zu fördern und die Treibhausgasemissionen zu reduzieren. Das Land hat sich zum Ziel gesetzt, den Anteil der erneuerbaren Energien an seinem Energiemix zu erhöhen und will durch seine nationale Klimaschutzpolitik dazu beitragen, den Klimawandel einzudämmen und sich an die klimatischen Veränderungen anzupassen. Darüber hinaus steuert der 2019 eingeführte Masterplan für erneuerbare Energien (REMP) die Entwicklung Ghanas in diesem Bereich. Dieser Masterplan enthält auch Bestimmungen für die Entwicklung von Wasserstofftechnologien.

Es gibt keine speziellen Finanzmittel für Wasserstoffinvestitionen in Ghana, aber die Regierung ermutigt Projektentwickler*innen, Hersteller*innen von grünem Wasserstoff und öffentlich-private Partnerschaften mit lokalen und internationalen Partner*innen, strategisch wichtige Pilotprojekte zu grünem Wasserstoff durchzuführen. Der Bericht listet Regierungsstellen auf, an die sich Unternehmen wenden können, die an Geschäftsmöglichkeiten in Ghana interessiert sind.

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1 CURRENT SITUATION OVERVIEW

1. Current Situation Overview

Hydrogen is a promising energy carrier with the potential to play a significant role in Ghana's low-carbon transition. While the hydrogen sector in Ghana is still in its early stages of development, the country has taken steps to explore its potential as a clean energy source and to link it to its energy and climate policies. Ghana has abundant renewable energy resources, including solar, wind, hydro and biomass, which could be used to produce hydrogen through electrolysis.

Ghana's energy and climate policies aim to promote the use of renewable energy sources and reduce greenhouse gas emissions. The country has set targets to increase the share of renewable energy in its energy mix and has adopted a National Climate Change Policy to guide its efforts to mitigate and adapt to climate change. Moreover, the REMP, launched in 2019, aims to guide the development of Ghana's renewable energy sector and includes provisions for the development of hydrogen technologies. The plan recognises the potential of hydrogen as a clean energy source and highlights the need for research and development, infrastructure development and policy support to promote its use.

Overall, the hydrogen sector in Ghana is an area of growing interest and has the potential to contribute to the country's energy security, reduce its reliance on fossil fuels and help meet its climate change commitments. By using hydrogen and its derivatives, industries can reduce their greenhouse gas emissions and contribute to the decarbonisation of their operations. Additionally, the use of hydrogen can enhance energy security by reducing the dependence on imported fossil fuels and promoting the development of local renewable energy industries.

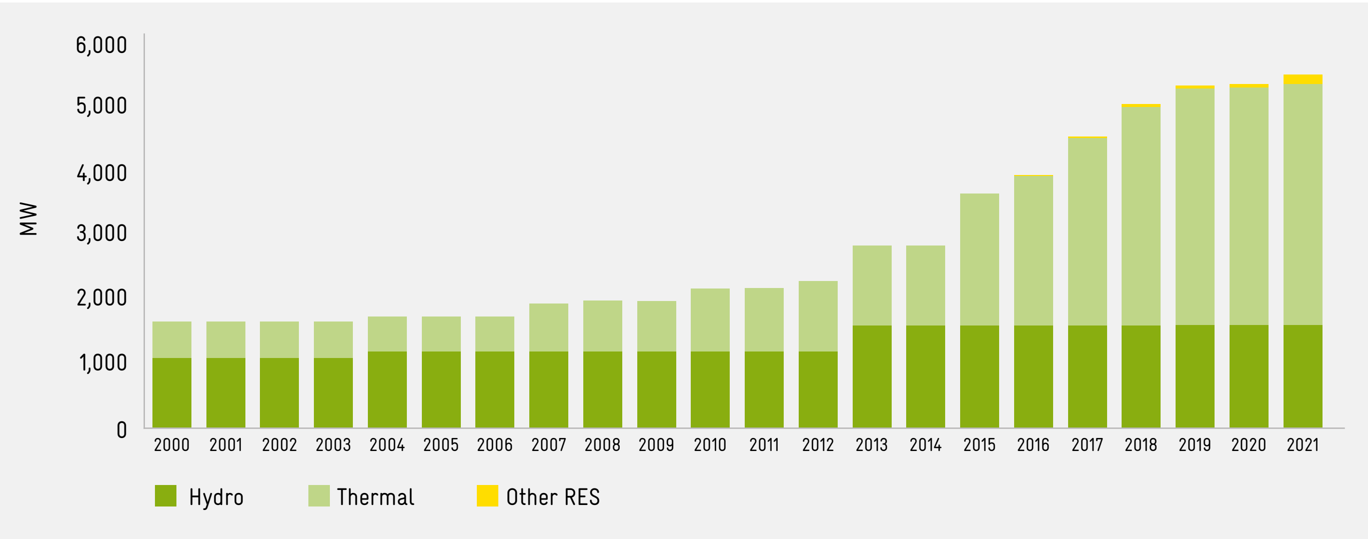
1.1 Assessment of the energy landscape

The energy sector in Ghana is currently dominated by thermal generation, with hydro accounting for around one third of production and other renewable energy sources (RES) producing less than 1% of the total. The country has been encouraging the implementation of renewables for nearly 30 years, putting in place several policy mechanisms. However, the system suffers from high costs and overcapacity issues, which have led to a sharp slowdown in new investments.

1.1.1 Electricity generation

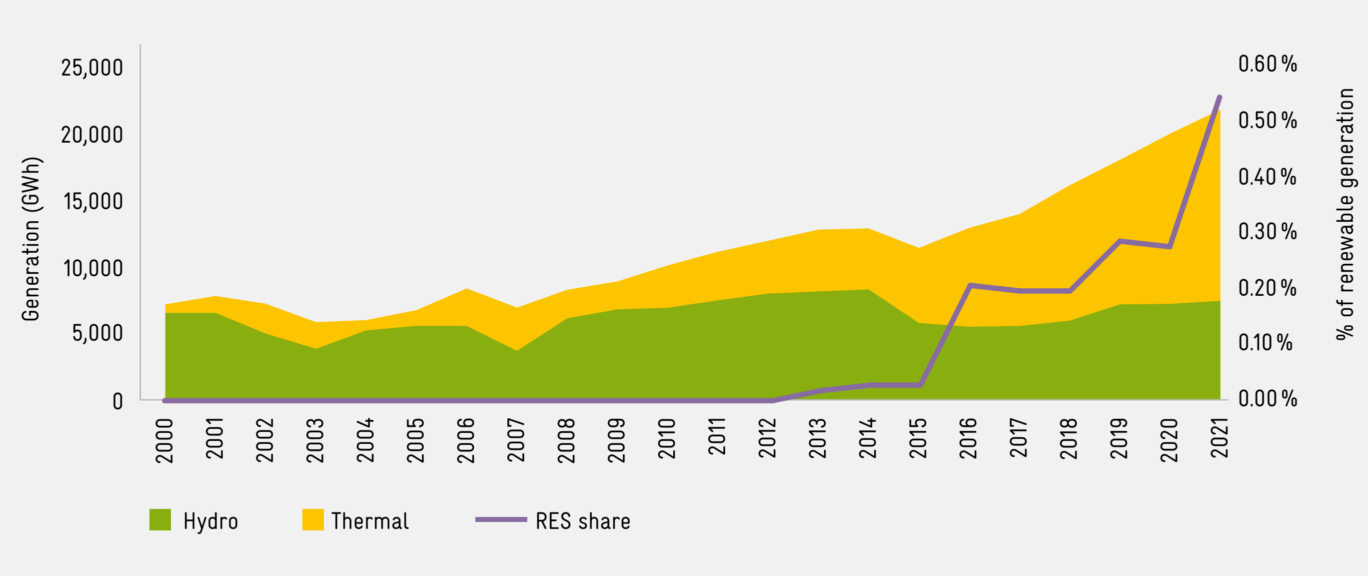
The total installed generation capacity has increased by 9.7% over the past 10 years, reaching 5,481 MW in 2021 (including distributed generation). Figure 1 shows the trend in the source of installed generation by technology over the last 20 years. Thermal power plants (fired using natural gas, light crude oil, heavy fuel oil and diesel) account for close to 70% of the total generation capacity. However, the installation of renewable energy (excluding hydro) is slowly increasing, from zero in 2015, to 144 MW in 2021. Renewable energy in Ghana comprises solar PV and biomass.

FIGURE 1. INSTALLED GENERATION CAPACITY



Source: Authors' own illustration, ENGIE Impact GmbH (2023), based on (Energy Commission, 2022)

FIGURE 2. ELECTRICITY GENERATION AND RENEWABLE SHARE TRENDS



Source: Authors' own illustration, ENGIE Impact GmbH (2023), based on (Energy Commission, 2022)

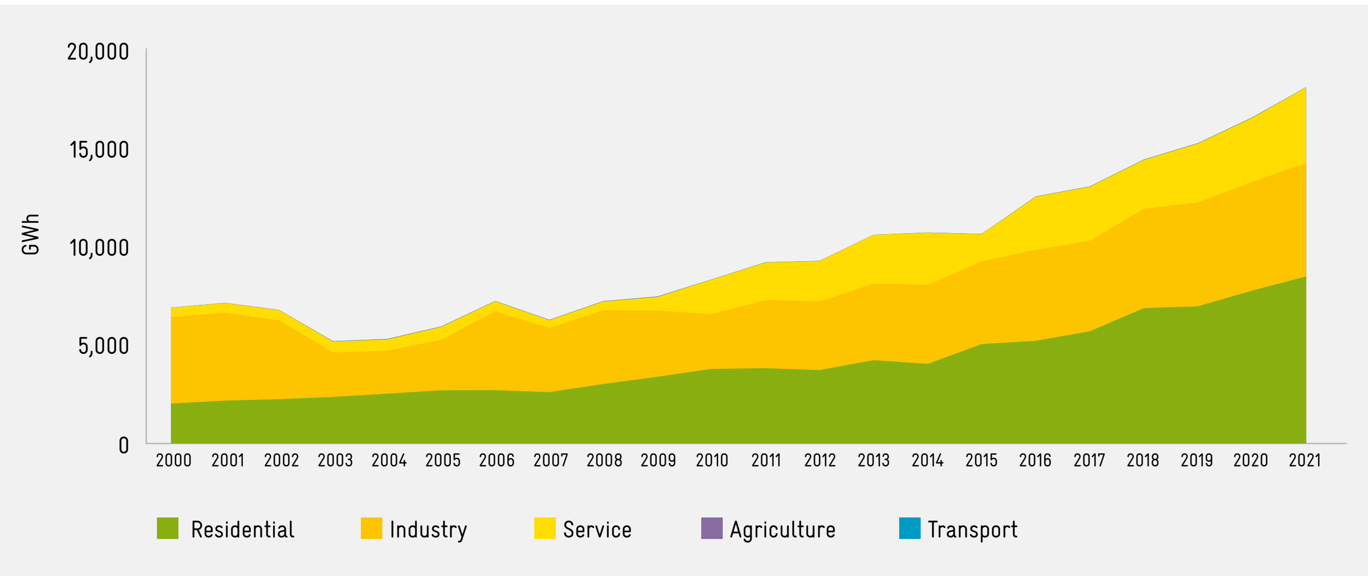
Analogous to the increasing trend in installed capacity, the energy produced by thermal power plants has steadily increased in recent years, reaching 65% in 2021, as shown in Figure 2. Hydropower production dropped from 92% of the total in 2000 to only one third of the total production in 2021. The share of other renewables than hydro in 2021 was 0.55%, almost twice that of the 0.28% in 2020.

Peak load in 2000 was 1,161 MW. Since then, the demand has been increasing year on year, reaching 3,246 MW in 2021. Ghana has experienced rapid growth in peak demand in recent years, as shown, with an annual growth of around 13% in 2018 and almost 10% in both 2019 and 2020, before slowing to 4.5% in 2021. Moreover, the Ghanaian power system faces a significant overcapacity issue: in 2021 installed capacity was 5.4 GW while peak demand was 3.2 GW, resulting in 2.2 GW of overcapacity. This overcapacity has resulted in high system costs, i.e. costs for unused power capacity and costs for quantities of natural gas (for example, from take-or-pay agreements) that are not needed (IRENA and GIZ, 2021).

1.1.2 Composition of electricity demand

Total electricity consumption in 2021 was 18,069 GWh, with demand increasing by 31% since 2016, as shown in Figure 3. Households represented almost half of the total demand in 2021, the industry and service sector consuming 32% and 21% of the total, respectively. Agriculture and transport play a marginal role in electricity consumption (Energy Commission, 2022).

FIGURE 3. ELECTRICITY CONSUMPTION BY SECTOR



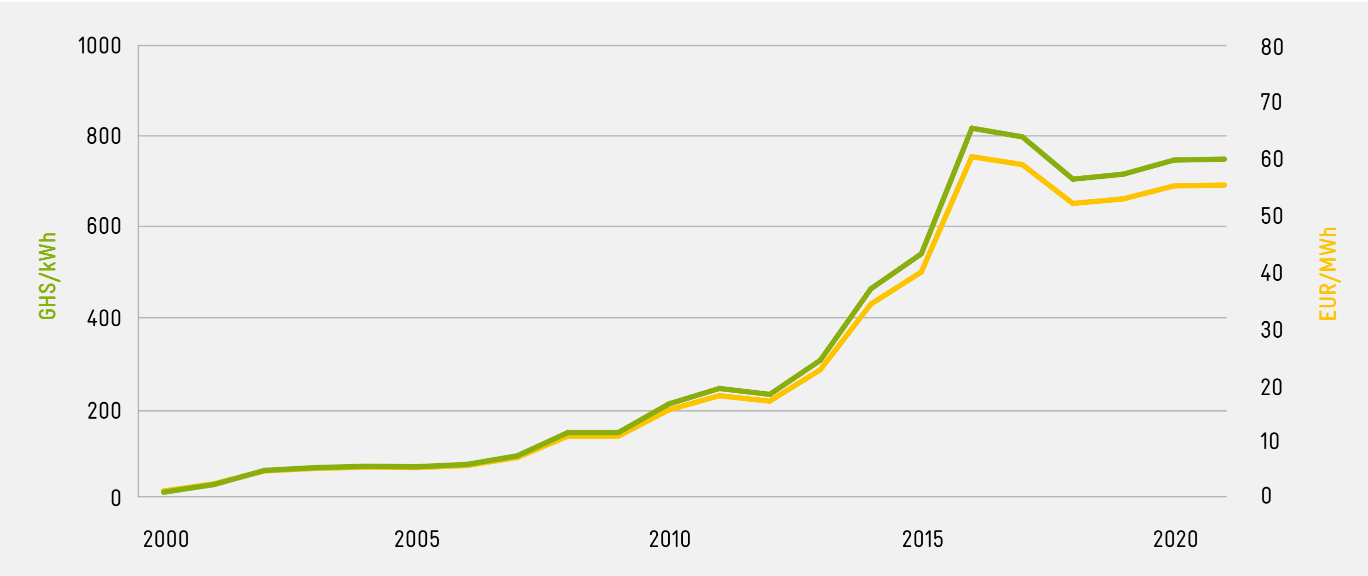
Source: Authors' own illustration, ENGIE Impact GmbH (2023), based on (Energy Commission, 2022)

1.2 Energy prices

1.2.1 Electricity prices

The average electricity end-user tariff has increased dramatically over the past 20 years, reaching GHS 749/MWh in 2021 (EUR 55.364/MWh) (note that GHS to EUR exchange rates have varied significantly in recent years, going from 4.2532 on 14 November 2016 to 13.5286 on 14 November 2022 (Central Bank of Ghana, 2022)). In setting the tariffs, the Public Utilities Regulatory Commission (PURC) considers factors such as the cost of power, the weighted average cost of gas, inflation and the GHS/USD exchange rate, network upgrade/expansion and investments, operation and maintenance of service delivery infrastructure, financial viability of the utility service providers. Since most of these factors are subject to high variability and have been facing an increase, the utility tariffs have shown an upward trend over the years.

FIGURE 4. AVERAGE ELECTRICITY END-USER TARIFF



Source: Authors' own illustration, ENGIE Impact GmbH (2023), based on (Energy Commission, 2022).
Exchange rate: EUR 1 = GHS 13.5286 (Central Bank of Ghana, 2022)

The electricity tariff in Ghana varies depending on voltage level, overall consumption and type of customer. Residential rates range from GHS 419/MWh to GHS 1,284/MWh (EUR 31-95/MWh, exchange rate: EUR 1 = GHS 13.5286 (Central Bank of Ghana, 2022)) and are based on consumption (PURC, 2022). The so-called special load tariff (SLT) customers (mainly industrial) are subject to the tariffs summarised in the table below. It is worth noticing that steel companies are subject to specific tariffs, with particularly advantageous results compared to other industrial customers.

TABLE 1. SPECIAL LOAD TARIFF RATES

Customer class	Tariff GHS/MWh	EUR/MWh
SLT – Low voltage	1,326	98
SLT – Medium voltage	1,007	74
SLT – High voltage	1,057	78
SLT – High voltage – Steel companies	745	55
SLT – High voltage – Mines	2,640	195

Source: (PURC, 2022). Exchange rate: EUR 1 = GHS 13.5286 (Central Bank of Ghana, 2022)

1.2.2 Gas prices

Natural gas is sold in Ghana as liquefied petroleum gas (LPG) and is regulated by the National Petroleum Authority (NPA) in accordance with NPA Act 691 passed in 2005 by the Parliament of Ghana. Around 85% of natural gas supply is domestic, while 15% comes from imports (Energy Commission, Dec 2021).

Liquefied petroleum gas marketing companies (LPGMC) procure and sell LPG to the public through retail outlets like fuel stations and other reselling outlets. With regard to the use of gas for power generation, the increasing share of electricity supply from thermal sources is mainly driven by natural gas.

In August 2022, PURC set the Weighted Average Cost of Gas (WACOG) to GHS 44.4/MMBtu (PURC, 2022) (EUR 3.28/MMBtu). This tariff shall be applied by the Commission in computation of the fuel recovery charge for each power plant utilising natural gas.

1.3 Legislative and regulative framework

1.3.1 Renewable energy incentive mechanisms

The government of Ghana started promoting renewable energy in the mid-90s, by reducing import duties and promoting research on the topic of penetration of RES in the power system. The versions of the Strategic National Energy Plan (SNEP) published between 2006 and 2009 identified renewables (especially solar, wind and biomass) as key technologies for the development of the sector. However, these documents were not binding. The first REMP was issued in 2016 and updated in 2019, setting a target of 1,364 MW of RES capacity installed by 2030 (IRENA and GIZ, 2021). The Integrated Power System Master Plan (IPSMP) (last updated end of 2019) builds on the REMP to explore several scenarios characterised by different ambitions in terms of RES penetration.

Due to electricity oversupply and grid network stress caused by a high degree of implementation of solar PV in Ghana, the government introduced the Moratorium on Independent Power Producers (IPP) in 2019 that suspended the issuance of licences for the development of new power plants by private entities. In the meantime, the government focused on optimising the existing infrastructure and improving the efficiency of the power sector.

However, as of November 2022, service providers are allowed to offer renewable energy to clients via lease-to -own agreements.

To support the evolution of Ghana's renewable energy sector and align with the country's climate goals defined in its Nationally Determined Contribution under the Paris Agreement, the Ministry of Energy, in partnership with the Energy Commission, on the 5th April 2023 announced the immediate lifting of the temporary suspension. This means that industry stakeholders are now able to submit applications for Wholesale Electricity Supply Licences for the development of renewable energy generation projects, whether for private or self-consumption, in compliance with the provisions outlined in the Renewable Energy Act of 2011 (Act 832).

Currently, the government is offering FIT through competitive bidding processes only. All new PPAs negotiated by the government are "pay-and-take". The former "take-or-pay" contracts are no longer allowed (Sogbadji, 2022). This shifts the burden for overcapacity and non-evacuated power to the developer. Table 2 summarises the key enabling regulatory mechanisms which have been put in place.

TABLE 2. SUMMARY OF RENEWABLE ENERGY POLICY INSTRUMENTS

RE Policy Instruments	Description
Mechanisms to support solar PV	20-year FIT (replaced in November 2020 by a competitive procurement scheme) GHS 59.78/kWh (EUR 4.42/kWh)
Mechanisms to support wind energy	20-year FIT (replaced in November 2020 by a Competitive Procurement Scheme) GHS 65.35/kWh (EUR 4.83/kWh)
Power purchase agreements	Unsolicited and negotiated PPA from 2012 to 2016, resulting in high system costs and overcapacity. Average price re-negotiated in 2019 from EUR 0.20/kWh to EUR 0.12/kWh. Moratorium on contracting new PPAs in 2020, active until new contracting framework is developed.
Investment supports	African Renewable Energy Funds to mobilise financial resources to promote, develop, sustainably manage and utilise RES. It is expected to offer financial incentives, capital subsidies, production subsidies and equity participation for renewable energy power generation. Practical implementation is yet to be defined.
Import tax	Solar compact systems are exempt from import tax. All other products are taxable. Importers can only claim the tax refund from the Ministry of Finance after paying the duties initially. Import VAT exemptions for RES products. Exceptions to customs import duties on renewable plants, machinery, equipment and accessories that are specifically imported to set up an enterprise.

Source: (IRENA and GIZ, 2021) (Sogbadji, 2022)

1.3.2 Hydrogen legislation

Although there are ongoing discussions regarding the development of hydrogen, Ghana has not yet published a national strategy on hydrogen development (Ballo, et al., 2022).

The key agencies responsible for hydrogen-related policies in Ghana are shown in Table 3.

TABLE 3. INSTITUTIONS RESPONSIBLE FOR HYDROGEN DEVELOPMENT AND REGULATORY FRAMEWORKS

Name	Head-quarters	Key business/function
Ministry of Energy	Accra	Formulates policies and oversees all players in the energy sector
Ministry of Finance	Accra	Supports public utilities; procures fuel for public utilities and some IPPs; and in some cases, provides sovereign guarantee for PPAs contracted by public utilities
Energy Commission	Accra	Licensing, regulation and monitoring of energy service providers; develops indicative national energy plans; and advises the Minister on energy policy issues
Public Utility Regulatory Commission	Accra	Prepares and publishes guidelines on the tariff approval process; sets and approves tariffs; and mediates disputes between utilities and consumers
Environmental Protection Agency (EPA)	Accra	Provides permits for all major power projects and monitors environmental performance of power plants
National Petroleum Authority	Accra	Regulation of petroleum downstream industry
Ghana National Petroleum Corporation	Tema	Exploration, development, production and disposal of petroleum regulation
West African Gas Pipeline Company Limited	Accra	Operators of West African Gas Pipeline (natural gas)
Petroleum Commission	Accra	Regulates and manages the utilisation of petroleum resources, coordinates the policies in the upstream petroleum sector.

1.4 Pilot projects and enabling infrastructure

The African Hydrogen Partnership Trade Association (AHP) identified Ghana together with Nigeria as two of the suitable “landing zones” to initiate hydrogen programmes in Africa. “Landing zones” are identified as the areas with the most favourable conditions where AHP is willing to sustain rapid developments in hydrogen fuel cell technology programmes (AHP, 2019). These two countries form the West African landing zone due to their extensive pipeline, including the West African Gas Pipeline (WAGP), road and port infrastructure, ideal weather conditions and proximity to the major sea shipping routes. There is also a supporting business climate, political stability and presence of industry that creates future hydrogen demand in both countries. Some examples of research and pilot projects in Ghana include:

- In 2022, the Dutch consulting company Impact Hydrogen started a collaboration with the Ghanaian construction company Jacob Lawren Ltd to assess the opportunity to develop a hydrogen valley in the country (Becker, 2022).
- The West African Science Service Centre on Climate Change and Adapted Land Use (WASCAL) has also published a Call for Tenders for the Design and Construction of Energy Infrastructure at WASCAL headquarters in Accra. The project includes the use of an electric or hydrogen vehicle with a 100% solar-powered charging unit to serve as a demonstrator in the region and for the visibility of WASCAL (WASCAL, 2022).
- Don Bosco Technical Institute, located in Tema, is developing a pilot project to install a 10 kW electrolyser next year to use excess solar-generated electricity at the school to produce and store green hydrogen to use to generate power (Startschuss für grünen Wasserstoff in Ghana, 2023).

Ghana is well positioned for the development of a H_2 transport infrastructure, given the access to ports and the presence of the West African Gas Pipeline (WAGP), an international pipeline transporting natural gas that has the potential to transport hydrogen (Becker, 2022). However, as of yet no advanced planning nor implementation of such infrastructure has been carried out.

2 GREEN HYDROGEN TECHNOLOGY AND ESTIMATION OF COSTS IN THE GHANAIAN CONTEXT

2. Green hydrogen technology and estimation of costs in the Ghanaian context

2.1 Introduction to hydrogen-based products

Hydrogen is the most abundant element on earth and an important chemical building block for numerous production processes, including the refining of petrochemicals, industrial processes such as glass and semi-conductor production and in food production. Hydrogen is also a feedstock used in the production of downstream products such as ammonia and methanol.

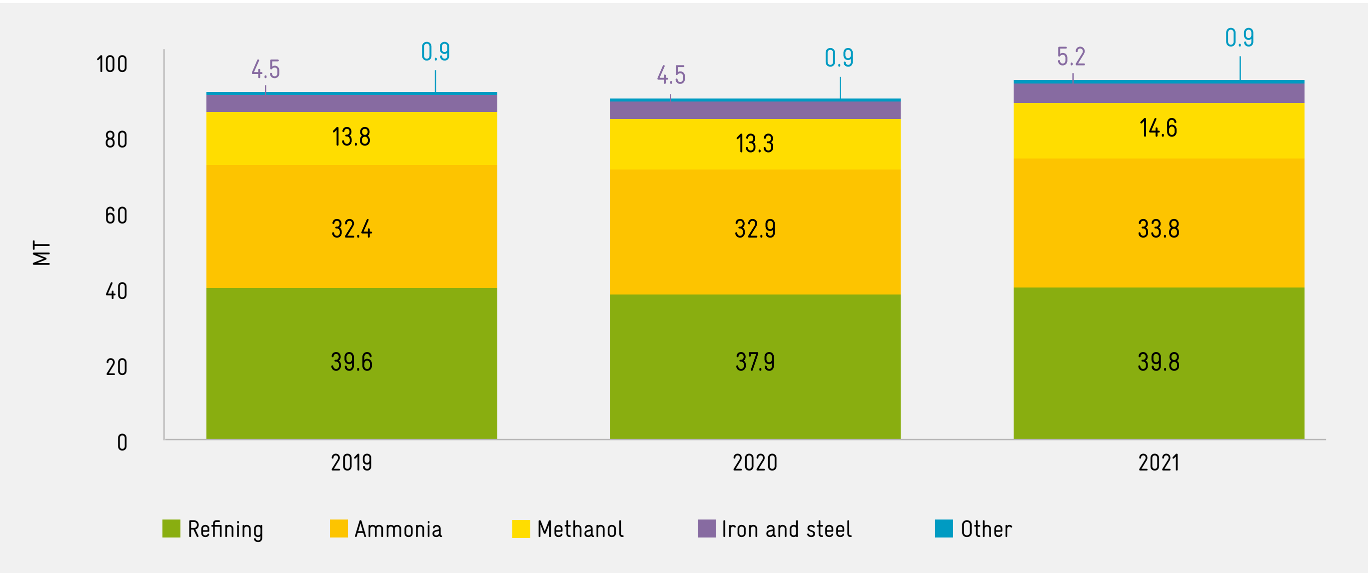
Hydrogen has been produced on a significant industrial scale for decades. Currently, 95% of global hydrogen is produced using fossil fuels (grey hydrogen) (IRENA, 2018), primarily through the natural gas-based steam reforming process which is used to produce around 69 million tons of hydrogen annually (Statista). For the production of hydrogen, a typical natural gas-based steam reforming plant with 607 tpd capacity results in a H_2 production cost of USD 1.22/kg, depending on natural gas prices (A.O. Oni, 2022). The primary drawback to this process are the significant CO_2 emissions, which range on average between 8-9 kg CO_2/kg H_2. Global demand for hydrogen in 2021 was 94 Mt, a 5% increase compared to 2020 (IEA, 2022).

Hydrogen is predominantly used in refining as well as in the production of downstream products such as ammonia and methanol. Only about 6% of hydrogen produced is used for pure hydrogen demand (IEA, 2019). This share of hydrogen goes into the manufacturing processes of a wide variety of petrochemical products (PU foams, oxo-alcohols, nylon, etc.), pharmaceuticals, food production, electronics, etc. Hydrogen is mainly produced on-demand and on-site for treatment purposes or the production of chemicals.

In the context of the decarbonisation of industrial processes, green hydrogen is one of the favoured commodities. There are several utilisation routes for green hydrogen. One is the replacement of fossil-based hydrogen in synthesis or treatment processes. It is also used as a reduction gas, for example, in the steel industry. Another is the replacement of fossil energy sources for heating purposes, as well as an energy carrier for electrical storage purposes.

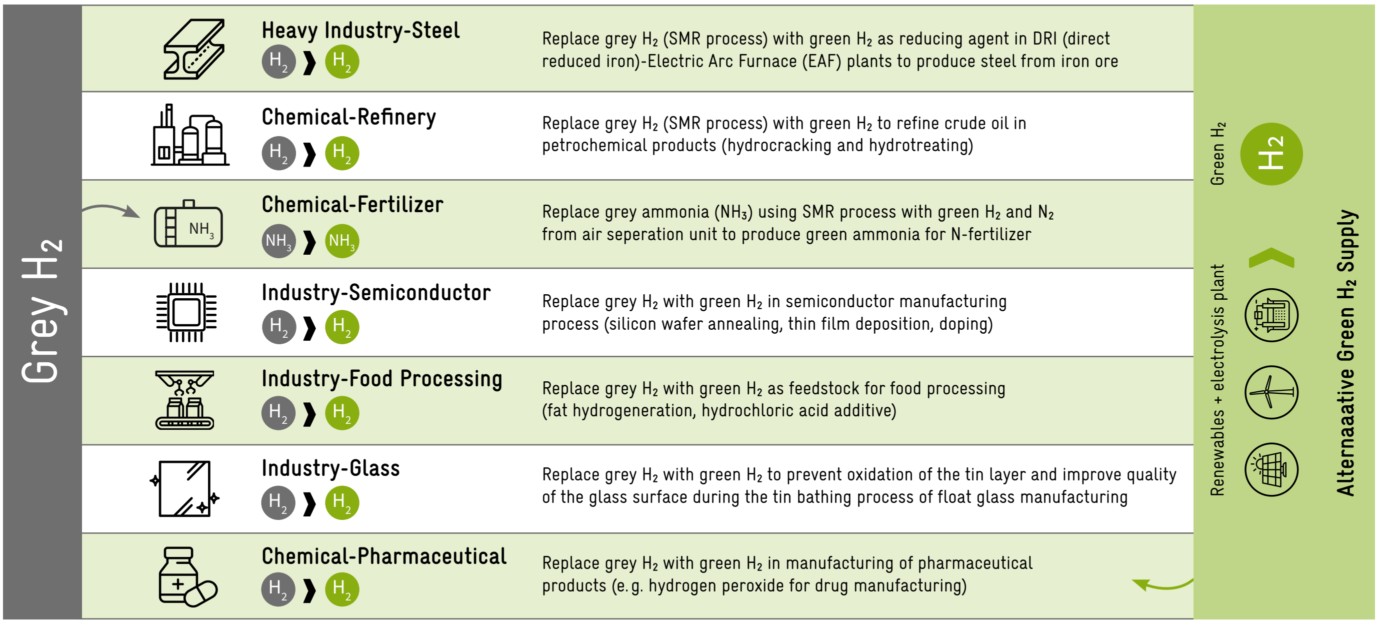
Numerous sectors currently use hydrogen (or hydrogen-based products) as part of their production processes. These include heavy industry, for example, in steel production, in the chemical sector in refineries, for fertiliser production and pharmaceuticals and in the industrial sector, for example, in floating glass, semi-conductor or food production. Figure 6 shows a selection of the current industrial uses of hydrogen and how these can be replaced with carbon-free green hydrogen alternatives.

FIGURE 5. HYDROGEN DEMAND BY SECTOR



Source: Authors' own illustration, ENGIE Impact GmbH (2023), based on (IEA, 2022)

FIGURE 6. CURRENT INDUSTRIAL USES OF GREY HYDROGEN



Source: Authors' own illustration, ENGIE Impact GmbH (2023)

As described above, hydrogen is extremely versatile and green hydrogen unlocks new possibilities for industry decarbonisation as well as contributing to energy security. However, hydrogen is a gas under atmospheric conditions and therefore needs to be processed either through compression or conversion to make it suitable for transport. The most attractive options for shipping hydrogen are ammonia, liquid hydrogen and liquid organic hydrogen carriers (LOHC) (Blanco, 2022).

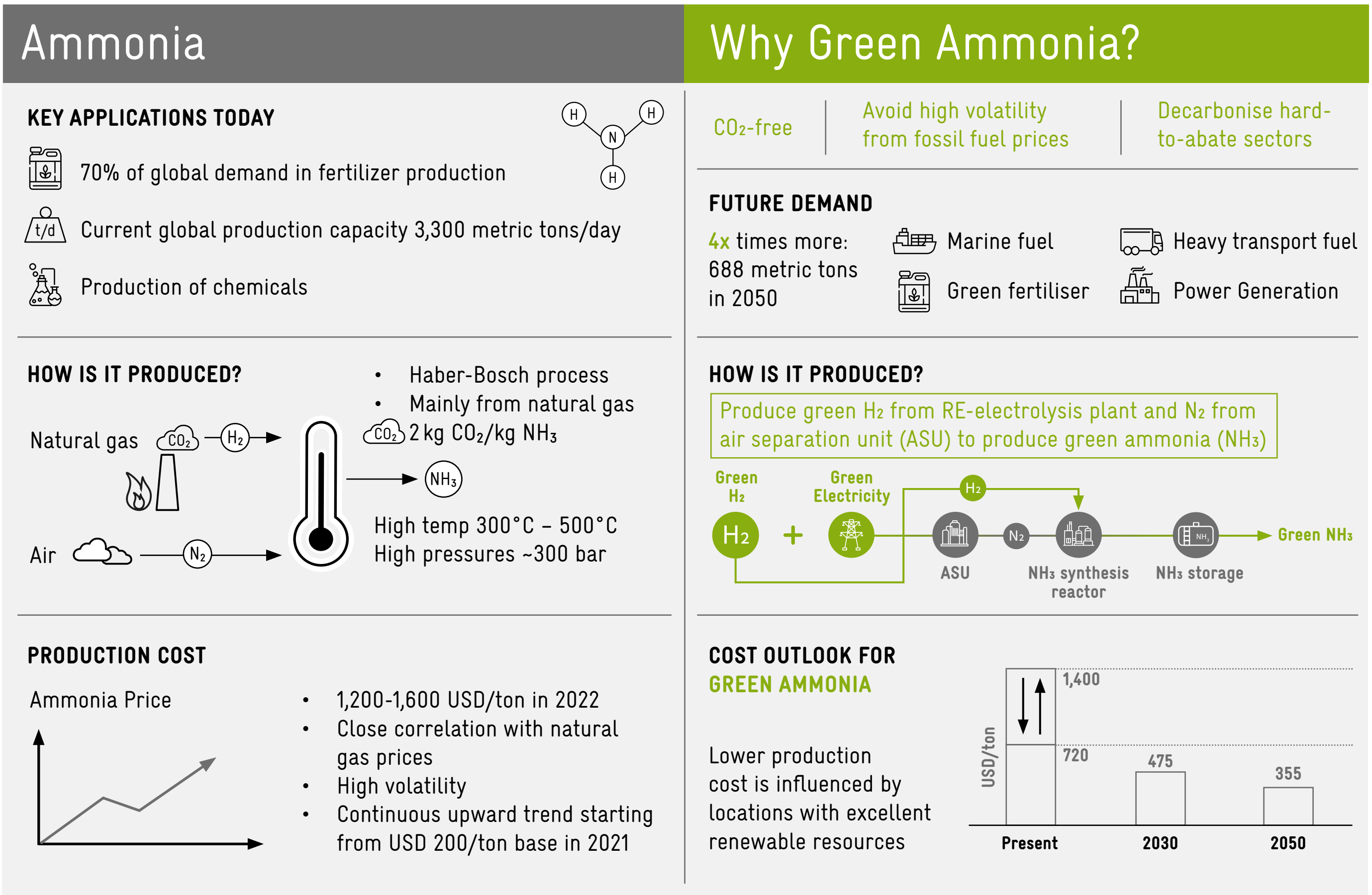
2.2 Hydrogen downstream products

The two primary downstream hydrogen-based products are methanol and ammonia. Methanol is a highly versatile commodity which is used as a fuel and in the production of plastics, silicone, acetic acid and formaldehyde, among others. Ammonia is primarily used as a chemical to create fertilisers, including urea and diammonium phosphate (DAP).

2.2.1 Ammonia

Ammonia (NH_3) is the largest hydrogen-based downstream chemical by volume, representing around 43% of the global hydrogen demand, with around 236 million tons produced worldwide in 2021 (Statisa, 2022). It is the primary feedstock for nitrogen fertilisers, which account for around 70% of the global ammonia demand. The production of NH_3 is a chemical synthesis process which requires H_2 and nitrogen (N_2), at a ratio of 18% H_2 and 82% N_2 as feedstock. As most of the current ammonia production is dependent on natural gas, ammonia prices are strongly correlated with those of natural gas. Conventional ammonia production is an emission-intensive process as it primarily relies on fossil fuels with over 70% of production using natural gas and the remaining 30% using coal. The most common fossil fuel-based Haber-Bosch process emits CO_2 in the order of 2 kg per kg of ammonia. (Ghavam, 2021). Switching to green ammonia can significantly reduce greenhouse gas emissions in agriculture and transportation as it could be used as carbon-free fuel or fertiliser.

FIGURE 7. GREY AND GREEN AMMONIA PROPERTIES

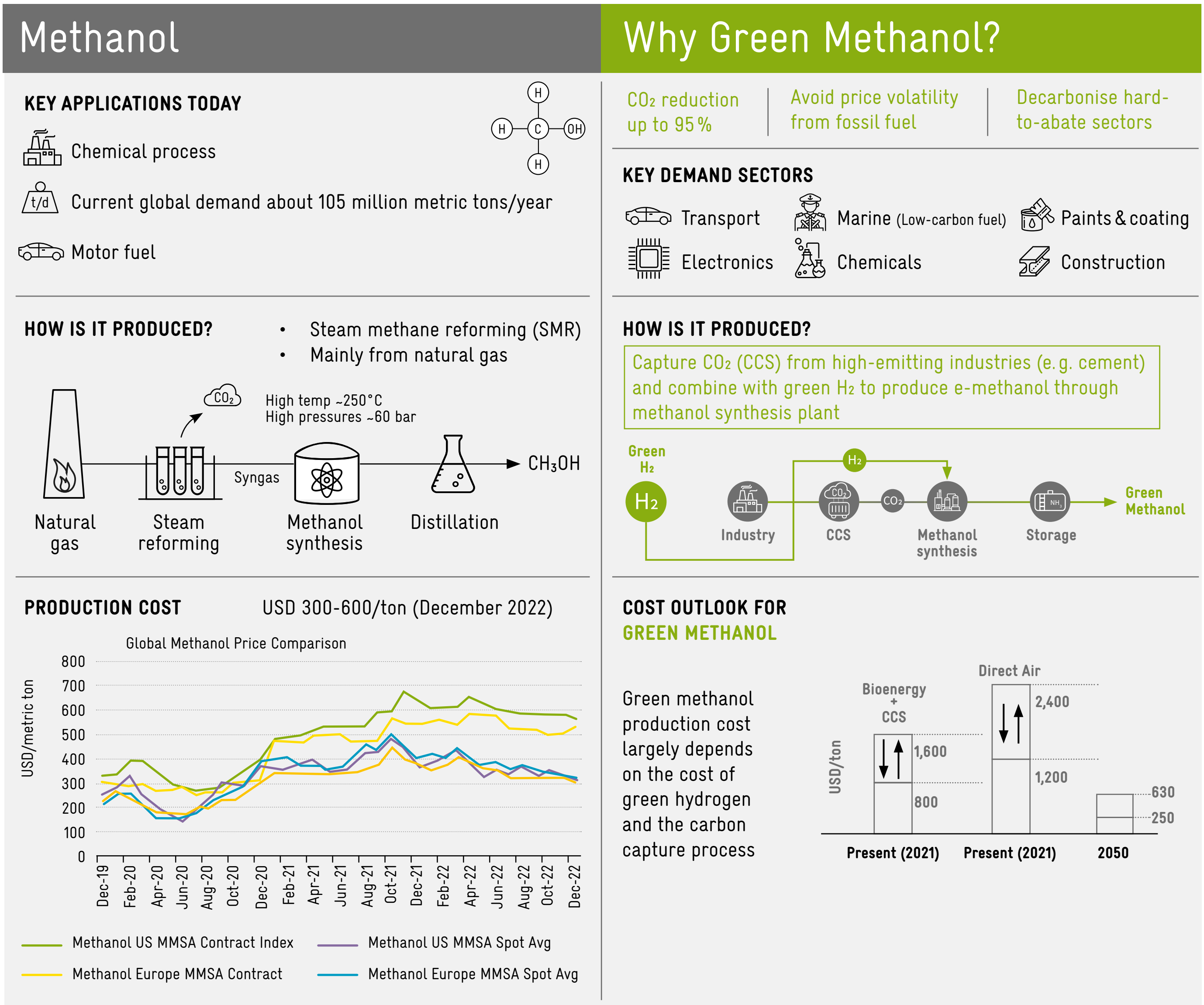


Source: Authors' own illustration, ENGIE Impact GmbH (2023)

2.2.2 Methanol

Methanol (CH_3OH) is a simple water-soluble alcohol which can be used as a fuel for combustion engines or in methanol fuel cells, as a solvent, an anti-freeze, and a base chemical in the production of various downstream chemicals such as polymers, formaldehyde and acetic acid. The predominant methanol consumer is the automotive sector where it is mainly used as a motor fuel offering multiple advantages due to its high-octane content, which improves engine efficiency. Methanol is typically produced through the process of catalytic reduction of carbon monoxide (CO) with hydrogen (H_2), called syngas, with a catalyst used at high pressures (up to 60 bar) and high temperatures (about 250°C), in a process known as „methanol synthesis". Green methanol is gaining significant interest as its production methods could cut up to 95% of CO_2 emissions compared to traditional methods (Methanol Institute, 2021).

FIGURE 8. GREY AND GREEN METHANOL PROPERTIES



Source: Authors' own illustration, ENGIE Impact GmbH (2023)

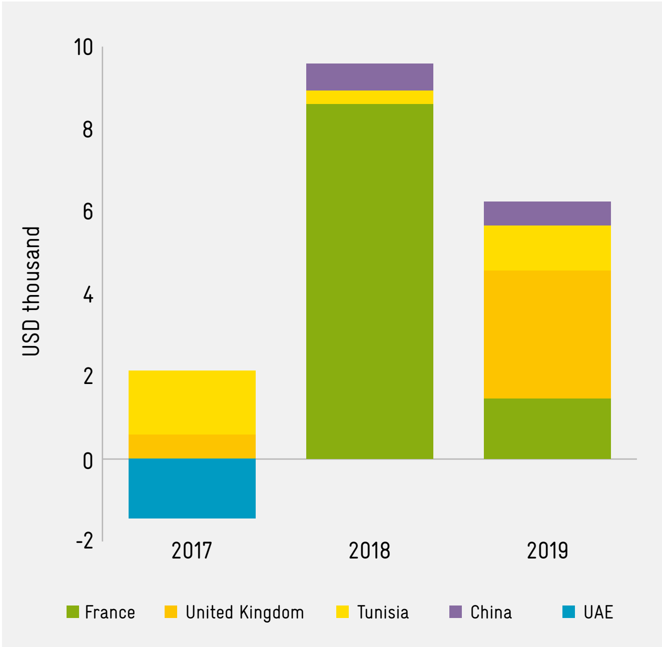
2.3 Industrial use of hydrogen in Ghana

The main hydrogen-consuming industry in Ghana is the fertiliser sector as well as, to a lesser extent, food production.

- Chemical – fertilisers. Ghana has 15 fertiliser plants, 7 of which are blending/processing plants, 7 are organic production and 1 is a manufacturing facility (Africa Fertalizer, 2023).
- Industry – food production. There are 5 food production plants in Ghana.
- Oil (refining) – currently most hydrogen in Ghana is used in refining fossil fuels.
- Other – there is also a small number of pharmaceutical and steel sectors in Ghana which could develop as future markets, as well as developing the use of green hydrogen in the manufacture of cement.
- Methanol is currently being used by a number of industries primarily as a fuel source, providing future opportunities for methanol made from green hydrogen.

Ghana imports about USD 6 k p.a. of hydrogen, an estimated 2 tons/year with no growth trend. The country is a net importer of ammonia from France and Germany with rather stable volumes of around USD 165 k p.a. Most importantly, Ghana is an importer of methanol, with an annual volume of around 2,000 tons, amounting to about USD 2,000 k p.a. with a slight growth trend. Ghana exported small volumes of hydrogen of around USD 1.42 k in 2017 mainly to the United Arab Emirates (UAE).

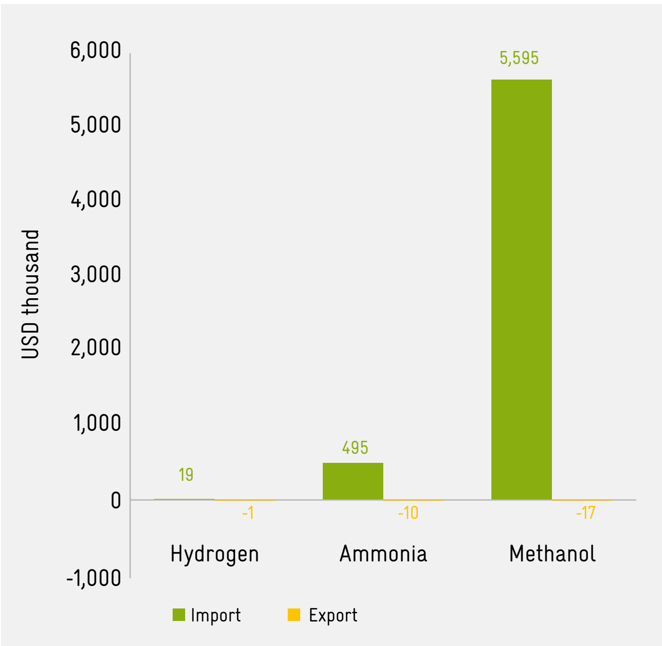
FIGURE 10. HYDROGEN IMPORTS AND EXPORTS TO AND FROM GHANA BY COUNTERPARTY 2017–2019



Source: Authors' own illustration, ENGIE Impact GmbH (2023), based on (World Bank, 2022)

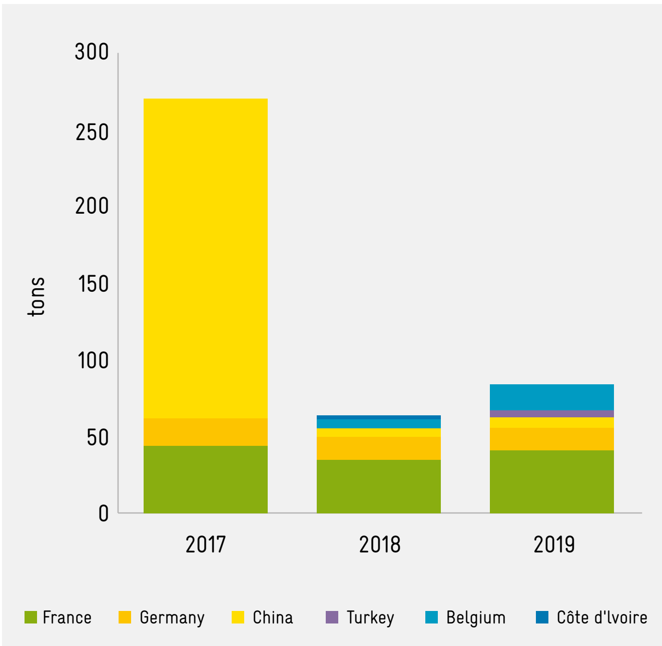
Trade volumes for hydrogen are not available. However, assuming hydrogen costs of around USD 3/kg, annual hydrogen imports of USD 6.8 k represent around 2.2 tons of imported H_2 annually.

FIGURE 9. GHANAIAN TRADE BALANCE BY FEEDSTOCK IN 2017–2019



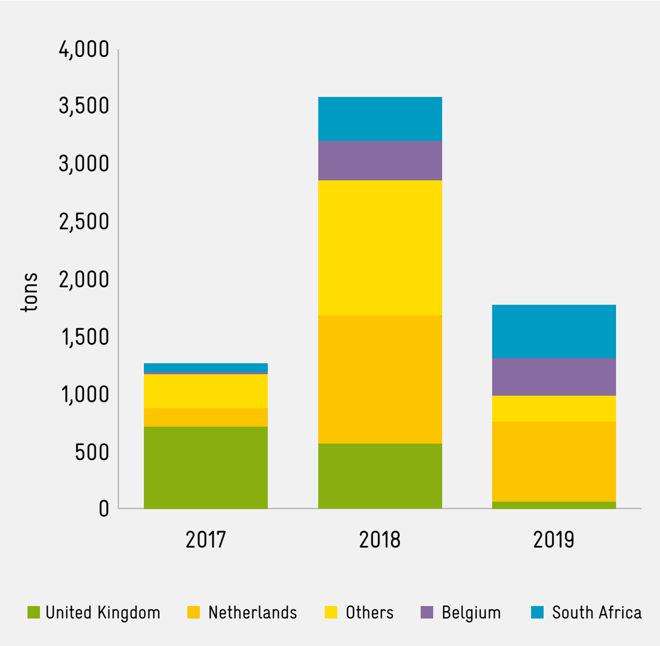
Source: Authors' own illustration, ENGIE Impact GmbH (2023), based on (World Bank, 2022)

FIGURE 11. AMMONIA IMPORTS TO AND FROM GHANA BY COUNTERPARTY 2017–2019



Source: Authors' own illustration, ENGIE Impact GmbH (2023), based on (World Bank, 2022)

FIGURE 12. METHANOL IMPORTS TO AND FROM GHANA BY COUNTERPARTY 2017–2019



Source: Authors' own illustration, ENGIE Impact GmbH (2023), based on (World Bank, 2022)

The main hydrogen-based import products for Ghana are pure hydrogen, ammonia and methanol, with the latter accounting for the largest share in terms of volume – representing almost 80% of the total imported value. Key derivative products where methanol is used are acetic acid, methyl methacrylate, silicone, olefins and formaldehyde, which are further applied in construction, packing and pharmaceutical industries. Ghana has 15 fertiliser plants which further process the ammonia imports.

The consistent, if modest, import volumes of hydrogen and derivative products shows that there is market potential for local production and deployment of Power-to-X (PtX) technologies. Producing green ammonia and methanol on-site would bring multiple benefits to the country's economy. Firstly, the final users of grey ammonia and methanol will reduce their dependency on imports and risks associated with market price fluctuations. Moreover, developing a green ammonia and methanol industry can help diversify a country's economy, reducing its reliance on a few key industries and increasing its resilience to economic shocks.

Introducing green methanol into Ghanaian industry presents many opportunities, such as using it as an energy carrier for storing the electricity generated by renewable resources, an additive to conventional fuels, or as a fuel for direct methanol fuel cells. There is significant interest from shipping companies worldwide to move towards methanol-powered fuel cells, and in Ghana, this could be relevant for Lake Volta, where local companies run river transportation for passengers, bulk haulage and many cross-lake services. The great advantage of green methanol is that existing fuelling infrastructure could be used directly or inexpensively converted for green methanol (thyssenkrupp Industrial Solutions AG).

The key reason why Ghana should invest in green ammonia production facilities is its growing agricultural sector, with an increasing demand for fertilisers. Green ammonia can provide a sustainable source of nitrogen for fertiliser production, which can help meet this demand while reducing the environmental impact. One key distinction with regard to ammonia is that it is safer and less costly to transport than hydrogen. Shipped ammonia could be directly consumed or reconverted back into pure hydrogen. It is important to note that the regions with the highest hydrogen potential in Ghana are situated in the northern part of the country, which will require it to be transported to the main industry clusters mainly located in Accra and Tema. Green ammonia could be a solution and intermediate medium allowing hydrogen to be transported further distances via tank cars or ships. In addition, ammonia could also be used as fuel in power plants or as a means of storing and transporting renewable energy from variable renewable sources such as solar and wind.

While pure hydrogen volumes represent the smallest portion of the imports, there is still potential for Ghana to move to green hydrogen, mainly in the refining and food industry. Compared to grey hydrogen, green hydrogen is more efficient, safer and improves product quality by providing a more precise and controlled operation for food production processes. For the refining industry, the greatest benefit will come from increased energy security and a lower carbon footprint.

Ghana's key industrial centres, and thus the location of the primary hydrogen and derivative-product users, are in Accra and Tema, located along the coast on the Gulf of Guinea. These established industrial clusters create an ideal opportunity for the future development of hydrogen hubs by proving access to a water source, ports, transportation facilities and potential clients.

FIGURE 13. CLUSTERING OF KEY HYDROGEN-CONSUMING SECTORS IN GHANA

Source: Authors' own illustration, ENGIE Impact GmbH (2023)

2.4 Power-to-X technology

Two PtX technologies will be considered in this sector analysis as they suit best to the current market in the country. Green hydrogen and green ammonia will be discussed from a techno-economic point of view.

2.4.1 Green hydrogen production process

In the context of Power-to-X systems, green hydrogen is produced via the electrolysis of water, using electricity and water as inputs to produce hydrogen as the main product. The electrolysis of water is an electrochemical process in which water is electrochemically dissociated into its molecular components – hydrogen and oxygen.

The main inputs for the electrolysis process are pure water – which needs to be supplied in demineralised quality – and electricity - which needs to be supplied as direct current either from a Direct Current (DC) power source or an Alternating Current (AC) power source after conversion. Depending on the electrolyser type, the average pure water demand is 14 litres water per kg of hydrogen produced. The main product of the electrolysis process is hydrogen in gaseous form. Oxygen and waste heat are produced as by-products, which can be utilised for external applications.

There are different water electrolysis technologies, of which alkaline electrolysis (AEL) and proton exchange membrane (PEM) electrolysis are the currently most mature technologies for low-temperature systems. Upcoming electrolysis technologies include anion exchange membrane (AEM) and high-temperature solid oxide (SOEC) electrolysis which are currently in the prototype (AEM) and demonstration phase (SOEC), respectively.

The electrolysis process itself is dependent on the technology and is characterised by different electrochemical and process parameters.

TABLE 4. OVERVIEW OF THE MAIN PERFORMANCE VALUES OF ALKALINE AND PEM ELECTROLYSIS

	Alkaline electrolysis	PEM electrolysis
Stack efficiency range at full load (LHV)	48-50 kWh/kg ~67-70%	48-52 kWh/kg ~64-70%
Operating temperature range	50-80°C	50-80°C
Operating pressure range	0.15-30 barg	0.15-40 barg
Operating range per module	20-100%	10-100%

Authors' own table, ENGIE Impact GmbH (2023)

The main hydrogen production process takes place in the electrolysis cell stacks, which are composed of multiple individual cell modules. At plant level, electrolysis plants include various subsystems for the supply of utilities to the cell stacks. These subsystems include, for example, water treatment, gas treatment, cooling, power conversion and distribution as well as instrumentation and control systems.

Electrolysis plants are characterised by a modular design approach, with current available designs in the range of 1 MW (small-scale) and 100 MW or more (large-scale). Small-scale electrolysis plants can be delivered as turnkey units based on standardised solutions, while large-scale electrolysis plants are developed as project-specific solutions based on predefined subsystems.

2.4.2 Green ammonia production process

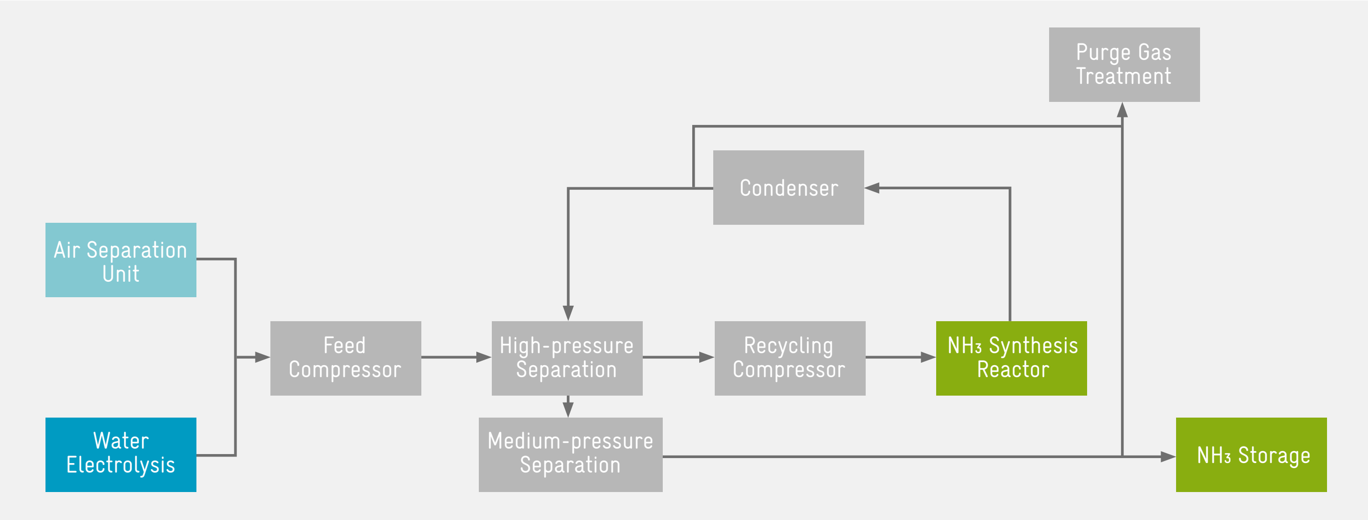
Wind- or solar-based green ammonia production requires the separate production of both hydrogen and nitrogen. Within the scope of this sector analysis, hydrogen is generated by electrolysis. Nitrogen is obtained from ambient air and, from a technical point of view, can be produced in three different ways: cryogenic distillation (ASU – air separation unit), pressure swing adsorption or separation using a membrane process. All processes are commercially viable and primarily require electrical energy. The process of cryogenic distillation has the lowest specific energy consumption. Hydrogen and nitrogen are then introduced downstream into an ammonia synthesis loop. With a starting material ratio of 18% hydrogen weight to 82% nitrogen weight, ammonia is produced by means of catalytic synthesis – also known as Haber-Bosch synthesis – at temperatures between 300°C and 500°C and high pressures of up to 300 bar. Full conversion to ammonia cannot be achieved in a single pass due to the equilibrium conditions of the Haber-Bosch reaction. Consequently, the overall yield of the plant can be increased by implementing a so-called recycling loop to recycle unreacted reactants.

TABLE 5. OVERVIEW OF HABER-BOSCH SYNTHESIS CONDITIONS

Technology	Reaction	Process conditions	Specific consumption for 1 kg NH_3
Haber-Bosch synthesis	$1.5\ H_2 + 0.5\ N_2 \leftrightarrow NH_3$	300°C to 500°C up to 300 bar	0.18 kg H_2 0.82 kg N_2

Authors' own table, ENGIE Impact GmbH (2023)

FIGURE 14. GREEN AMMONIA PROCESS



Source: Authors' own illustration, ENGIE Impact GmbH

During green ammonia production, attention should be paid to ensure that Haber-Bosch synthesis is effected at a constant operating mode when possible. The same applies to cryogenic air separation for the supply of nitrogen. In contrast, PEM electrolysis can be "ramped up or down" under changing current loads. Therefore, when developing the overall system process, appropriate compensation of load changes on the upstream side must be taken into account. Consideration should also be given to how constant production quantities can be ensured for the consumer market.

Figure 14 provides an overview of the green ammonia production process.

2.5 PtX costs

A set of technical and economic assumptions are defined for the calculation of the levelised cost of hydrogen as well as for the business case calculations, which are summarised in Table 6 and Table 7. The cost assumptions are differentiated between medium- (5 MW) and large-scale (100 MW) system sizes in order to show economies of scale. Note that the CAPEX assumptions are based on the total installed cost (TIC), including direct costs for equipment supply and indirect costs for plant installation and design.

The technical assumptions are based on average values, common per technology, without differentiation between plant scale.

TABLE 6. TECHNICAL AND ECONOMIC ASSUMPTIONS FOR THE ELECTROLYSIS SYSTEM

		PEM		Alkaline		AEM	SOEC
		Large-scale	**Medium-scale**	**Large-scale**	**Medium-scale**	**Small-scale**	**Small-scale**
Spec. CAPEX	EUR/kW	1,300	2,700	840	1,900	4,683	3,650
Spec. fixed OPEX	EUR/kW/year	15	20	20	25	19	32
System efficiency	% LHV	62%	62%	62%	62%	62%	81%
Efficiency degradation	%/year	1.3%	1.3%	1%	1%	1.3%	4%
Stack operational lifetime	hours	65,000	65,000	60,000	60,000	35,000	20,000
Spec. tap water consumption	L/kg H_2	14	14	14	14	14	14
Operating pressure	barg	30	30	0.15	0.15	35	0.15

Authors' own table, ENGIE Impact GmbH (2023)

TABLE 7. TECHNICAL ASSUMPTIONS FOR THE HYDROGEN COMPRESSION AND STORAGE SYSTEM

		PEM		Alkaline		AEM	SOEC
		Large-scale	Medium-scale	Large-scale	Medium-scale	Small-scale	Small-scale
Delivery pressure	barg	100	100	100	100	100	100
Spec. compression power	kWh/kg	0.7	0.7	2.8	2.8	0.7	2.8
Max. storage pressure	barg	100	100	100	100	100	100
Max. storage autonomy	hours	72	72	72	72	72	72

Authors' own table, ENGIE Impact GmbH (2023)

2.5.1 Green ammonia production costs

The following provides an illustrative example of the cost of green ammonia production when considering the capacity of a 300 tpd ammonia synthesis plant. Table 7 summarises the technical assumptions. Based on the Haber-Bosch reaction, the hypothesis is that the complete conversion of hydrogen and nitrogen into ammonia takes place via the ammonia synthesis cycle. Green hydrogen is produced using PEM electrolysis with a specific consumption of 50 kWh/kg H_2. The total specific consumption for the ammonia synthesis loop including nitrogen generation is about 1.2 kWh/kg NH_3. Hence a total of approx. 10 kWh of energy is required to produce 1 kg of NH_3, of which H_2 production is a major component.

TABLE 8. TECHNICAL ASSUMPTIONS FOR GREEN AMMONIA PRODUCTION

Specific Technical Assumptions		
H_2 demand	0.18	kg H_2 /kg NH_3
N_2 demand	0.82	kg N_2 /kg NH_3
PEM electrolysis (50 kWh/kg H_2)	8.8	kWh/kg NH_3
NH_3 synthesis (incl. ASU)	1.2	kWh/kg NH_3
Total energy demand	**10** 36	**kWh/kg NH_3** MJ/kg NH_3

Authors' own table, ENGIE Impact GmbH (2023)

Table 9 summarises the capacity and price assumptions. To produce 300 tpd of ammonia, 53 tpd of hydrogen and 247 tpd of nitrogen are required. The production cost calculation considers levelised hydrogen production costs of EUR 8/kg H_2. The energy required for NH_3 synthesis including ASU is assumed to be provided via grid electricity at EUR 0.16/kWh. Due to the cryogenic process, ASU cannot be "ramped up and down" depending on the availability of renewable energy; it must remain relatively constant 24 hours a day. The total investment cost for the NH_3 synthesis loop including ASU amounts to approx. EUR 82 million.

TABLE 9. GREEN AMMONIA CAPACITY AND PRICING ASSUMPTIONS

Capacity and Pricing Assumptions	
NH_3 capacity	300 tpd NH_3
H_2 demand	53 tpd H_2
N_2 demand	247 tpd N_2
CAPEX NH_3 synthesis (incl. ASU)	EUR 82 m
LCoH	EUR 8/kg
Grid electricity cost	EUR 0.16/kWh

Authors' own table, ENGIE Impact GmbH (2023)

Table 10 shows the specific production costs separated according to the shares for H_2 and NH_3 synthesis. Both shares consider operating costs and TIC. When calculating the specific cost shares for NH_3 synthesis, a depreciation period of 10 years and annual operating hours of 8,000 h are assumed.

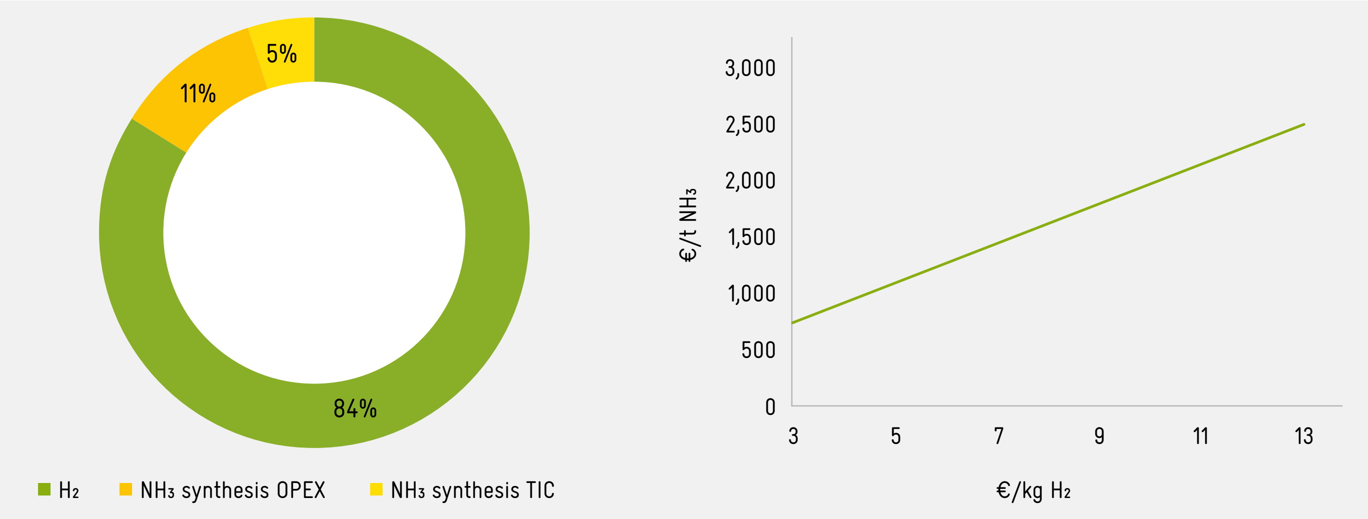
TABLE 10. GREEN AMMONIA SPECIFIC PRODUCTION COSTS

Specific Production Costs			
	H_2	NH_3 synthesis	Total
EUR/t NH_3	1,412	274	1,686
	84%	16%	100%

Authors' own table, ENGIE Impact GmbH (2023)

As with the specific energy requirement, the calculation shows that the main cost driver is hydrogen production. At around 84%, this is more than three quarters of the total production cost for ammonia. The 16% NH_3 synthesis cost comprises 11% operating costs and 5% TIC. The influence of the levelised cost of hydrogen on NH_3 production is shown in Figure 15. Impact of the H_2 price on the Levelized Cost of Ammonia (LCoA).

FIGURE 15. IMPACT OF THE H_2 PRICE ON THE LCOA



Source: Authors' own illustration, ENGIE Impact GmbH (2023)

2.5.2 Levelised cost of hydrogen in Ghana

The green hydrogen production potential from PV energy in Ghana and the associated levelised cost of hydrogen production were estimated. For this purpose, a high-level geographical analysis has been performed, estimating the regional hydrogen production potential and specific cost based on local solar potential. A map of the solar PV capacity factor with assumptions can be found in the Appendix in Figure 20 and Table 16.

In the geographic information system (GIS) analysis, the technical hydrogen production potential is estimated. The technical production potential describes the maximum annual hydrogen quantity that can be produced in a defined area, taking into account the local PV energy yield, conversion efficiencies (electrolysis) as well land-use constraints. Land-use constraints are applied according to the level 2 constraints based on the Energy Sector Management Assistance Program (ESMAP) (ESMAP Global Solar Atlas, 2020), which considers areas with rugged terrain, extreme remoteness, built-up environments, dense forests and, additionally, cropland and conservation areas as exclusion areas for the installation of solar PV plants. Therefore, areas with these land-use constraints are excluded from the analysis and the overall production potential (for electricity and hydrogen) is reduced accordingly.

Due to the land-use constraints applied, in regions with high population densities, complex terrain or large nature reserve areas, locally large areas are considered as unsuitable for the production of hydrogen. The exclusion areas are shown as white space in the following coloured maps. Due to the land-use constraints, several areas were not considered for hydrogen production, including south-western areas, the Savannah Region (Mole National Park and the Upper East region).

Figure 22 gives an indication of the maximum technical H_2 potential (MTHP) for a specified area, taking into account the land-use restrictions. The average H_2 potential for Ghana is 4,048 tpa/km². The MTHP for the Upper East Region district is 4,300 tpa/km². Other areas with significant potential in the northern part of the country are the Upper West Region and the North East Region with estimated MTHP of 4,298 tpa/km² and 4,248 tpa/km², respectively. Note that local water constraints are not considered in the hydrogen potential maps and must be assessed on a case-by-case basis.

As can be seen on the maps, the areas with the greatest potential are located in the northern parts of the country. The proximity of the Keta municipality (Volta Region) to the Ada West District (Greater Accra Region) would be advantageous if a project were to be set up to produce green hydrogen for export. The areas with most land without constraints can be observed in the Upper West Region, Savannah Region, Northern Region, Bono East Region and Oti Region.

FIGURE 16. HYDROGEN PRODUCTION POTENTIAL

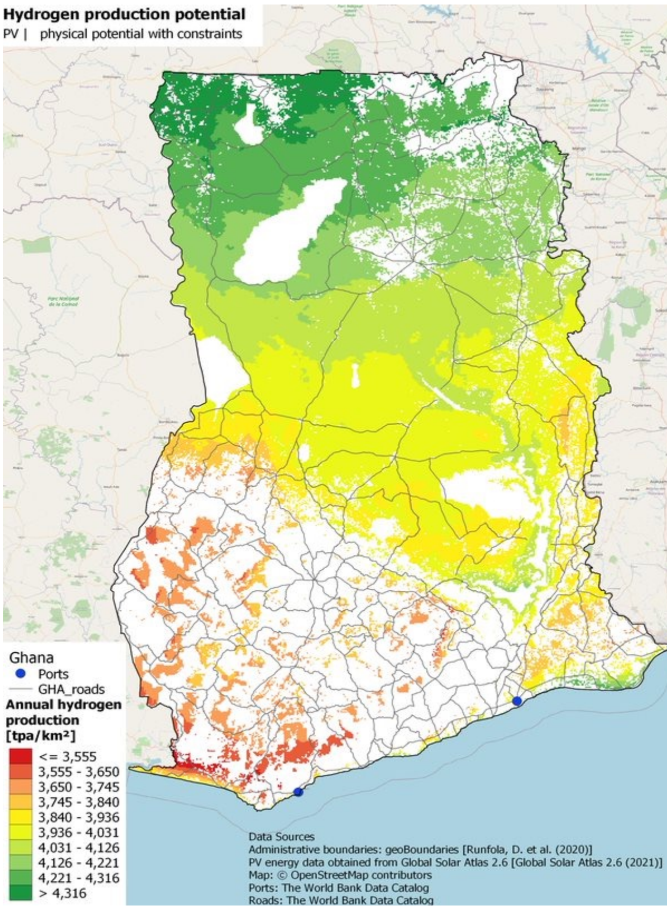


FIGURE 17. LEVELISED COST OF HYDROGEN (LCOH)

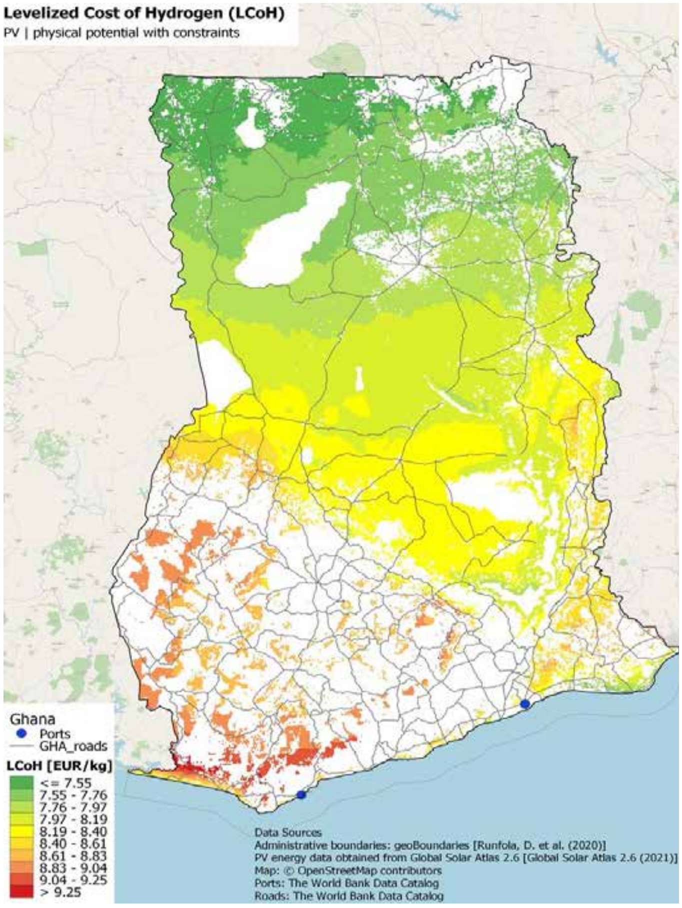


Figure 16 and Figure 17 show the spatial distribution of the levelised cost of hydrogen (in EUR/kg) in Ghana taking into account land-use constraints (level 2 constraints). The spatial distribution of the LCoH is directly proportional to the local irradiance and power yield of the PV plants.

The lowest LCoH level of EUR ≤ 7.55/kg can be observed in the Upper West and Upper East Regions, while the highest LCoH level of USD > 9.25/kg can be observed in the Western Region in the Jomoro municipality. In the Appendix, Figure 21 and Figure 22 show the LCoH without land-use constraints and the H_2 production potential.

The top locations in terms of renewable energy and hydrogen production potential in Ghana are the Upper East and Upper West Regions, as shown in Table 11. The capacity factor for PV, the average specific hydrogen production potential per region, the total hydrogen production potential per region and the calculated average levelised cost of hydrogen for all locations can be found in Table 17 in the Appendix.

TABLE 11. SUMMARY OF PV AND GREEN HYDROGEN PRODUCTION POTENTIAL PER REGION

Region	PV capacity factor [%]	Theoretic green hydrogen production potential		LCoH
		Area-specific potential [tpa/km²]	Total potential [tpa]	[EUR/kg]
Upper West Region	18.23%	4,298	57,192,911	7.54
Upper East Region	18.32%	4,300	15,858,772	7.53

Source: Authors' own calculation, ENGIE Impact GmbH (2023)

3 POTENTIAL GREEN HYDROGEN BUSINESS CASES

3. Potential Green Hydrogen Business Cases

To understand the potential interest of local businesses in Ghana in converting from current conventional hydrogen consumption to producing their own green hydrogen, detailed research was conducted with private sector representatives. The main sources of information were two industry interviews with current grey hydrogen users, during which they were asked about their hydrogen processes, motivation for interest in green hydrogen production, perceived challenges in converting to local green hydrogen production, hydrogen (or derivative product) demand and cost levels, land availability for PV and access to sufficient water. A complete list of questions included in the questionnaire could be found in the Appendix in Table 18. The attached list is not exhaustive and additional informal discussions, e-mail exchanges and literature reviews were used to present a full picture of the private sector in Ghana and its willingness to switch to green hydrogen. The chosen method of research allowed the responders of this sector analysis the freedom of response that was further supplemented by a detailed industry sector analysis. Based on the interviews, illustrative business cases were developed which represent typical sector scenarios replacing grey hydrogen used in the manufacturing process with green hydrogen.

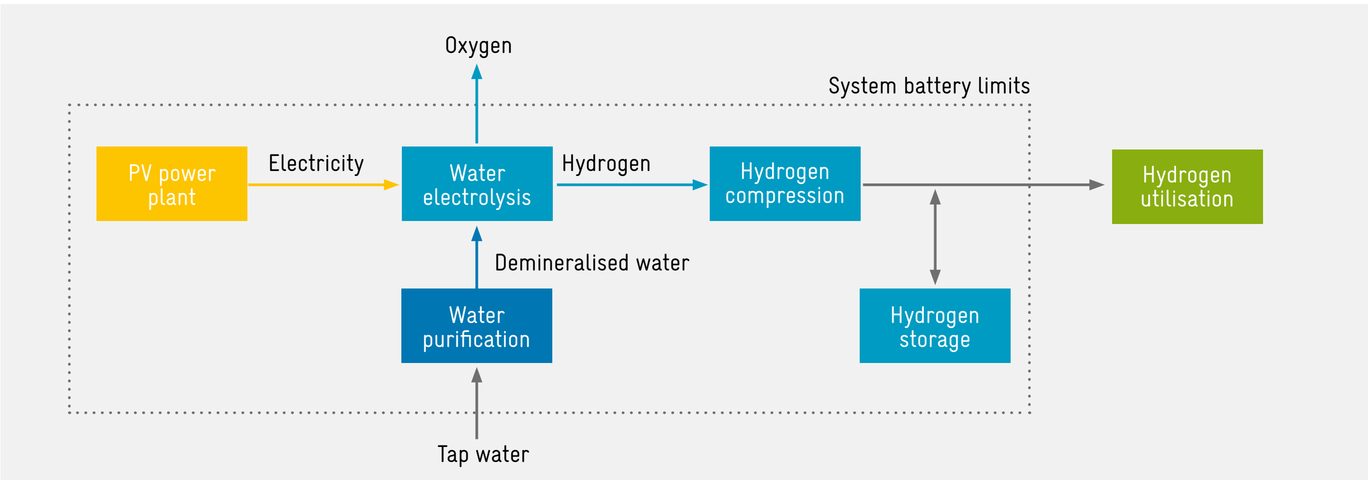
The premise of the business cases is the replacement of current grey hydrogen with locally produced green hydrogen, which would be created solely using carbon-free electricity supplied from on-site solar PV. These business cases focus on current grey hydrogen consumers where the hydrogen, or hydrogen derivative product, is either a production feedstock or an element in the current manufacturing process (e.g. process gas). Use cases for hydrogen as a thermal or energy carrier or as a transportation fuel are not considered within this sector analysis. The production concept for the business cases is shown in Figure 18.

For each business case, a high-level cost-benefit analysis was carried out based on the estimated sizing and cost of the electrolyser system and solar PV plant, as well as the LCoH as per the local solar resource. To estimate the system cost, the PV and the electrolysis system are sized to meet the H_2 demand, and it is assumed both are implemented as a combined greenfield project without pre-existing equipment. The methodology for the calculation is described in the Appendix and the key assumptions used are shown in Table 19.

When considering green hydrogen production solely powered by PV electricity, due to the variable nature of the solar resource, the sizing of system components will be influenced by the operational mode of the H_2 processing. Although the same volume in annual tons of H_2 produced is the same, for business operations where a constant or baseload supply of hydrogen is required, the PV plant must be oversized to ensure minimum baseload production even during non-peak solar resources. In cases where flexible production is possible, i.e. production scheduled following the solar resource, then PV plants could be significantly smaller, but the electrolyser would need to be oversized to fully utilise solar peak production. The choice between flexible and baseline H_2 production also has a significant impact on system costs and the resulting LCoH, particularly in cases where extra electricity from the PV plan can be sold back to the grid, which can account for substantial additional revenue. Please see the Appendix for a thorough explanation.

For each case, the complete LCoH is calculated. In addition, the "effective" LCoH is calculated by adding back the discounted value of electricity sales revenue and oxygen sales revenue, which are benefits which would not accrue without the project. Finally, the effective LCoH is also provided for informational purposes, also taking into account the value of avoided GHG emissions.

FIGURE 18. GREEN HYDROGEN PRODUCTION CONCEPT



Source: Authors' own illustration, ENGIE Impact GmbH (2023)

The LCoH presented in the case studies varies from the global specific LCoH presented on the GIS maps as the GIS maps represent simplified costs of production, which is a common standard methodology, and are comparable to what is found in the LCoH in literature and other studies. The LCoH in the business cases, on the other hand, include additional costs which the company will likely incur, for example, import taxes (when applicable), inflation on OPEX, capitalised financing costs and increased CAPEX and Operational expenditures (OPEX) related to system sizing (or oversizing) required to achieve the specified H_2 production profile as well as additional oversizing of the PV field to ensure a minimum level of annual production taking into account the degradation of both the PV and the electrolyser system over time, which requires adding significant additional PV capacity. Together, these result in a LCoH which can, in some cases, vary significantly from the simplified specific production costs.

Given the comparatively low plant utilisation rates, due to the variable solar resource and lack of economies-of-scale production, small-scale local green hydrogen is not currently cost-competitive with conventional sources on a specific cost-of-production basis. However, as electrolyser technology costs come down and the decarbonisation of industry takes on a more important role with financial consequences, for example, through carbon tax, this could change. Therefore, the business cases set out to determine what it would take in terms of financial support to make the local production of green hydrogen, powered by solar PV, cost-effective for local businesses in Ghana.

Note: the business cases are intended for illustrative purposes only and do not represent an actual company.

3.1 Case 1. Green hydrogen for ammonia fertiliser production

A fertiliser production company located in the Tema region of Ghana which currently imports all raw materials for fertiliser mixing is considering expanding to include local green H_2 production. In the first phase, the ammonia demand would be 30,000 tpa. There is seasonal peak production in March to October; however, at the site of the existing production facilities, there is plenty of on-site storage to manage seasonality. Given that ~18% hydrogen and ~82% nitrogen is required to produce ammonia, for 30,000 tons/year of NH_3 production, 5,300 tpa H_2 is required.

Given the solar resource in the southern region of Ghana, to produce 5,300 tpa of H_2 in baseload operational mode a 425 MW PV plant and an 83 MW electrolyser would be required. In flexible operation mode, the PV plant would only need to be 215 MW and the electrolysis system would need to be sized at 162 MW. Both systems have almost the same upfront investment cost of around EUR 530 m. About 42 tons of oxygen per year would be produced as a by-product of the hydrogen production process, which could be sold to industrial users (assumed price EUR 0.30/kg). The table below shows system sizing for both flexible and baseload operational modes.

TABLE 12. BUSINESS CASE 1. GREEN HYDROGEN FOR AMMONIA FERTILISER PRODUCTION SYSTEM SIZING

System Sizing	Flexible Operation	Baseload Operation
Installed PV power (kWp)	215,519	424,680
Design power electrolysis (kW)	161,909	82,925
Annual net electricity generation PV (kWh/year)	379,257,663	747,325,499
Annual net electricity consumption EL (kWh/year)	284,917,742	284,917,742
Total investment cost (EUR thousand)	528,667	529,975

Source: Authors' own table, ENGIE Impact GmbH (2023)

Using the cost assumptions as described in Section 3.22 for AEL technology, the resulting specific LCoH is EUR 13.4/kg in baseload operation and EUR 12.7/kg with flexible operation sizing. However, when considering the equivalent value of the surplus PV electricity, which could be sold to the grid, as well as revenue from oxygen sales, the resulting effective LCoH is EUR 9.4/kg with flexible and EUR 4.3/kg with baseload operation sizing. The key difference is the volume of extra electricity which could be sold, reducing the effective LCoH by EUR 6.8/kWh. In the baseload case, revenue from the sale of extra electricity and oxygen would cover more than 2/3 of the green H_2 production costs.

Given the target LCoH of EUR 3.09/kg to achieve price parity with conventional H_2 sources, subsidies equaling EUR 6.4/kg or the equivalent of a CAPEX grant of EUR 342 m would be required with flexible operation sizing and EUR 1.2/kg or the equivalent of a EUR 61 m CAPEX grant with baseload operation sizing would be required. The breakdown of the LCoH for the business case is presented in the following table.

TABLE 13. BUSINESS CASE 1. GREEN HYDROGEN FOR LCOH BREAKDOWN

Levelised Cost of Hydrogen	Flexible Operation	Baseload Operation
	EUR/kg	EUR/kg
Levelised Cost of Hydrogen	**12.66**	**13.44**
Equivalent levelised value of benefits per kg H_2 produced		
Equivalent value of oxygen revenue per kg H_2 produced	2.43	2.43
Equivalent value of electricity revenue per kg H_2 produced	0.79	6.75
Effective LCoH (incl. electricity and oxygen sales)	9.43	4.26
Effective LCoH (incl. revenue + CO_2 avoided costs)	8.65	3.48
Target LCoH (cost comparable to market price for grey H_2)	3.09	3.09
Required Subsidies		
Effective green H_2 LCoH	9.43	4.26
Target LCoH (cost comparable to market price for grey H_2)	3.09	3.09
Price gap between effective green LCoH and target LCoH [EUR/kg]	6.35	1.17
Subsidy required to achieve target (investment subsidy in EUR)	341,991	61,336

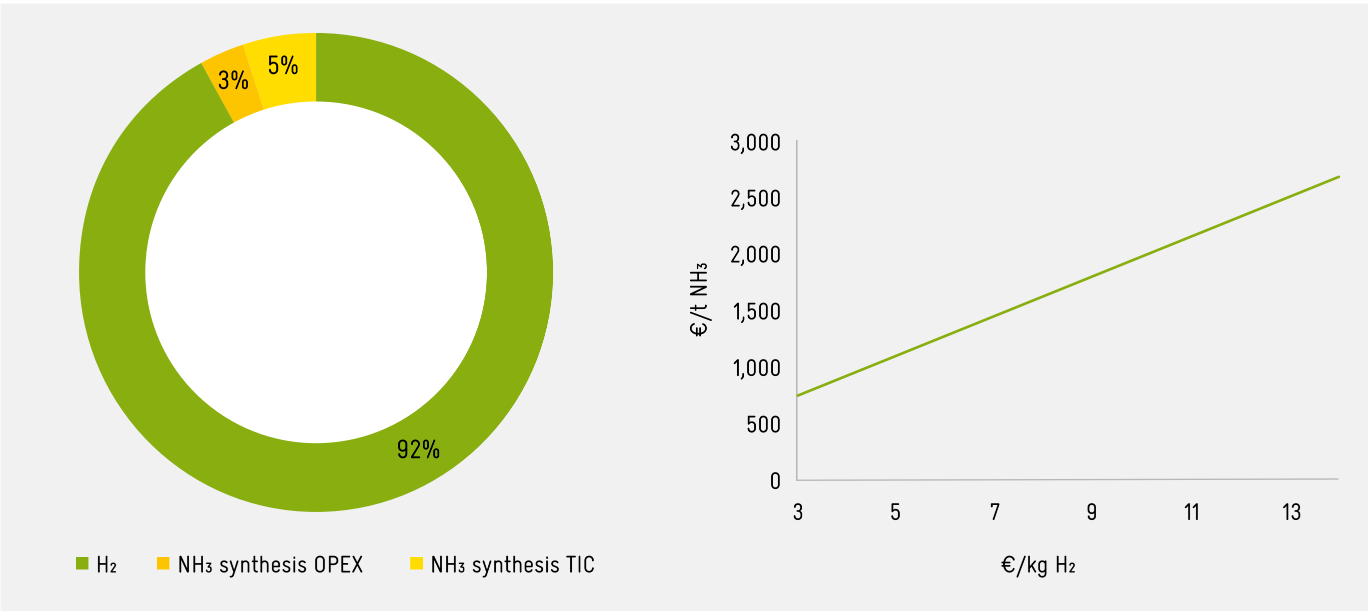
Source: Authors' own table, ENGIE Impact GmbH (2023)

The replacement of conventional H_2 with green H_2 would result in a reduction of 53,000 tons/p.a. of CO_2 emissions, which has a cost of carbon of over EUR 113 m (assuming High-Level Commission on Carbon Prices) over the 25-year lifetime of the plant.

The next step in the process is to convert the green H_2 to NH_3.

Given the small size of the ammonia plant, the CAPEX is estimated to be EUR ~35.4 m (around EUR 129/ton annual capacity). Applying the previously calculated LCoH of EUR 13.4/kg H_2 and the local cost of electricity of EUR 0.07/kWh for the ASU, the resulting LCoA would be EUR 2,578/ton and would range from EUR 742-2,578/ton, based on the different effective LCoH presented.

FIGURE 19. IMPACT OF THE H_2 PRICE ON THE LCOA



Source: Authors' own illustration, ENGIE Impact GmbH (2023)

3.2 Case 2. Green hydrogen for food production

A food sector company located in the Tema region of Ghana produces margarine and uses H_2 for the hydrogenation of their products to increase the melting point, as a preservative and to harden the texture. The plant can process 1,400 tons of oil per year and is set up to process 5 tons of oil per batch. This requires 6 kg H_2 per ton, with a total of 8.40 H_2 tpa. As they run a batch process operation and short interruptions in hydrogen flow do not impact the final product, flexible operation of the electrolysers can be followed.

Given the solar resource in the Tema region, to produce 8.4 tpa of H_2 in flexible mode, a 0.34 MW PV plant and a 0.25 MW electrolyser would be required. As the PV would produce around 0.60 GWh electricity per year and the electrolyser system uses only 0.45 GWh, the remaining 0.15 GWh per year could be sold to the grid or used to offset electricity consumption in other parts of the production facility.

In addition, 1,680 tons of oxygen per year would be produced as a by-product of the hydrogen production, which could be sold to industrial users (assumed price EUR 0.30/kg). If baseline operation sizing was used, then to ensure consistent minimum production throughout the day the PV plant would need to be oversized at 0.67 MW and the electrolyser system size could be reduced to 0.13 MW. This would result in nearly 40% more electricity production for almost the same initial investment cost and the resulting “extra” electricity could be sold, generating an additional revenue stream or used to offset electricity consumption in other parts of the production facility.

TABLE 14. BUSINESS CASE 2 SYSTEM SIZING

System Sizing	Flexible Operation	Baseload Operation
Installed PV power (kWp)	343	673
Design power electrolysis (kW)	257	131
Annual net electricity generation PV (kWh/year)	601,088	1,184,440
Annual net electricity consumption EL (kWh/year)	451,568	451,568
Total investment cost (EUR thousand)	838	840

Authors’ own table, ENGIE Impact GmbH (2023)

Using the cost assumptions as described earlier for AEL technology, the resulting specific LCoH is EUR 13.4/kg in baseload operation and EUR 12.7/kg with flexible operation sizing. However, when considering the equivalent value of the surplus PV electricity which could be sold to the grid, as well as revenue from oxygen sales, the resulting effective LCoH is EUR 9.4/kg with flexible and EUR 4.3/kg with baseload operation sizing. As both methods have almost the same investment costs and produce the same volume of H_2 annually, the difference is in the value of the sales of the extra electricity, which in the baseload case contributes an equivalent value of EUR 6.75/kg of H_2 produced.
Given the target LCoH of EUR 3.09/kg to achieve price parity with conventional H_2 sources, subsidies equalling EUR 6.4/kg or the equivalent of a CAPEX grant of EUR 542 k would be required with flexible operation sizing and EUR 1.2/kg or the equivalent of a EUR 97 k CAPEX grant with baseload operation sizing would be required.

The breakdown of the LCoH for the business case is presented in the following table.

TABLE 15. BUSINESS CASE 2 LCOH BREAKDOWN

Levelised Cost of Hydrogen	Flexible Operation EUR/kg	Baseload Operation EUR/kg
Levelised Cost of Hydrogen	12.66	13.44
Equivalent levelised value of benefits per kg H_2 produced		
Equivalent value of oxygen revenue per kg H_2 produced	2.43	2.43
Equivalent value of electricity revenue per kg H_2 produced	0.79	6.75
Effective LCoH (incl. electricity and oxygen sales)	9.43	4.26
Effective LCoH (inc. revenue + CO_2 avoided costs)	8.65	3.48
Target LCoH (cost comparable to market price for grey H_2)	3.09	3.09
Required Subsidies		
Effective green H_2 LCoH	9.43	4.26
Target LCoH (cost comparable to market price for grey H_2)	3.09	3.09
Price gap between effective green LCoH and target LCoH [EUR/kg]	6.35	1.17
Subsidy required to achieve target (investment subsidy in EUR)	542	97

Authors’ own table, ENGIE Impact GmbH (2023)

The replacement of conventional H_2 with green H_2 would result in a reduction of 84 tpa in CO_2 emissions, which has a cost of carbon of more than EUR 0.18 m over the 25-year lifetime of the plant.

3.3 Business case conclusions

As can be seen in the illustrative business cases, the production of green hydrogen solely by means of solar energy will require significant fiscal incentives over the short, medium, and long term to become cost-competitive with conventional H_2 sources. This is due to the required system "oversizing" needed to enable the constant production of H_2, as well as a lack of economies of scale due to the small production sizes compared to large, centralised production. Alternative sources of green energy could be harnessed to reduce the required system size and increase plant utilisation enabling 24/7 production, thus significantly lowering the overall MTHP.

The business cases further demonstrate the significant impact of system sizing on the overall financial feasibility due to operational methods, tapping into additional revenue streams and the assumed financial support structure. Although oversizing the PV system increases the overall initial investment cost, in most cases the resulting revenue from the sale of "extra" green energy more than offsets this cost and serves to subsidise the cost of H_2 production. Furthermore, financial incentives such as grants for the PV or electrolyser system could help to enable the small-scale decentralised production of green H_2 to become financially viable in the medium term.

4 THE WAY FORWARD

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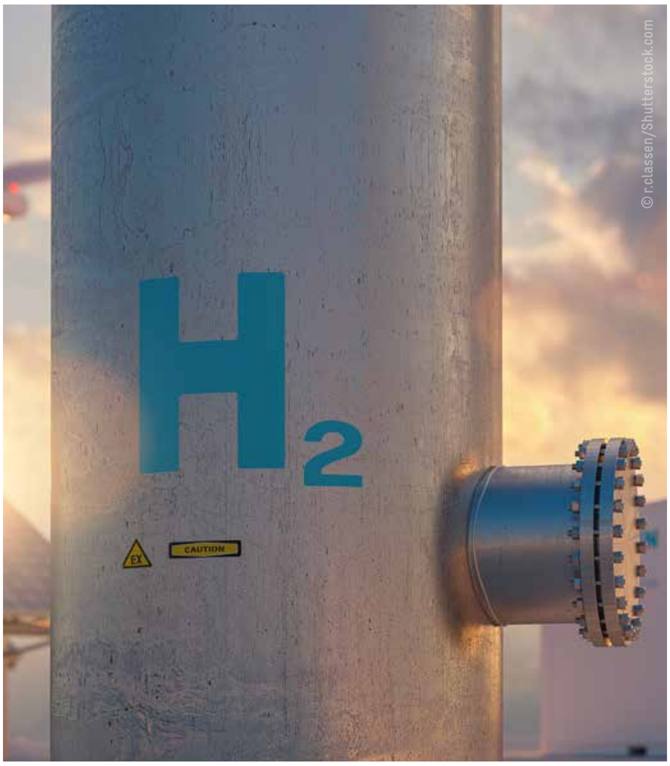
4. The way forward

4.1 Challenges and considerations for hydrogen implementation

Considerations for the implementation renewable energy and electrolysis facilities for hydrogen production at existing industrial facilities include:

- **Investment costs.** High investment costs leading to production costs that are higher than market costs and a lack of sufficient accessible financing.
- **Regulatory framework and approval process.** As the decentralised production of green hydrogen is relatively new, the regulatory, environmental requirements and permitting regulations are non-existent or unclear. This adds significant uncertainty and additional time and overheads to the project development process.
- **Operation staff.** Trained staff available for operations & maintenance activities.
- **Supply chain shortages.** In recent years there have been a number of factors (COVID, Ukraine, etc.) impacting supply chain components, parts and materials leading to long lead times for delivery of equipment.
- **Area requirements.** Availability of sufficient space for installation of an electrolysis plant, hydrogen storage and balance-of-plant equipment as well as the PV plant. The average space requirement for 1 MWp solar PV generating capacity requires at least 5 acres (Land Use & Solar Development, n.d.).
- **Logistical issues.** Potential issues in carrying out construction while the existing operations continue, as well as potential impacts on production and what types of tie-ins are necessary.
- **Design and engineering of plant.** Which codes and standards on the industrial site are valid and must be complied with, particularly with regard to the storage of harmful gases.
- **Power supply.** Is a reliable power supply as well as back-up power supply secured? There will be increased metering requirements to demonstrate the use of green electricity for green H_2 production.



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- **Water supply.** Availability of water in the required quality and quantity (tap water or demineralised water). Hydrogen production requires significant quantities of water at a time when water is becoming increasingly scarce across Africa. It is crucial to build a green hydrogen industry in a way that it will not negatively affect water security and water-heavy industries. Water desalination is one of the proposed solutions that can reduce the hydrogen water footprint.
- **Safety aspects.** Integration of hydrogen production and the storage facility into the existing safety concept of the existing industrial plant site.
- **Control and operation.** Integration of hydrogen production and the storage facility into existing control systems.
- **Supply considerations.** Is a constant hydrogen supply necessary for operations and is this possible given local renewable resources?
- **Storage facilities.** Adequate hydrogen and electricity storage facilities are required if production relies on VRE to ensure uninterrupted production.

4.2 Opportunities and supporting frameworks for hydrogen implementation

The production of green hydrogen offers numerous opportunities which are in line with the country's climate and decarbonisation policies and their targets, including:

- Ghana Renewable Energy Act passed in 2011, which provides a framework for the promotion, development and utilisation of renewable energy sources, including solar, wind, hydro and biomass.

- National Climate Change Policy. In 2013, Ghana adopted a National Climate Change Policy to guide the country's efforts to mitigate and adapt to climate change.

- Climate Change Adaptation Strategy. In 2016, Ghana developed a Climate Change Adaptation Strategy to guide the country's efforts to adapt to the impacts of climate change. The strategy focuses on building resilience in key sectors, including agriculture, water resources and coastal zones.

- Renewable Energy Master Plan. In 2019, Ghana launched a Renewable Energy Master Plan to guide the development of the country's renewable energy sector. The main targets of the plan include: increasing the share of renewable energy in Ghana's electricity generation mix to 10% by 2020 and to 20% by 2030, increasing access to modern and sustainable energy services to at least 50% of the population by 2030 and raising renewable energy capacity from the current 1,600 MW to about 10,000 MW by 2030.

The development of the green hydrogen sector will:

- reduce the country's GHG emissions and support the country's clean energy transmission policies, through the decarbonisation of hard-to-abate industrial sectors;

- decarbonize the agricultural sector through more sustainable production of fertilisers using green ammonia;

- reduce the country's dependency on hydrogen derivative imports such as ammonia and methanol, and could be a starting point for developing local production capacities for industry;

- accelerate investment and speed up the technological development of the country. In addition, new skilled jobs will be created providing new opportunities to its population.

In addition, Ghana provides some incentives to help attract foreign capital. The Ghana Investment Promotion Centre (GIPC) Act and the Free Zone Act are the key legislative documents which create a transparent and favourable investment environment for external capital through multiple supporting frameworks: such as custom duty exemptions, a 10-year tax holiday for free zone developers, free transferability of dividends and profits, personal remittance for expatriate personnel and the ability of both foreign and local investors to own 100% of the shares.

4.3 Local Ghanaian financing instruments

Ghana does not yet have green hydrogen sector-specific financial and policy incentives or preferential mechanisms. The government of Ghana is expected to encourage project developers, green hydrogen producers, public-private partnerships with local and international partners to implement strategically important pilot hydrogen demonstration projects. In the hydrogen market's current technology demonstration phase, public financing, subsidies and fiscal incentive instruments, as well as project-specific offtake arrangements are being used globally to reduce the projects' financial risks, allowing producers to demonstrate successful operation (and business cases) of hydrogen plants in the absence of market mechanisms, policy and financing support frameworks. Climate funds that are operational in Ghana, such as Sustainable Energy Fund for Africa (SEFA) (African Development Bank, 2023), may support developing green hydrogen projects together with private sectors in the near future. However, as a starting point to encourage more investments in the green hydrogen sector, a national-level green hydrogen strategy needs to be established for Ghana. The energy, industry and transport sector policies, especially, need to consider green hydrogen as another clean technology and align their sectoral low-carbon roadmaps with green hydrogen-specific actions.

4.4 Green hydrogen financing opportunities for German companies

There are four categories of financing opportunities for German companies active in green hydrogen technologies:

- EU-level funding opportunities;
- national public funding for hydrogen projects by EU Member States, for example, the German H2Global mechanism;
- national banks such as the European Investment Bank (EIB), Kreditanstalt für Wiederaufbau (KfW), leveraging private capital investments in green hydrogen projects. A wide variety of financing instruments such as debt finance, equity finance, guarantees, which could come in addition to EU support programmes;
- private finance such as venture capital funds (e.g. Breakthrough Energy founded by Bill Gates); private banks are also showing interests in investing in the hydrogen sector. There are four categories of financing opportunities for German companies active in green hydrogen technologies:

EU-level funding opportunities
The Clean Hydrogen Partnership (public-private partnership) aims to provide research and innovation funding for hydrogen projects for European companies (Hydrogen Europe, 2023). The funding comes in the form of grants and EU co-funding for green hydrogen production, storage, distribution, transportation, heat and power application, hydrogen valley development, etc.

Another example is the ETS Innovation Fund (European Union, 2023) for H_2 demonstration projects, where money raised via the EU ETS (European Union Emissions Trading System) is reinvested into the Innovation Fund (public-private partnership). Under grant agreements, the fund can be used for the demonstration of innovative low-carbon technologies including green hydrogen. For example, one of the hydrogen projects that received funding from the ETS Innovation Fund is the fossil-free steel production “HYBRIT” project in Sweden.

National public funding for hydrogen projects specific to the EU Member State

Examples of national public funding include the German (H2Global) mechanism (H2 Global Stiftung, 2022). H2Global is an auction-based financing mechanism for green hydrogen which will conclude long-term purchase contracts on the supply side and short-term resale contracts on the demand side, ensuring planning and investment security for green H_2 investments, given the current lack of fully functioning green H_2 markets. The concept provides for the compensation of the difference between the purchase price (production plus transport costs) and the sales price (currently the market price for fossil hydrogen) for green H_2 and H_2-based derivatives. The first tender was launched in November 2022 as an auction for green ammonia, e-methanol and sustainable aviation fuel from international producers (outside EU and EFTA countries). The concept is developed with funding from the German Federal Ministry for Economic Affairs and Climate Action (BMWK).

In addition, in 2022 the Federal Government launched the “Hydrogen Pilot Office” website, which provides combined information for hydrogen funding opportunities at national, EU and international level. The „International Hydrogen Ramp-up Programme“ (H2Uppp) supports German SMEs in identifying, preparing and implementing pilot projects for the production and use of green hydrogen in developing and emerging countries (BMWK, 2023). Guidance on sources of funding can be found on the BMWK website “Funding advice – Hydrogen Guidance Service” One-Stop-Shop – Wasserstoff – Funding advice (bmwk.de).

National and European banks
European and national banks such as the EIB and KfW leverage private capital investments in green hydrogen projects. A wide variety of financing instruments – including debt and equity finance, as well as investment guarantees – are available in addition to previously mentioned EU support programmes.

For instance, the EIB will provide financing advisory support as well as dedicated EIB financing products (European Investment Bank, 2021) for green hydrogen projects introduced through Hydrogen Europe – the association representing European industry, research and national and regional associations in the hydrogen and fuel cell sectors.

Private finance such as venture capital funds
Private finance such as venture capital funds (e.g. Breakthrough Energy founded by Bill Gates) and private banks are also showing interests in investing in the hydrogen sector. With over $1 billion raised in committed capital, Breakthrough

Energy, through its Energy Catalyst platform, funds and invests in project companies utilising emerging climate technologies including clean hydrogen, storage, sustainable aviation fuel, etc. (Breakthrough Energy, 2022). A special programme in Europe has recently been established (Breakthrough Energy Europe) to support research and innovation in clean technology, including green hydrogen (Breakthrough Energy, 2022).

However, hydrogen projects solely based on private financing are yet to gain momentum given that there are no fully functioning markets yet for offtakers or pricing green hydrogen products.

4.5 Where to go for more information

The following resources are available to learn more about investing (in H_2) in Ghana:

- **Ghana Investment Promotion Centre – GIPC**
  Investment attraction and promotion agency under the Office of the President. Mandate of attracting and promoting investments, investment facilitation and helping establish and maintain liaisons between investors and Ministries, Government departments and agencies, institutional lenders and other authorities concerned with investments.

- **Doing Business and Investing in Ghana (pwc.com)**
  Guide on doing business in Ghana, published by PWC (2020), including an overview of regulatory and tax requirements.

- **Doing business – Ministry of Trade & Industry (moti.gov.gh)**
  Ministry of Trade and Industry describing minimum investment requirements for investing in Ghana.

- **Home – Ghana Invest (ghana-invest.org)**
  A private organisation which serves as an intermediary for Ghanaian and foreign businesses, government agencies and organisations.

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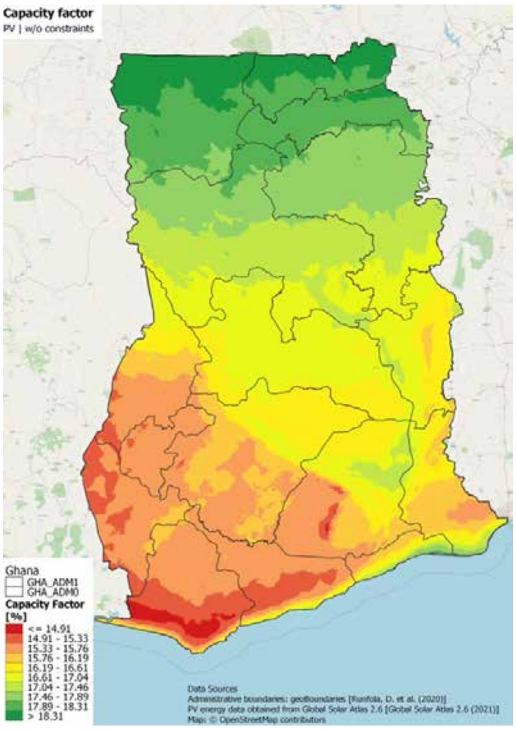
Appendix

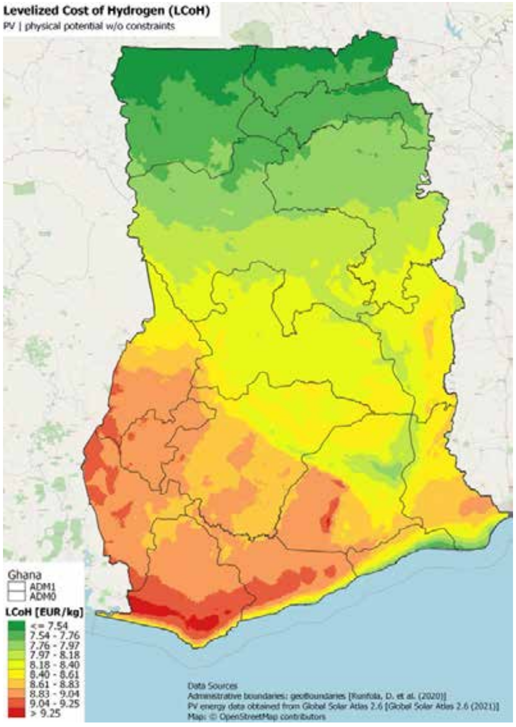
LCoH GIS maps and cost assumptions

FIGURE 20. PV CAPACITY FACTOR



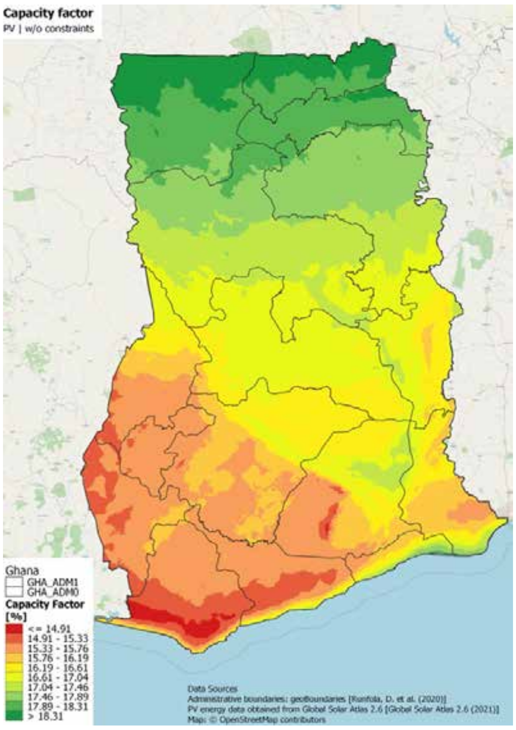
Source: Authors' own illustration, ENGIE Impact GmbH (2023)

FIGURE 21. LEVELISED COST OF HYDROGEN (LCOH)



Source: Authors' own illustration, ENGIE Impact GmbH (2023)

FIGURE 22. HYDROGEN PRODUCTION POTENTIAL



Source: Authors' own illustration, ENGIE Impact GmbH (2023)

TABLE 16. GIS MAP LCOH ASSUMPTIONS

Levelised Cost of Hydrogen Assumptions (GIS maps)		
Water price	4	EUR/m^3
Electrolysis efficiency	62	%
CAPEX PV	713	EUR/kWi
CAPEX Electrolysis	1,300	EUR/kW
fixOPEX PV	20	EUR/kW/a
fixOPEX Electrolysis	15	EUR/kW/a
varOPEX PV	0	EUR/kWh/a
varOPEX Electrolysis	0	EUR/kg/a

TABLE 17. SUMMARY OF PV AND GREEN HYDROGEN PRODUCTION POTENTIAL BY REGION

Region	PV capacity factor PV [%]	Theoretic green hydrogen production potential		LCoH
		Area-specific potential [tpa/km²]	Total potential [tpa]	[EUR/kg]
Western North Region	15.46%	3,697	8,195,697	8.85
Ahafo Region	15.51%	3,682	4,076,418	8.87
Bono East Region	16.71%	3,978	61,524,052	8.20
Savannah Region	17.31%	4,090	100,353,528	7.95
North East Region	18.03%	4,248	19,312,134	7.63
Oti Region	16.63%	3,955	25,648,338	8.24
Western Region	15.35%	3,669	12,489,011	8.93
Eastern Region	16.20%	3,926	19,192,280	8.33
Northern Region	17.49%	4,129	60,088,805	7.87
Central Region	15.57%	3,749	2,223,063	8.75
Ashanti Region	16.04%	3,893	25,041,435	8.39
Bono Region	15.94%	3,833	16,272,000	8.51
Volta Region	16.26%	3,905	11,509,346	8.38
Upper West Region	18.23%	4,298	57,192,911	7.54
Upper East Region	18.32%	4,300	15,858,772	7.53
Greater Accra Region	16.54%	3,959	2,763,693	8.28

Potential business case questionnaire

TABLE 18. CASE STUDIES QUESTIONNAIRE

Question	
1	Does the Company have decarbonisation goals/objectives? Are these major factors in your current investment planning?
2	Current use of hydrogen/ammonia (processes used, volume, source)
3	How do you currently transport/store your hydrogen?
4	Have you installed, or do you plan to install, PV at your facility? If not, why not?
5	Do you face challenges in the supply chain (reliable grid electricity, sourcing feedstock since COVID and Ukraine, etc.)?
6	Have you considered local green H_2 production? What aspects are you in favour of? What against?
7	Opportunities for improvement. What regulatory/policy changes would make it easier for you to do business? What types of incentives or financial support for modernisation/decarbonisation do you wish were available?

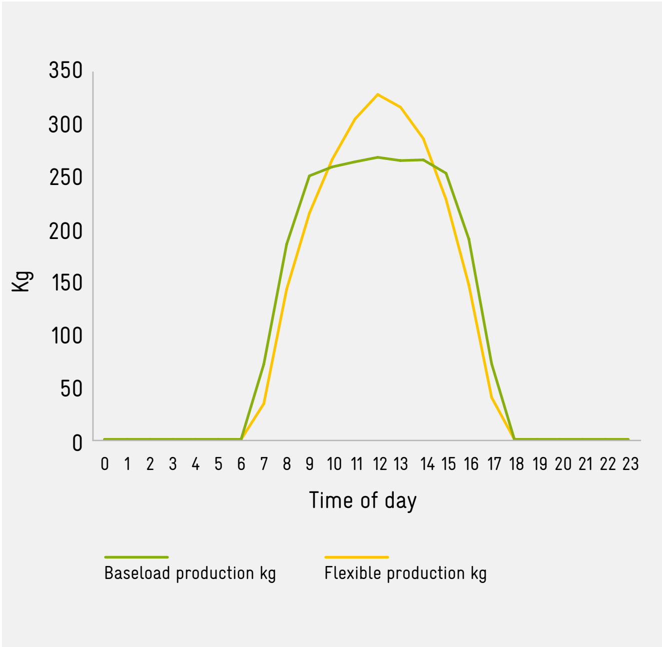
Business cases. Baseload vs flexible operation

It is necessary to keep in mind that oversizing of both PV and EL for a baseload H_2 supply is always required when operating hydrogen production from PV. For example:

- Consider a H_2 demand of 800 tpa, with a baseload hourly demand of approx. 91 kg/h
- This requires, at minimum, an electrolyser of approx. 5 MW if it the electrolyser were to be running 24/7/365 at full load
- Considering an average capacity factor of PV systems of 20%, a PV system of 5x the electrolyser capacity is required, at minimum, to supply enough electricity over the course of the year (without matching hourly demand)
- Considering the day/night characteristics of sun light and no electricity storage, the electrolyser needs to be oversized by a factor of approx. 2 (charging H_2 storage during the day)
- In this example the electrolyser capacity would be at least ~10 MW and the PV capacity would be at least 25 MW.

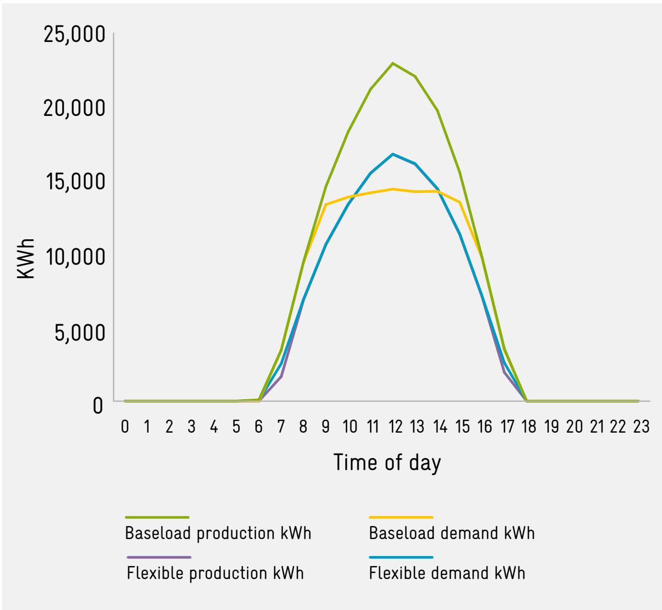
Since, from the optimisation point of view, the installation of a PV system is less expensive than the installation of an electrolysis system, the PV system is more strongly oversized than the electrolyser. The following two figures show the same annual volume of H_2 production, in flexible and baseload mode. The first figure shows the production of H_2 in flexible mode. In this case, the electrolyser needs to be oversized to be able to take full advantage of the solar peak. Whereas the green line shows production under baseload where more H_2 is produced during off-peak times, filling the H_2 storage for use when needed. However, in order to be able to produce this extra H_2 outside of the solar peak, the PV plant must be scaled up to provide the power. This can be seen in the second figure where the green and yellow lines show the electrical demand of the electrolysers in baseload and the energy production of the PV field. To provide the extra energy during the off-peak period, the solar field must be oversized; this also results in significant "extra" electricity (the difference between the green and yellow lines) during peak solar production.

FIGURE 23. FLEXIBLE VS BASELOAD H_2 PRODUCTION



Source: Authors' own illustration, ENGIE Impact GmbH (2023)

FIGURE 24. FLEXIBLE VS BASELOAD ELECTRICITY PRODUCTION AND CONSUMPTION



Source: Authors' own illustration, ENGIE Impact GmbH (2023)

Business case financial calculation methodology

The business cases presented are illustrative of the conversion to green hydrogen for current conventional hydrogen consumers. As the business cases focus on the grey-to-green H_2 conversion, the indicative financial assessment is based on the levelised cost of hydrogen (LCoH) and the "effective" LCoH. The LCoH represents the cost to produce 1 unit (1 kg) of hydrogen, taking into account the time value of money in the form of the applied discount rate. It is calculated by dividing the total discounted lifetime system costs by the lifetime discounted volume of hydrogen production.

The first step in calculating the LCoH for the selected business is the choice of investment location, electrolyser technology and required hydrogen production volumes. The CAPEX and OPEX assumptions for the different electrolyser technologies are described in the PtX costs section. One of the key aspects of the model is the choice of electrolyser operating mode: baseload or flexible operation mode. Most key calculation assumptions for the business cases are in Table 19

TABLE 19. GHANAIAN LCOH BUSINESS CASE ASSUMPTIONS

Business Case Assumptions		
Prices		
Tap water price	EUR/m³	2.00
Electricity tariff (sell)	EUR/kWh	0.07
Oxygen tariff (sell)	EUR/kg	0.30
Taxes		
Import tax rate on PV	%	-
Import tax rate on electrolyser system	%	0.10
Operation		
Oxygen production volume per 1 kg of H_2	kg	8.0
Annual inflation rate (Local)	%	10.0
Water tariff escalation rate	%	2.0
Electricity tariff escalation rate	%	2.0
Oxygen escalation rate	%	0.0
Hydrogen storage	hrs	72
Financing		
Depreciation method		Straight-line depreciation
Operation period	years	25
Discount rate	%	8.0
Debt/equity ratio	%	60.0
Repayment period	years	10
Up-front fee	% of debt capital	1.0
Commitment fee	% of undrawn debt	1.5
Applied interest rate	%	9.0

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