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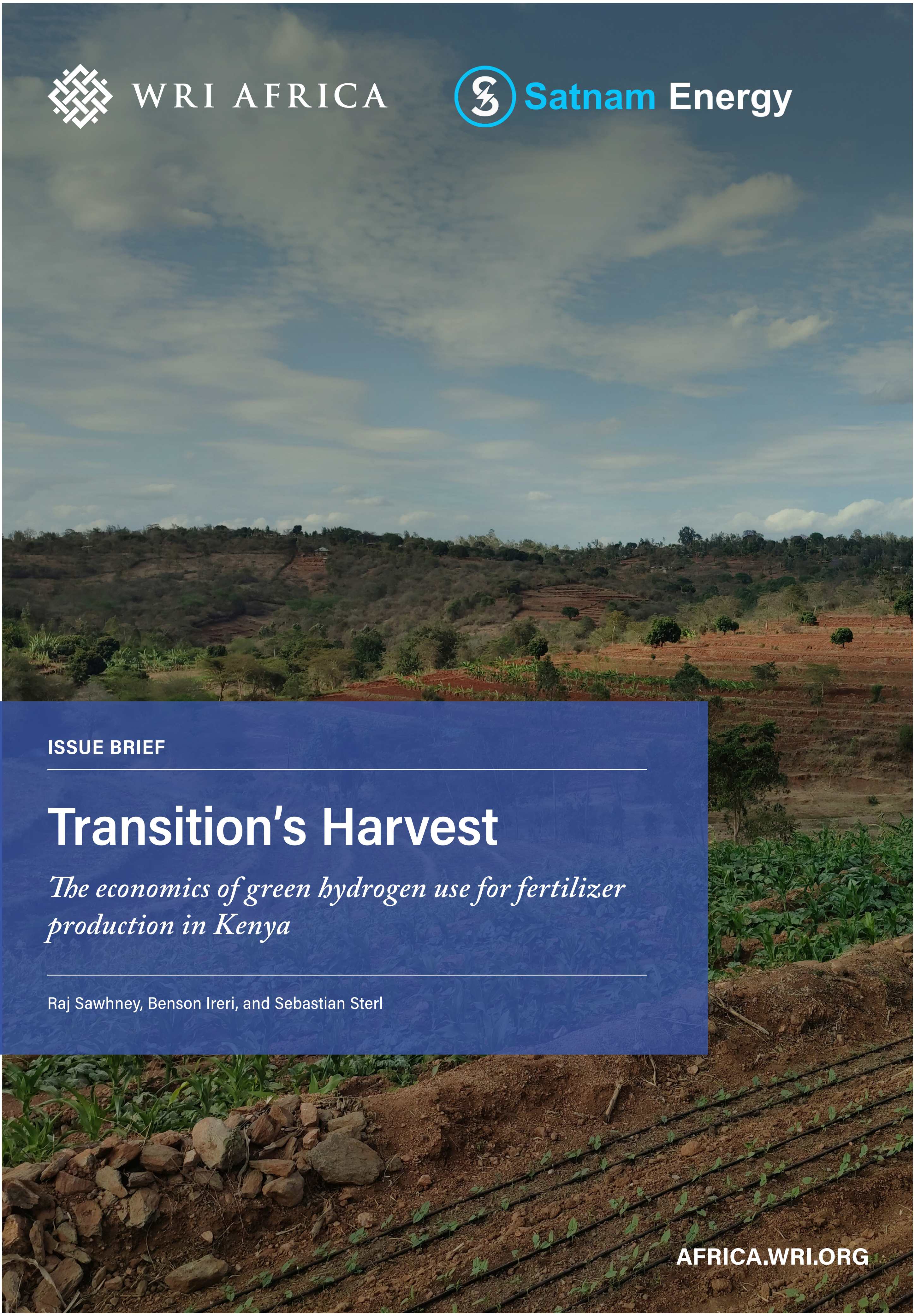

ISSUE BRIEF

Transition's Harvest

The economics of green hydrogen use for fertilizer production in Kenya

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Issue briefs focus on policy issues, and clearly draw out the implications of existing evidence for decision makers.

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HIGHLIGHTS

- Kenya faces a critical energy transition challenge, with emissions projected to rise six-fold by 2050, driven by increased energy demand across residential, industrial, and transportation sectors. Green hydrogen, particularly in fertilizer production, is identified as a key component of Kenya's decarbonization strategy.
- This report, using green hydrogen and ammonia cost modeling, assesses the technical, economic, and social challenges that Kenya must address in order to kickstart a successful, equitable domestic green fertilizer industry.
- Without policy and financial intervention, domestic green fertilizer production is economically unviable and inequitable for the local population. High green hydrogen production costs result in domestic fertilizer being ~20 percent more expensive than current imports.
- Farmers cannot adequately absorb this cost increase, potentially leading to a 10.4 percent decrease in fertilizer application rates, and a 7.6 percent decrease in overall crop production.
- Kenya also faces non-economic challenges including fertilizer value chain inefficiencies, a lack of technical expertise, and equity and sustainability concerns that must be addressed.
- To achieve economic viability, domestic fertilizer production must both reduce production costs through concessional financing tools like currency hedges and low-interest-rate loans and increase revenue streams by selling into Kenya's carbon market and exporting to international markets with higher willingness-to-pay.

Executive summary

Context

Kenya faces a critical transition point in its energy and emissions trajectory. Without strategic intervention, the country's CO_2 emissions could increase more than six-fold from 20 million tons (Mt) in 2021 to 130 Mt by 2050, driven by economic development and population growth. This dramatic increase reflects the country's development imperatives, though on a per capita basis, emissions would remain significantly below global averages.

While the country's renewable energy foundation provides advantages, it is not sufficient on its own to address all the challenges facing the sector. Kenya has successfully developed substantial renewable electricity capacity with geothermal, hydropower, wind, and solar contributing over 80 percent of its electricity generation. However, hard-to-abate sectors, including transportation, industry, and agriculture, require solutions beyond electrification.

Agriculture represents both a significant emissions source and a strategic economic sector for Kenya. The sector employs approximately 40 percent of the country's total population and 70 percent of the rural population, while contributing roughly 33 percent of the country's GDP (FAO n.d.). Agricultural productivity remains heavily dependent on fertilizer inputs, with Kenya currently importing nearly all its fertilizer requirements at substantial economic cost.

Fertilizer price volatility and supply chain disruptions have created significant food security challenges. The Russia-Ukraine conflict and COVID-19 pandemic have underscored Kenya's vulnerability to international market disruptions, as fertilizer prices surged at the height of both events. This price instability has a direct impact on agricultural yields, food prices, and rural livelihoods.

Green hydrogen presents a potential strategic solution at the intersection of climate and development priorities. Kenya's National Hydrogen Strategy identifies green hydrogen as a pathway to establish domestic fertilizer production capacity while leveraging the country's renewable resources. This approach addresses multiple national priorities, including emissions reduction, energy security, agricultural productivity, and industrial development.

About this report

This study provides an analysis of Kenya's green hydrogen-based fertilizer production potential, evaluating both economic viability and implementation barriers. The research combines 15 years of renewable energy data and cost modeling with assessment of critical non-economic challenges including technical expertise gaps, fertilizer value chain inefficiencies, and resource competition with electrification and water security priorities. By examining the full production chain from hydrogen to ammonia to fertilizer, alongside workforce deficits and market disruptions like those seen in the National Cereals and Produce Board's subsidy scheme, the report provides actionable insights for Kenya's 2025 NDC revision process. The findings target policymakers, financing institutions, and energy developers with specific recommendations for overcoming the identified barriers. These include policy frameworks, capacity-building initiatives, and targeted financial mechanisms designed to improve cost competitiveness while ensuring equitable access to agricultural inputs.

Key findings

Modeled green hydrogen production in Kenya is currently expensive compared to incumbent fuels. The median production cost is estimated at \$6.10/kg, driven primarily by solar and electrolyzer capital expenditures and high costs of capital. Even in the most optimistic scenarios, green hydrogen costs are not projected to fall below \$3.90/kg by 2050, remaining significantly more expensive than gray hydrogen production costs of \$1.00–\$2.00/kg.

The cost differential between green and gray ammonia production is also substantial. Domestic green ammonia costs are twice as expensive as domestically produced gray ammonia, primarily due to the high cost of green hydrogen feedstock. This cost difference translates to higher fertilizer prices, potentially leading to reduced fertilizer application and crop production.

Non-economic barriers also present significant challenges to green hydrogen adoption. A lack of technical expertise in the renewable energy and hydrogen sectors make implementing projects difficult. Project developers must weigh the potential use of electricity and water for green hydrogen against other demand sources, like rural electrification and agriculture.

Furthermore, the high estimated domestic fertilizer costs could exacerbate existing inefficiencies within Kenya's fertilizer value chain. Retail agro-dealers cannot afford to stock high-priced, non-"name brand" fertilizers and replace higher volume, lower price point products. Without access to agro-dealer shelves, domestic fertilizer would need to be introduced into Kenya's fertilizer subsidy program for distribution to local populations. However, high leakage rates and induced public-private competition are barriers to adoption.

Conclusion and recommendations

To overcome the challenges facing domestic green fertilizer production, Kenya must take a multi-faceted approach. Reaching economic viability will require the country to both reduce production costs and find higher-paying or external revenue sources. To do so, the following policy and financing tools are recommended:

- **Leverage Kenya's carbon market**: The Climate Change Act provides a framework for a carbon credits market, which could offer an additional revenue stream for a green fertilizer project. The Act also requires the implementation of a community benefits agreement, which could help to address equity concerns.
- **Explore international markets for export**: Expand hydrogen and ammonia production capacity to capitalize on exports to high-value international markets, enabling cross-subsidization and lower domestic prices.
- **Implement innovative financing solutions**: Local-currency bonds and currency risk hedging mechanisms could help reduce the cost of capital, one of the largest cost barriers to green hydrogen, ammonia, and fertilizer projects.
- **Develop public-private partnerships**: A Build-Operate-Transfer model could bring in necessary technical expertise and investment while allowing for knowledge transfer to local communities.
- **Address structural inefficiencies**: Reform the existing fertilizer subsidy scheme to minimize market distortions and ensure equitable access to green fertilizers.

By implementing these recommendations, Kenya could pave the way for a sustainable and economically viable green hydrogen future. This transition offers the potential to stabilize fertilizer supply, enhance food security, create jobs, and support broader industrial growth, advancing Kenya's long-term sustainable development goals.

Introduction

Kenya is at a critical moment in the global shift towards clean energy. Over the past five years, hydrogen has emerged as a promising solution to cut emissions and drive economic growth. Governments and industries worldwide initially embraced clean hydrogen with great optimism, viewing it as a key solution for decarbonizing sectors like heating, power generation, aviation, and steel-making. This optimism created significant global hype. The number of announced hydrogen projects surged in 2021, with promises of rapid scale-up and major investments. However, reality has since tempered these expectations. By early 2024, only 7 percent of announced hydrogen projects worldwide had reached a Final Investment Decision (FID), highlighting the gap between ambition and reality (Burgess et al. 2024).

Several challenges contributed to slowing momentum. High production costs have made green hydrogen significantly more expensive than fossil-based alternatives (Navarrete and Zhou 2024). The technology required, including electrolyzers and specialized infrastructure, has proven more complicated and costly to deploy at scale than initially expected (Crellin 2024). Additionally, uncertainties around policy frameworks, regulatory support, and clear market demand have deterred investors, causing many proposed projects to stall or scale back.

Despite these challenges, global interest in hydrogen remains resilient, though more focused. Strong economic incentives continue to propel its adoption in key hard-to-abate sectors. The European Union's Carbon Border Adjustment Mechanism (CBAM) will soon impose tariffs on imported goods based on carbon intensity. This provides exporters with a strong incentive to use green hydrogen in sectors such as steel, chemicals, and transportation fuels to maintain competitiveness in European markets. Germany's H2Global initiative further supports hydrogen adoption by directly subsidizing green hydrogen derivative projects such as ammonia, methanol, and sustainable aviation fuels (SAF). The program offers long-term, above-market offtake contracts so that producers can cover the gap between high production costs and current market prices, significantly reducing investment risks and attracting private capital.

Japan and South Korea have also implemented market mechanisms to accelerate hydrogen adoption. Japan's new Contract for Difference (CfD) subsidy scheme provides approximately ¥3 trillion (around US$19 billion) over 15 years. Under this program, hydrogen producers—both domestic and foreign—receive stable revenues, bridging the price gap between low-carbon hydrogen and fossil fuels. This scheme reduces investor risk, drives down long-term production costs, and accelerates the development of Japan's hydrogen economy (Bocobza et al. 2024). Similarly, South Korea has introduced the Clean Hydrogen Portfolio Standard using competitive auctions to secure long-term hydrogen supply contracts for power generation. By encouraging competition among suppliers, these auctions aim to steadily increase hydrogen's share in South Korea's energy mix while keeping costs manageable (Singh et al. 2024).

Beyond economic factors, strategic considerations also strongly influence global hydrogen adoption. For many countries, hydrogen development represents a strategic opportunity to strengthen domestic industries, generate employment, and enhance energy security. Investing in local hydrogen infrastructure reduces reliance on imported energy, protecting economies from volatile global fuel prices and disruptions in international supply chains.

Kenya recognizes green hydrogen as an opportunity to achieve these strategic and decarbonization objectives. In September 2023, the country partnered with the European Union (EU) to launch its first Green Hydrogen Strategy and Roadmap, targeting the construction of 100 megawatts of electrolyzer capacity by 2027, and up to 250 megawatts by 2032 (Burgess 2023). The EU has committed approximately $13 million (€12 million) to support Kenya's hydrogen ambitions, signaling international confidence in the country's potential.

Agriculture is Kenya's priority sector for green hydrogen. Farmers in the country are heavily dependent on imported nitrogen-based fertilizers, particularly calcium ammonium nitrate (CAN) and diammonium phosphate (DAP). This reliance leaves farmers vulnerable to volatile global markets, supply chain disruptions, and steep import bills. In 2023 alone, Kenya spent approximately $451 million on fertilizer imports, highlighting the need for a more sustainable and secure alternative (Trading Economics n.d.).

Kenya can enhance food security, lower fertilizer imports, and stabilize prices by investing in local green hydrogen fertilizer production. This move also aligns closely with the country's broader goals of industrialization, job creation, and increased energy independence.

This report examines the barriers Kenya must address to successfully establish a green hydrogen fertilizer industry. It begins by providing an overview of the country's current fertilizer market and explores the potential roles of green hydrogen and ammonia within this context. The publication then evaluates Kenya's competitiveness in the broader regional market by estimating baseline production costs for green hydrogen and ammonia, and identifying key cost drivers. It also analyzes the potential impact of higher green fertilizer costs on agricultural productivity and fertilizer affordability. Following this, the report addresses additional, non-cost-related barriers that could hinder the adoption of green fertilizers. Lastly, it presents targeted policy and financing strategies—including innovative financing models, carbon market mechanisms, public-private partnerships, and others—to address both economic and non-economic challenges.

If Kenya successfully navigates these barriers, it can serve as a model for other East African countries facing similar challenges. Establishing a domestic green hydrogen-based fertilizer industry would position the country as a regional leader, boosting economic resilience, improving food security, and supporting sustainable development across East Africa.

The status of Africa's green hydrogen ambitions

Several African governments have published dedicated hydrogen strategies or integrated hydrogen into broader energy policies, signaling high-level commitment. These strategies differ in their production targets, technological pathways, intended end-use cases, and the balance between export and domestic markets, as demonstrated in Table 1. While most strategies emphasize hydrogen exports, there is diversity across the amount of hydrogen prioritized for domestic consumption versus export markets. For instance, Morocco's Green Hydrogen Roadmap leverages its substantial solar and wind resources with a clear export orientation, aiming for 14 terawatt-hours (TWh) of green hydrogen production, 10 TWh of which is earmarked for export. Egypt's National Low-Carbon Hydrogen Strategy (2023) adopts a phased deployment approach (pilot in the 2020s, scale-up in the 2030s, full deployment by the 2040s) targeting both green and blue hydrogen. Egypt's strategy is also export-focused, aiming to secure 8 percent of the global hydrogen market by 2040, with more than 80 percent of its hydrogen intended for export in 2030, and around 50 percent by 2040. Mauritania leverages its excellent wind and solar resources, coupled with geographic proximity, to supply green hydrogen primarily to European markets.

In contrast, South Africa adopts a hybrid strategy, balancing export ambitions with domestic industrial decarbonization, specifically targeting industries such as green steel, fertilizer, and sustainable aviation fuel. Similarly, Kenya's approach emphasizes domestic priorities—particularly fertilizer production—as an initial step before expanding into broader applications and exports in the medium to long term.

Table 1 captures the varied maturity and ambition levels across Africa, with projects ranging from early-stage concepts to operational. This diversity underscores the complexity of hydrogen development pathways in the continent and points to the potential that intra-African cooperation and knowledge exchange could have on

Table 1. **Progress among African countries in formulating national hydrogen strategies, launching clean hydrogen projects, and planning electrolyzer capacity**

COUNTRY	PUBLISHED HYDROGEN STRATEGY?	NUMBER OF PROJECTS	TOTAL PLANNED ELECTROLYZER CAPACITY (MW)
Angola	In progress	▪ Feasibility study (2)	604
Botswana	In progress	▪ Feasibility study: (1)	0
Democratic Republic of the Congo	No	▪ Concept: (1)	0
Djibouti	No	▪ Concept: (3)	1000
Egypt	Yes	▪ Concept: (24) Decommissioned: (1) Feasibility study: (9) ▪ Operational: (1)	58,275
Kenya	Yes	▪ Concept: (1) ▪ Feasibility study: (4) ▪ Operational: (1)	1421
Morocco	Yes	▪ Concept: (11), FID/Construction: (1) Feasibility study: (2) ▪ Demonstration: (1)	24,815
Mozambique	Yes	▪ Concept: (1)	8427
Mauritania	Yes	▪ Concept: (6) ▪ Feasibility study: (4)	94,098
Namibia	Yes	▪ Concept: (1) FID/Construction: (3) Feasibility study: (7) ▪ Operational: (1)	4929
Niger	No	▪ Concept: (1)	0
South Africa	Yes	▪ Concept: (6) ▪ FID/Construction: (1) ▪ Feasibility study: (6) ▪ Demonstration: (1) ▪ Operational: (1)	27,478
Zimbabwe	No	▪ Concept: (1) Decommissioned: (1)	22

Notes: FID = Final Investment Decision. Countries with published hydrogen strategies have more projects. Egypt, Mauritania, and Morocco lead across both number of projects and planned electrolyzer. The data are aggregated from the International Energy Agency (EIA) project database which was last updated in October 2024. To the best of their ability, the authors have also tried to include projects not included in the database, or those commissioned or announced after October 2024.

Source: IEA Hydrogen Production and Infrastructure Database.

expediting and de-risking hydrogen development across the continent (European Investment Bank 2022). Many of these initiatives are currently under way. The Africa Green Hydrogen Alliance (AGHA), established by six leading African nations—Egypt, Kenya, Mauritania, Morocco, Namibia, and South Africa, aims to build cooperation in public policy, capacity building, financing, and certification to mobilize green hydrogen production for both domestic use and export (ESMAP 2024).

The East Africa Hydrogen Corridor envisions connecting multiple countries to interlink evolving hydrogen ecosystems within the region. It aims to mitigate national risks and reduce market uncertainties by promoting green hydrogen applications across various sectors, including power supply, fertilizer production, and maritime transport. Such regional integration not only enhances energy security but also stimulates economic growth through shared infrastructure and knowledge exchange (Greenbury et al. 2022).

These collaborative efforts underscore the importance of intra-African partnerships in developing a robust and sustainable hydrogen economy, leveraging shared resources and expertise to address common challenges and capitalize on collective opportunities.

The fertilizer landscape in Kenya

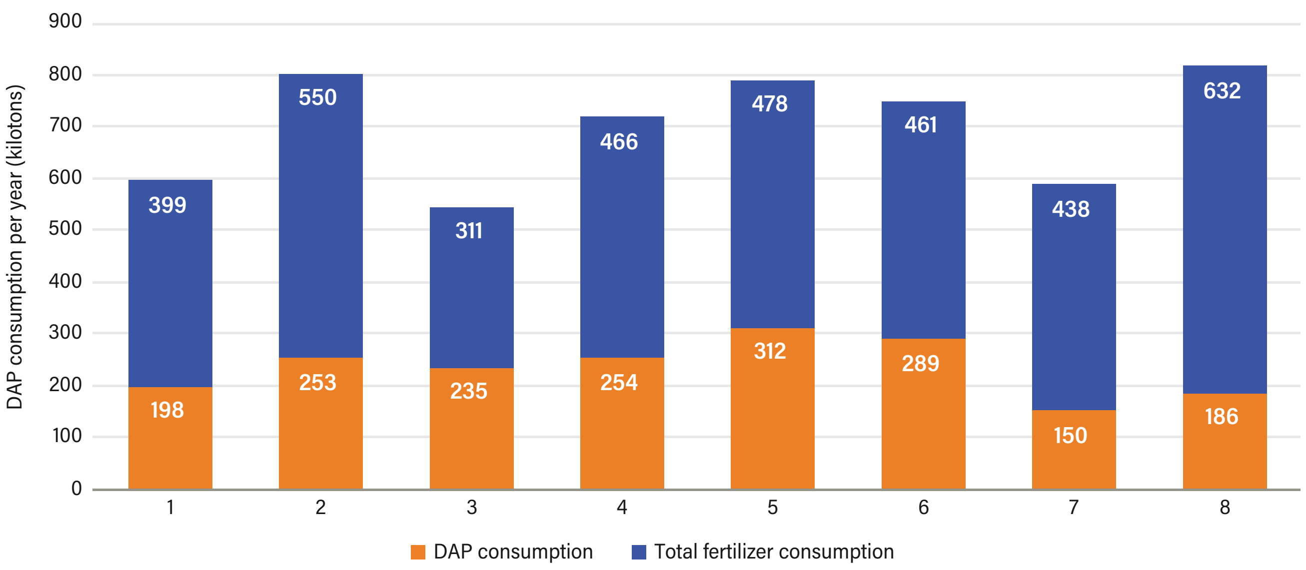
Kenya's agricultural productivity relies heavily on synthetic fertilizers, particularly nitrogen-based products such as diammonium phosphate (DAP), urea, and calcium ammonium nitrate (CAN). Annually, the country consumes approximately 750,000 metric tons of fertilizer (AfricaFertilizer 2024). DAP and CAN remain the most widely used fertilizers in Kenya, largely due to farmers' familiarity with them and their long-standing availability through government-supported programs. DAP, valued for its nitrogen and phosphorus content, is primarily applied at planting, while CAN and urea are commonly used for top-dressing during crop growth, especially for staple crops like maize.

In recent years, fertilizer consumption in Kenya has fluctuated significantly, with notable peaks and declines largely influenced by global market conditions. Figure 1 clearly illustrates these trends, emphasizing the significant share of DAP in the overall fertilizer market.

Fertilizer imports and distribution

Kenya's fertilizer market is heavily reliant on imports, with around 90 percent of supply sourced internationally, primarily from Russia, China, and the Gulf countries (AfricaFertilizer 2024). This heavy reliance on imports makes Kenya susceptible to global market fluctuations,

Figure 1. **Stacked bar chart comparing overall fertilizer consumption and DAP consumption in Kenya**



Source: Data from Africa Fertilizer (2024); Satnam Energy Calculation.

currency volatility, and logistical disruptions. For instance, fertilizer imports dropped from roughly 834,000 metric tons in 2020 to about 658,000 metric tons in 2022 due to soaring global prices and supply chain disruptions (AfricaFertilizer 2024).

Imported fertilizers enter Kenya through the Port of Mombasa and are primarily distributed by private firms including Yara, MEA Ltd., and Export Trading Group (ETG). Local blending facilities then produce tailored fertilizer blends using imported raw materials such as phosphate and potash. The National Cereals and Produce Board (NCPB) and Kenya National Trading Corporation (KNTC) support local distribution under government subsidy programs, while non-governmental organizations (NGOs) like One Acre Fund help extend reach to smallholders. Despite this network, transportation inland and reaching remote farmers remain logistical challenges, which result in low fertilizer application rates in counties with limited road infrastructure.

Kenya's fertilizer subsidy scheme

The Kenyan government has historically implemented fertilizer subsidies to cushion farmers from volatile global prices. The current National Fertilizer Subsidy Program provides the product at approximately half the market price, significantly reducing costs from around KSh 6000 ($46.5) to approximately KSh 2500–3500 ($19–27) per 50-kg bag (Ministry of Agriculture and Livestock Development 2024). Farmers register via local authorities or digital platforms and collect fertilizers from designated NCPB depots. Although broadly inclusive, the subsidy scheme has encountered distribution challenges, including logistical inefficiencies and occasional leakage into commercial markets.

Key challenges facing Kenya's fertilizer market and the potential role of green hydrogen

Despite government interventions, Kenya's fertilizer market remains constrained by several critical challenges. Price volatility is a significant issue; from 2020 to 2022, global fertilizer prices nearly tripled, significantly affecting Kenyan farmers and leading to an estimated 17 percent decline in both usage and imports (AfricaFertilizer 2024). High input prices led to suppressed demand, with maize yields dropping by about 7 percent in 2022 alone due to reduced fertilizer application rates (Agriculture and Food Authority 2024).

In addition, logistical inefficiencies drive up costs and hinder timely fertilizer delivery, with remote farming communities being the most affected. Delays in fertilizer distribution often undermine crop productivity, exacerbating vulnerabilities in the agricultural sector. These persistent challenges highlight the need for stable, affordable, and locally sustainable fertilizer solutions.

Addressing these vulnerabilities is central to Kenya's strategic shift toward domestic green hydrogen-based fertilizer production. By leveraging renewable energy sources available locally, green hydrogen-based fertilizers could reduce the country's exposure to international price fluctuations and supply chain disruptions, potentially enhancing both fertilizer affordability and agricultural productivity. However, to justify the transition toward green hydrogen and ammonia, it is essential to evaluate their economic viability and competitiveness compared to traditional fertilizers. The following sections provide a detailed analysis of these challenges, outlining the specific barriers that must be addressed for green hydrogen and ammonia to offer a sustainable, cost-stable solution for Kenya's agricultural sector.

Modeling analysis methodology

This analysis computes green hydrogen production costs throughout Kenya, at a resolution of 0.25 degrees latitude by 0.25 degrees longitude (approximately 550 km^2). This granularity captures local wind and solar variations in the levelized cost of hydrogen (LCOH) and offers a clearer view of geographic cost trends, enabling evaluation at county, subcounty, and other subnational scales. At each grid cell, an optimization procedure is run to identify the lowest green hydrogen production cost across a range of parameters. These parameters encompass renewable energy generation from wind and solar resources—based on hourly data averaged over 15 years—as well as capital *expenditure* and operating costs, cost of capital, and plant lifespan. A full list of parameter values and data sources, as well as a high-level description of the algorithm design is presented in Appendices A and B.

This analysis excludes grid-connected electrolyzers, as directly linking them to the existing grid without adding new renewable capacity could strain electricity supply and likely lead to higher system-wide costs, increased emissions, and reliability issues. It also excludes the impact of any existing domestic subsidies or tax incentives. The costs presented in this analysis reflect production costs only and do not account for storage or transportation expenses.

They are likely underestimates of true production costs since factors such as water expenses, land licensing, and construction time are not considered due primarily to data constraints within Kenya. These factors are usually not considered to be the largest cost drivers; water generally makes up ~2 percent of total project cost, and many projects are often co-located with demand, drastically decreasing midstream transportation costs. However, depending on an offtaker's demand profile, for example, constant 24/7 production, the cost associated with these factors, particularly downstream storage, could increase (Santana et al. 2024). Furthermore, the costs provided are levelized costs, calculated by dividing the total discounted capital and operating costs by the total discounted quantity of hydrogen produced over the lifetime of the plant. The analysis below presents lower-bound cost estimates. These estimates will provide key cost drivers and present a baseline from which relevant policy changes and financial incentives can be tested and implemented. The methodology is further explained in the Appendices.

Figure 2A. **Heatmap of current green hydrogen production costs throughout Kenya**

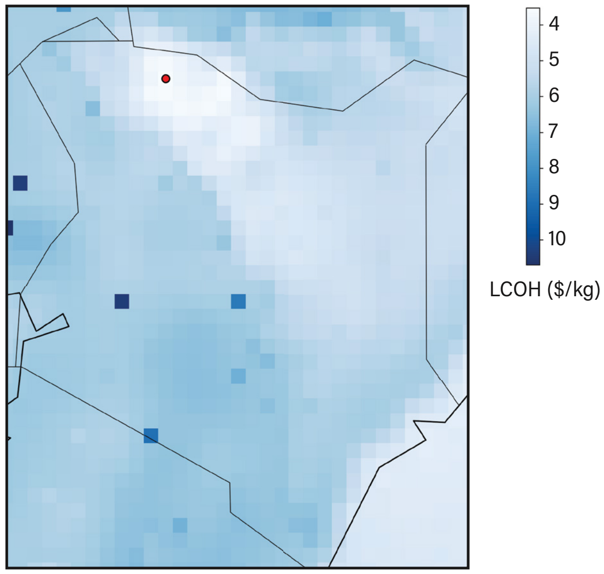


Figure 2B. **Mean, median, and minimum green hydrogen production costs throughout Kenya**

MEAN PRODUCTION COST ($/KG)	5.44
MEDIAN PRODUCTION COST ($/KG)	6.10
MINIMUM PRODUCTION COST ($/KG)	2.79

Note: The minimum cost location is denoted as a red dot in Figure 2A. Discount rate: 8.4 percent.
Source: ERA5 weather data (2008-2023); Satnam Energy Calculation.

Achieving cost parity: analyzing green hydrogen, ammonia, and fertilizer economics in Kenya

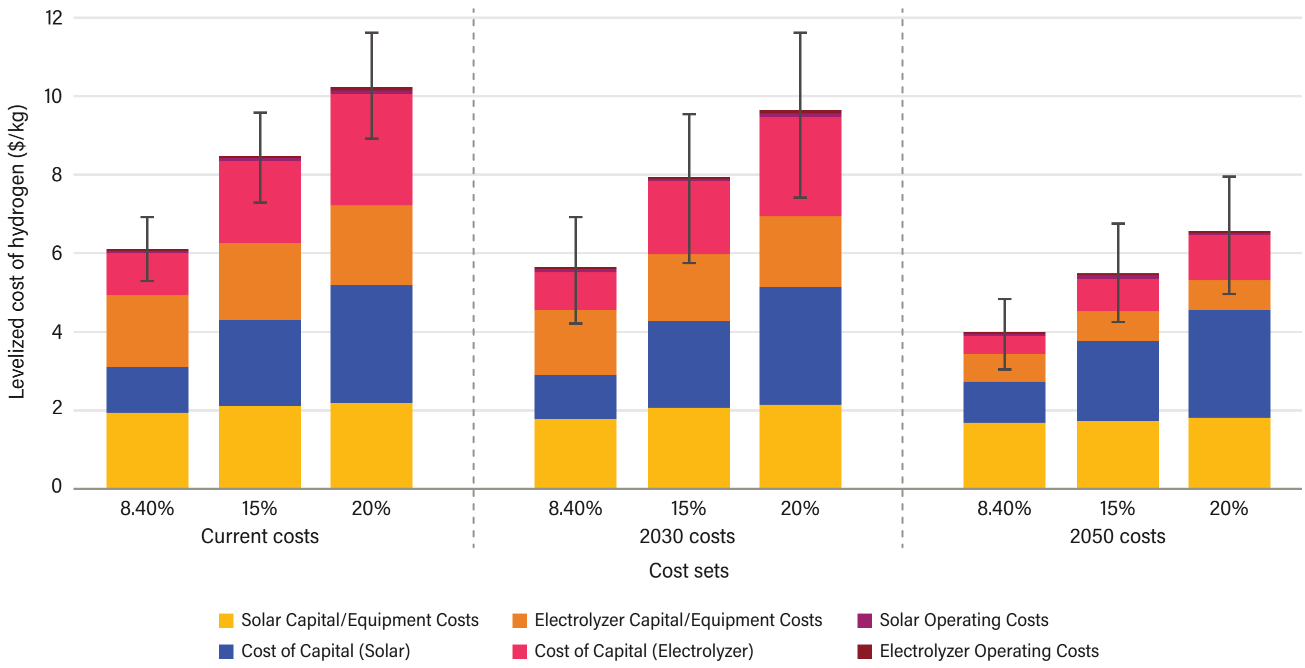
This section provides a techno-economic analysis of green hydrogen production in Kenya and its downstream impacts on ammonia and fertilizer manufacturing. It examines how variations in renewable energy availability, capital costs, and electrolyzer prices influence production costs and competitiveness with gray hydrogen. The analysis further explores the economic trade-offs for domestic green ammonia and fertilizer production, highlighting the challenges and policy implications for achieving cost parity and ensuring sustainable agricultural inputs.

Green hydrogen production costs in Kenya range from \$2.79 to over \$7.00/kgH_2 in the least favorable locations, as shown in Figure 2. These costs align with previous literature, which cites ranges of €3.7–9.9/kgH_2 (\$4.1–10.9/kgH_2) (Müller et al. 2023). The minimum cost location is found in the Lake Turkana region. Consistent wind speeds allow for high electrolyzer capacity factors, resulting in lower levelized costs of production. The range between minimum and median/mean production costs is a consequence of the difference in renewable energy availability across the region. Outside of the Lake Turkana region, Kenya lacks reliable wind resources, but is endowed with high solar capacity factors (over 20 percent), when compared globally (ENGIE Impact Gmbh 2023). Thus, this modeling finds that optimal production costs, throughout the majority of Kenya are achieved using solar-powered electrolysis. The remainder of this analysis will consider only median production costs in order to more accurately represent production costs throughout Kenya.

Cost reductions insufficient for green hydrogen parity

Median production costs are evaluated based on three cases: a business-as-usual scenario, an optimistic scenario with lower electrolyzer costs, and a pessimistic scenario with higher electrolyzer costs (Figure 3). The variation in these costs is represented in the error bars, with the business-as-usual value labeled and highlighted using bold text. Electrolyzer costs are projected across three different

Figure 3. **Breakdown of median green hydrogen production costs throughout Kenya at various discount rates**



Note: Each bar shows the median production cost at different costs of capital (8.4 percent, 15 percent, 20 percent). Error bars represent levelized cost given higher and lower electrolyzer cost estimates. Solar and electrolyzer capital expenditures make up most of the costs. As electrolyzer costs fall, its proportion of total levelized cost falls accordingly. Cost assumptions and data table are listed in Appendix A: Tables A-1, A-2, A-3, A-4.

Source: Solar/wind capital costs from IRENA (2021); Electrolyzer costs from IEA (2023a); Satnam Energy Calculation.

years: 2022, 2030, and 2050. Cost of capital also varies from 8.4 percent to 20 percent in order to evaluate the magnitude of effects that rising project risk and interest rates may have on LCOH (IEA 2024a).

Currently, the lowest cost of capital results in a median levelized cost of production of approximately $6.10. Higher costs of capital (15 percent, 20 percent) result in costs of $8.50 and $10.20, or cost multiples of approximately 1.4 and 1.7 times. By 2030 and 2050, declining electrolyzer costs will reduce production costs by approximately 10 percent and 56 percent, respectively, based on scenarios with the lowest cost of capital. Yet, the effect of increasing costs of capital remains, with highest levelized median costs in 2030 reaching $9.60 and $6.60 in 2050.

Cost of capital, solar capital expenditures, and electrolyzer capital expenditures are the largest drivers of overall production cost. Cost of capital alone, even in the lowest scenario, accounts for approximately 33 percent of total production cost, with solar and electrolyzer capital expenditures accounting for approximately 65 percent. Operating costs account for less than 5 percent of total production costs. Thus, even with optimistic electrolyzer cost reductions and cost of capital assumptions, levelized hydrogen production costs in Kenya do not fall below $3.90 by 2050. As a comparison point, the levelized cost of gray hydrogen production today is approximately $1.00–$2.00 and estimated to be $2.00 in Kenya (Schelling 2023; Enterprise 2022; Sayed 2022; Ministry of Energy and Petroleum 2023). Thus, if gray hydrogen costs hold consistent until 2050, green hydrogen costs would still be almost four times more expensive. Assuming a gray hydrogen carbon intensity of 10kgCO_2eq/H_2, this comparison imbues an implicit carbon price of $0.29/kg$CO_2$eq, over four times as expensive as the current carbon price in the EU's ETS ($0.0725) (IEA 2023b; Ember 2024). Thus, in order to be cost-competitive with gray hydrogen, falling electrolyzer costs are not sufficient. Achieving cost parity will require further reductions in either solar capital costs or the cost of capital.

Lowering the cost of capital would require mitigating underlying risk factors such as technology, political, and currency/exchange rate risks, commonly associated with green hydrogen projects (Saygin et al. 2023). Green hydrogen production carries substantial technical risk factors, primarily associated with electrolyzer lifetime, production rate, and maintenance uncertainty (OECD 2023). Projects in Kenya are also straddled with currency/exchange rate risk, which is associated with conducting transactions in a base currency with large exchange rate variations. Fluctuations in currency values can affect the costs and revenues of projects that involve international transactions. For projects in Kenya, where investments will likely be made in foreign currencies but revenues are earned in Kenya shillings, devaluation of the local currency could increase project costs and debt service in local terms. While not unique to Kenya, currency risk is likely a large barrier to low green hydrogen production costs and overall project financing, as shown in Figure 3. If left unaddressed, these risk factors, among others, could impede green hydrogen project development in Kenya.

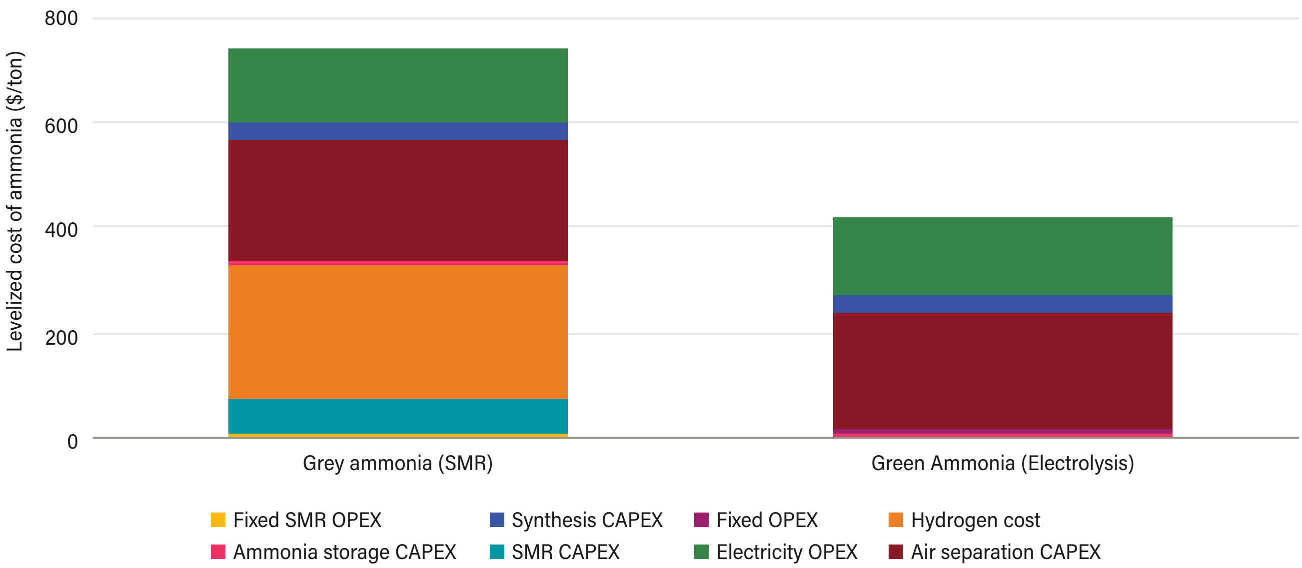
Green ammonia remains costly despite falling hydrogen prices through 2050

The median green hydrogen production price computed above is used to model and compare the break-even ammonia selling prices for domestic gray and green ammonia plants, highlighted in Figure 4. A complete list of modeling assumptions and a detailed model description are provided in Appendix B.

The green ammonia plant is assumed to access delivered hydrogen at a price of \$6.10/kgH_2 from a co-located hydrogen plant. The gray ammonia plant is assumed to generate hydrogen through natural gas (\$4/MMBtu) and steam methane reformation (SMR) and therefore entails high capital expenditure costs. While hydrogen feedstock costs are the largest cost drivers, the cost of capital accounts for 20 percent of total production cost in the gray case and 30 percent in the green case. Due to low natural gas prices, the hydrogen cost in green ammonia is roughly four to five times higher than in gray ammonia. This cost difference results in green ammonia that is twice as expensive than domestically produced gray ammonia. Achieving cost parity would require a fivefold increase in natural gas prices. The SMR process results in a carbon intensity of approximately 1790kgCO_2eq/tNH_3, which imbues a carbon price of \$0.43/kgCO_2, nearly seven times higher than the current EU carbon price. High green hydrogen costs make green ammonia production economically unviable—a trend that persists even as hydrogen prices decline.

Utilizing the hydrogen costs and sensitivities presented in Figure 3, the analysis evaluates the levelized cost of green ammonia across different time periods (hydrogen production prices) to evaluate the conditions under which green ammonia could become cost competitive. Historically,

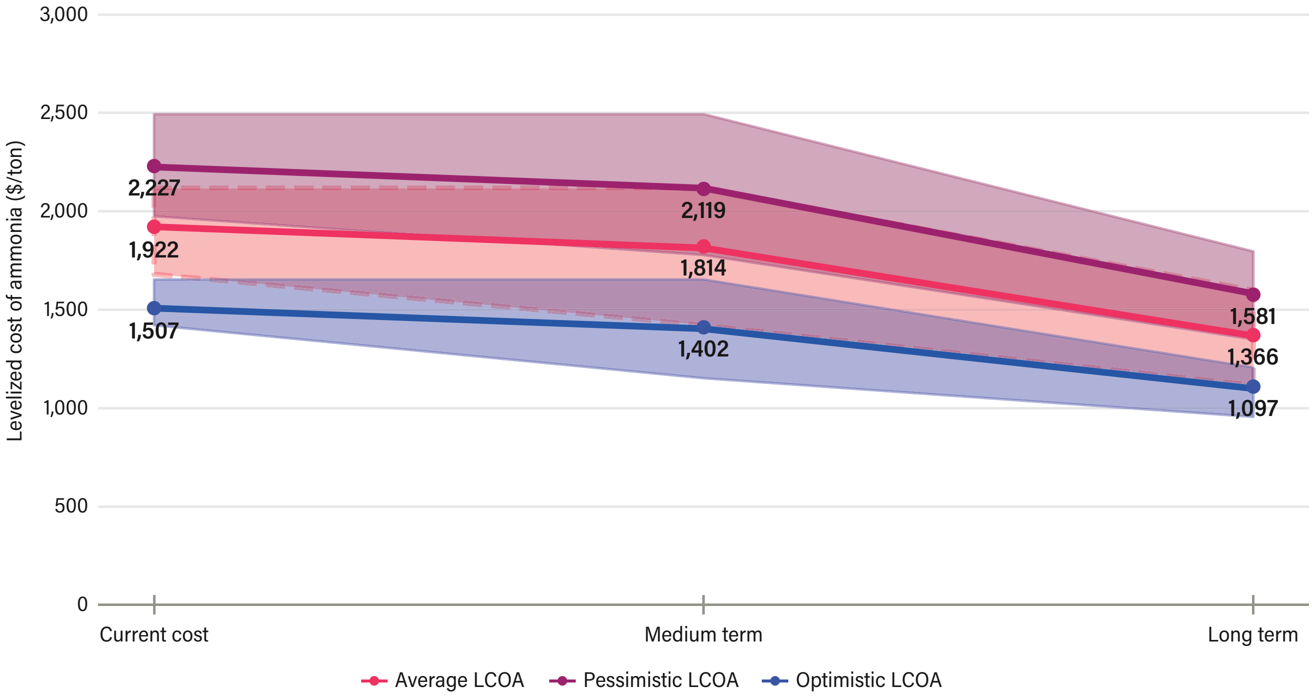
Figure 4. **Breakdown of break-even price required by a domestic gray ammonia plant against a green ammonia plant in Kenya**



Notes: SMR = Steam Methane Reformer, OPEX = Operating Expenditure, CAPEX = Capital Expenditure. We use the median green hydrogen production cost (\$6.10/kg) in the green ammonia example and a delivered natural gas price of \$4/MMBtu in the gray ammonia case. WACC: 8.4 percent. Cost assumptions and data table are listed in Appendix B: Tables B-1 and B-2.

Source: Ammonia capital costs from Jain et al. (2022), Nayak-Luke et al. (2021); Satnam Energy Calculation.

Figure 5. **Levelized cost of ammonia under various hydrogen production costs**



Notes: LCOA = Leveled Cost of Ammonia, WACC = Weighted Average Cost of Capital. Levelized costs of ammonia production are plotted at different time periods. Different time periods represent lower hydrogen costs (taken from the estimates in Figure 3. Optimistic and pessimistic LCOA trend lines are calculated using the optimistic (lower WACC) hydrogen production estimates and the pessimistic (higher WACC) hydrogen production estimates (e.g., the LCOA value of $1507 corresponds to a hydrogen cost of $6.10, the computed median current hydrogen cost in Figure 1). Shaded regions correspond to cost sensitivities due to uncertainty in electrolyzer costs for each of the pessimistic, average, and optimistic LCOA estimates.

Source: Electrolyzer capital costs from IEA (2024); Satnam Energy Calculation.

global gray ammonia prices have ranged from $200 to over $1100 at the peak of the Russia-Ukraine conflict (EIA 2022). Current green ammonia cost estimates range from $900 to $1100 from locations such as Australia, the Gulf Coast, and the Middle East (Edwardes-Evans et al. 2024).

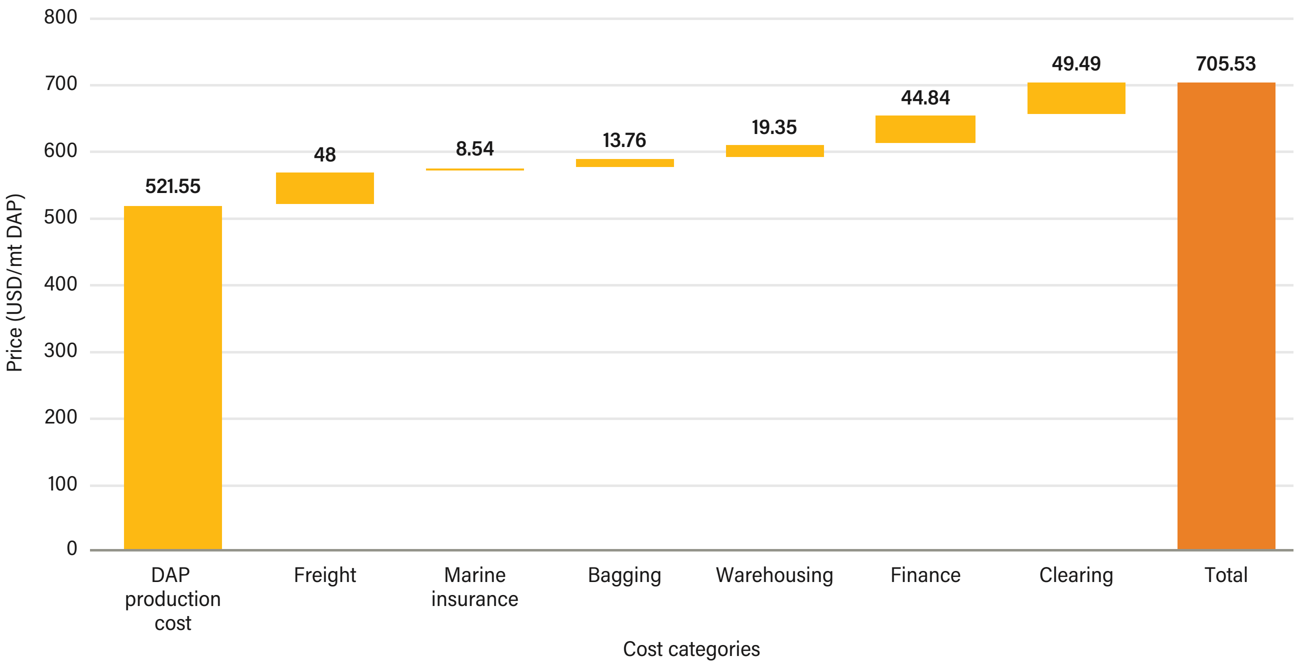
The analysis in Figure 5 indicates that Kenyan domestic green ammonia costs are unlikely to be cost competitive in the short- or medium-terms without financial or political intervention. Under the most optimistic assumptions, green ammonia production costs do not fall below $1400, higher than both current global gray and green price estimates. In the long-term, production costs align with top-end historical gray and green ammonia prices. To achieve cost parity, green hydrogen prices will need to fall drastically, a trend expected to be driven by reduction in capital costs, as well as decreased expenses for electrolyzers and renewable energy infrastructure. Without domestic policies, foreign mandates, or concessional financing, the existing cost premium associated with green ammonia will likely need to be passed on to the end consumer (fertilizer distributors and farmers), an unsustainable solution for a price-sensitive sector.

Green fertilizer production could lower use and yields without intervention

To understand how increased hydrogen and ammonia costs could affect fertilizer prices and usage rates, the cost of domestic DAP production using green ammonia is estimated and compared against Russian-imported DAP. As of 2023, DAP remained one of Kenya's top imported fertilizers, with imports exceeding 150,000 tons (AfricaFertilizer 2024).

The current costs associated with DAP imports from Russia are presented in Figure 6. Production costs represent over 70 percent of total imported fertilizer costs, with shipping, finance, and warehousing comprising the remainder. Establishing a domestic fertilizer plant in Kenya could offset approximately 20 percent of these import-related expenses—specifically freight, marine insurance, finance, and clearing costs—resulting in savings of about $150 per metric ton of DAP. Yet, these savings would be offset by higher ammonia feedstock prices. Domestic green ammonia is priced between three

Figure 6. **A breakdown of Russian DAP import costs**



Notes: DAP = Diammonium Phosphate. Production costs account for over 70 percent of total costs. Domestic fertilizer production would eliminate freight, marine insurance, finance, and clearing costs, or approximately 20 percent of costs. Cost data for each category were averaged over five years, from 2019 to 2024.
Source: Data adapted from Africa Fertilizer; Satnam Energy Calculation.

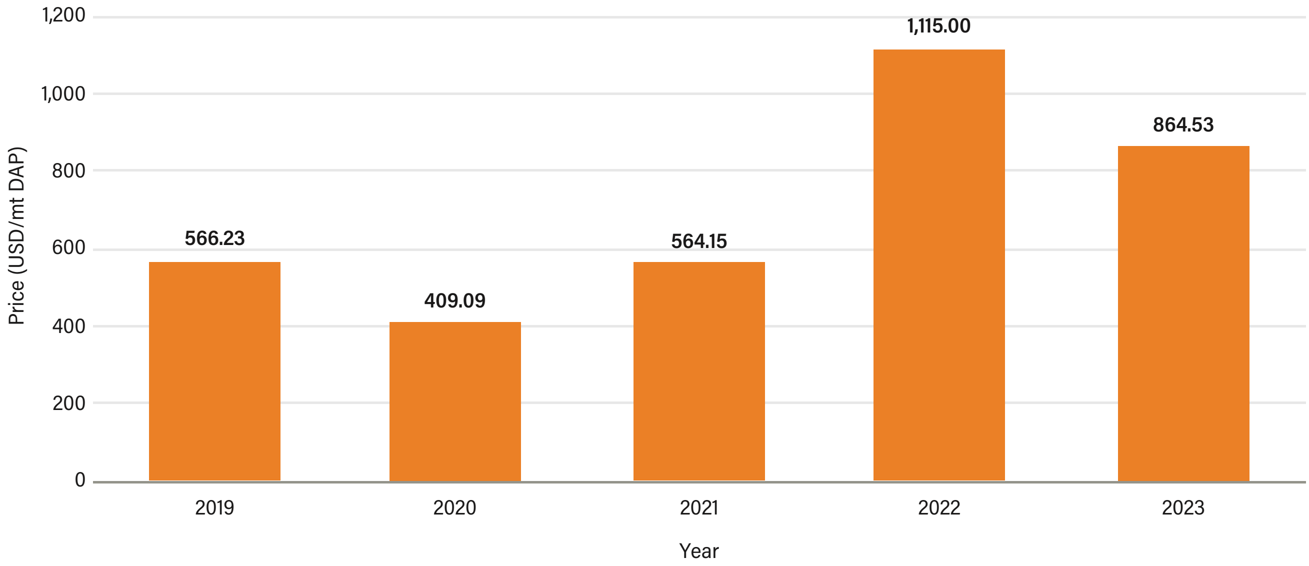
and four times the global average of approximately $500 per ton, while domestic gray ammonia is about 1.2 times higher. Considering a DAP formula that is 18 percent nitrogen (from ammonia) by weight, the shift to domestic green ammonia would raise DAP costs from $706 to $990 per ton, based on the costs in Figures 3 and 4 (Tata 2020). After accounting for the 20 percent savings from reduced import costs, the price of domestically produced DAP would be approximately $840 per ton, which is 20 percent higher than the current average price of $706 per ton. This increase would disproportionately affect fertilizers with higher ammonia content. Note that this estimation is likely an underestimate of true domestic DAP production costs as Kenya is unlikely to be able to replicate the infrastructure and production costs accessible in a country with an established fertilizer industry like Russia.

These cost increases could have measurable effects further downstream on both farmers and crop prices. Higher fertilizer costs could have a significant impact on farmers and crop prices. In Kenya's most fertile regions, for every 10 percent rise in fertilizer costs, there is a corresponding 5.2 percent drop in fertilizer use, and a 3.8 percent drop in crop production levels (ResilienceLinks 2022). Therefore, a 20 percent increase in fertilizer costs could lead to a 10.4 percent reduction in its application, potentially decreasing crop production by an estimated 7.6 percent (ResilienceLinks 2022).

While estimated production costs remain high, local fertilizer production could provide a buffer for farmers against unpredictable import prices caused by natural gas price volatility. From 2019 to 2024, Russian DAP prices had a standard deviation of $283, nearly 40 percent of the average price, as shown in Figure 7. Kenya is largely dependent on fertilizer imports, and DAP imports consistently represents the largest or second-largest single source of fertilizers since 2018 (AfricaFertilizer 2024). DAP fertilizer accounts for 32 percent of total fertilizer usage over the past four years. As a result, volatility in DAP prices have an impact on a significant proportion of farmers, forcing lower fertilizer consumption rates.

From 2021 to 2022, Russian DAP retail prices in Kenya increased by 97 percent as a result of both rising natural gas prices and the Russian invasion of Ukraine. Over the same time period, overall DAP consumption fell by 48 percent, from 289,000 tons to 150,000 tons. This drop, along with lackluster rainfall, increasing labor costs, and outdated farming techniques, contributed to maize pro-

Figure 7. **Russian DAP yearly average prices**



Note: DAP = Diammonium Phosphate, mt = Metric Ton.
Source: Data from Africa Fertilizer (2024); Satnam Energy Calculation.

duction declining from 42.1 to 36.7 to 34.3 million bags of maize (90-kg bags) from 2020 to 2022 (Milling Middle East & Africa 2023).

Without a source of domestic production, Kenyan fertilizer markets bear the full brunt of high natural gas prices and international supply chain disruptions. As a result, farmers face elevated input costs, leading to reduced crop yields and exacerbating the country's food security challenges.

Policy stakeholders and project developers must weigh the cost of increasing average fertilizer prices against the ability to hedge against market price surges. Without subsidized financing or policy measures, the existing cost of producing green hydrogen, ammonia, and fertilizers could lead to higher downstream expenses, reduced fertilizer usage, and lower crop yields. Such outcomes would directly oppose the objectives outlined in Kenya's National Green Hydrogen Strategy.

Non-technical barriers to adoption

Alongside the large economic barriers facing green fertilizer adoption in Kenya, there are several non-economic barriers that must be addressed; namely, a lack of technical expertise and skilled labor, inherent fertilizer value chain inefficiencies, plus concerns regarding equity and sustainable development.

Lack of technical expertise and skilled labor

Green hydrogen and its derivatives represent a new and complex technological landscape. Technical and safety requirements across the production, midstream, and downstream value chain components have yet to be established and are continuously evolving (IEA 2023). As a result, the lack of local (and global) technical knowledge and workforce required to implement large-scale green hydrogen projects is a barrier to project development. An Australian survey found that a third of industry participants estimated that 80 percent of their workforce would require hydrogen-related training and reskilling. Participants noted that this gap was driven by hydrogen equipment manufacturers holding and controlling knowledge to protect private intellectual property (Beasy et al. 2023). This gap likely reduces the flexibility a project or workforce may have as different electrolyzer technologies (PEM, SOEC, Alkaline) will require different materials, maintenance and repair schedules, plus operational knowledge.

Hydrogen pipelines and storage applications face similar challenges. The necessary expertise varies based on technology type, with each presenting unique requirements for material selection, safety protocols, and operational procedures. Maintenance requirements for liquid hydrogen storage differ significantly from those of high-pressure gaseous storage systems. Furthermore, hydrogen pipeline regulations and licensing requirements have yet to be established globally. Many countries are still developing regulatory and review frameworks in order to ensure that potential hydrogen pipeline leakage rates and embrittlement is safely understood and accounted for (OECD 2023).

Kenya faces a significant knowledge gap stemming from a shortage of skilled labor in renewable energy sectors that support hydrogen production, such as solar and wind. The country's recent request for funding from the Climate Investment Fund's Renewable Energy Integration Program (CIF-REI) underscores this deficit. The proposal noted the "challenge of inadequate skilled manpower in energy-related areas that impact Kenya's ability to tap into its abundant renewable energy resources" (Climate Investment Fund 2024). Recent skills assessments for hydrogen and hydrogen derivative projects have further identified specific technical expertise gaps within the country. Engineers across electrical, mechanical, chemical, and process disciplines, alongside technical specialists such as chemists, water experts, and skilled tradespeople (plumbers, welders, and electricians), all require hydrogen-specific training to address the unique safety concerns, material compatibility issues, and operational requirements of hydrogen systems. New expertise in standards and certification, particularly for emerging applications like aviation fuels, must also be developed (PtX Hub 2024). In the early stages, the country will depend heavily on foreign technical expertise, with equipment manufacturers expected to train local technicians on imported hydrogen technologies—highlighting the critical need for structured technical capacity-building programs.

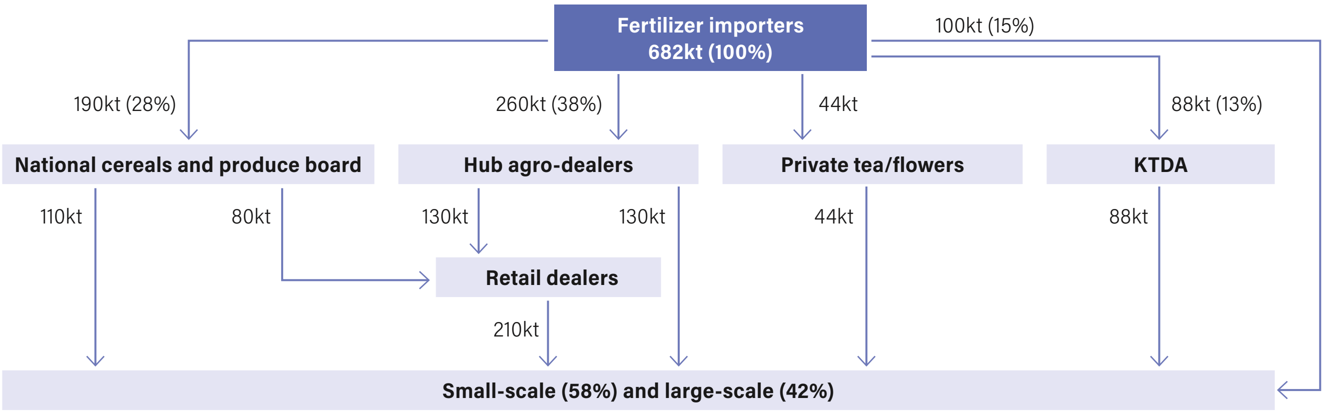
Addressing these workforce and knowledge gaps represents a significant challenge to green hydrogen adoption timelines and cost projections. Kenya's CIF proposal allocates over $9 million toward establishing "energy Centers of Excellence and labs to enhance operational capacity, capacity building for the National CIF Committee, enhance gender inclusivity, support R&D, and demonstrate new business models to utilize renewables." However, hydrogen-specific capacity building will likely require even greater investment due to the technology's complexity, lack of standardized global regulations, and diverse production pathways. Moreover, since green hydrogen production depends on renewable energy infrastructure, developing hydrogen expertise is inherently linked to building sufficient knowledge in renewables—creating a compounded challenge for workforce development initiatives.

Fertilizer value chain inefficiencies

The Kenyan fertilizer market is the second largest in eastern Sub-Saharan Africa, with total consumption amounting to over 800,000 MT (AfricaFertilizer 2024; IFDC 2018). Since 2018, Kenya has imported most of its fertilizer and has a large, but concentrated distribution network, highlighted in Figure 8. Fertilizer importers (Yara, ETG, MEA, etc.) sell the product through 150 hub dealers, who then distribute quantities to approximately 8,000 regional retail agro-dealers who sell to farmers (IFDC 2018).

Importers also supply fertilizer to the National Cereals and Produce Board, which offers certain types, such as NPK, to farmers at subsidized rates, thus reducing the price from Ksh 6500 ($50) to Ksh 2500 ($19). While the subsidy amount and fertilizer volume has varied under different support schemes, in 2023–2024 (as of June 2024), the program distributed over 400,000 metric tons of discounted fertilizer to farmers, falling short of its yearly target of 625,000 metric tons (AfricaFertilizer 2024). The NCPB's scheme has had mixed market effects. Although farmers benefit from affordable fertilizer, distribution often occurs at NCPB offices rather than with agro-dealers. This results in public-private competition, with subsidized fertilizer under-cutting private supply, such that every 1 kg of subsidized fertilizer displaces 0.2 kg of commercial fertilizer (Njagi and Carter 2019). Commercial fertilizer displacement has downstream ramifications. First, farmers face increased difficulty in procuring fertilizer. They are usually forced to wait in long lines at a limited number of NCPB stores, incurring transportation costs and time delays, taking anywhere from hours to days. The risks associated with costs and delays are non-trivial for farmers with low profit margins and tight planting windows, possibly discouraging some small-scale farms from collecting fertilizer at all (Wanga 2024).

Figure 8. **Kenya's fertilizer distribution system with volumes in kilotons (kt)**



Note: Percentages represent the percentage of total fertilizer amounts distributed to various intermediaries. This graphic uses data from 2017 as it is the latest year in which this breakdown is available.
Source: Adapted from the IFDC and AFAP (2018).

Second, the NCPB had difficulty in securing the promised 7.5 million bags of fertilizer for Kenya's planting season (Mengistu 2024). Fertilizer shortages represent a "worst-case" scenario, in which farmers must not only incur time and transportation costs to reach NCPB depots, but also face the uncertainty of limited or unavailable supply. Many small-scale farmers have been turned away before. These shortages force them to either use inadequate amounts of fertilizer, limiting their potential harvest, or rely on high-priced commercial fertilizer, cutting into already slim profit margins (Wanga 2024). Notably, high retail fertilizer prices are, in part, caused by the market disruption from subsidized fertilizers (Njagi et al. 2024). Finally, the NCPB fertilizer subsidy scheme is also prone to leakage. Approximately 40 percent of subsidized fertilizer leaks to non-target groups including agro-dealers, other countries, and higher-income farmers. This fertilizer is often resold at higher prices, reducing access for the intended beneficiaries (IFDC 2018).

Additionally, Kenyan farmers exhibit strong brand loyalty and are cautious about adopting unfamiliar products. This, along with thin margins and cash constraints, lead retail dealers to stock one or two of their "bestselling" lines rather than increase risk with unfamiliar, possibly more effective products (IFDC 2018).

Domestic green fertilizer production and distribution will have to operate under these existing inefficiencies. If distributed through the NCPB, green fertilizers could crowd out private sales, destabilize fertilizer prices, and cut into the margins of agro-dealers and farmers. Leakage of green fertilizer would reduce availability for small-scale farmers, undermining food security and equity goals. The higher price of green fertilizers could exacerbate these issues. The NCPB would likely have to subsidize smaller volumes of green fertilizer, building on the existing supply shortages and their downstream market ramifications.

Equity and sustainable development

Providing country-wide clean electricity is one of Kenya's top priorities, with the government hoping to achieve universal electrification by 2030 (IEA 2023a). Currently, only 75 percent of Kenya's population has access to electricity, with rural areas lagging behind urban centers. The push for green hydrogen production could potentially divert renewable energy resources and investments away from electrification efforts, especially in underserved rural areas. Green hydrogen production requires large amounts of electricity. Proton exchange membrane (PEM) electrolyzers require approximately 50 kWh of electricity per kilogram of hydrogen produced. Policymakers and community leaders must weigh the opportunity cost of investing private, government, and concessional funds towards electricity generation for green hydrogen production rather than improving electricity access or grid reliability.

The issue of water usage in green hydrogen production also raises concerns about sustainable development. Increasing water demand, droughts, and water contamination have resulted in approximately 15 million Kenyans lacking reliable access to safe drinking water (Mulwa et al. 2021; Water.org 2024). Hydrogen production requires approximately 20 to 30 liters of clean water per kilogram produced, 9 liters for electrolysis and an additional 10 to 20 liters for water purification and system cooling (Ramirez et al. 2023). Production facilities will likely require a constant, filtered supply of water to ensure that electrolyzers are not degraded and maximum production output is achieved. Again, policymakers must determine whether the opportunity cost of building water transportation infrastructure and water usage is best placed with domestic green hydrogen production.

Exploring future pathways

Kenyan green fertilizer production faces a multifaceted set of challenges. Addressing these will likely require a mixture of both financing and policy solutions. This section provides possible political and financial tools that could be used to mitigate concerns, de-risk projects, and reduce production costs.

Kenya's Climate Change Act, published in 2016 and subsequently amended in 2023, offers two key policy tools that could be used to help spur domestic green fertilizer production. First, the act defines and provides a regulation framework for a carbon credit market. It establishes a public registry, allowing buyers and sellers to track carbon credit transactions and build the infrastructure necessary to provide decarbonization projects with a viable external revenue source. In 2023, Kenya sold over 2 million carbon credits for approximately $6.30 per ton of carbon, generating over $13 million for decarbonization projects. This market is expected to grow, with some estimates placing the global carbon credits market at a valuation of over $1 trillion by 2030 (Herbling 2024). To sell into this market, a project must be "designed to remove, reduce, sequester or avoid carbon emissions" (Dentons 2024).

Moreover, Article 6.2 of the Paris Agreement allows countries to trade carbon credits (known as Internationally Transferred Mitigation Outcomes, or ITMOs), which gives nations the ability to meet their Nationally Determined Contributions (NDCs) by selling credits across borders. This international framework builds market confidence and drives carbon credit demand, improving the bankability of green hydrogen projects by solidifying an additional revenue stream. A domestic green fertilizer plant could sell the carbon offsets associated with the difference between gray and green fertilizer production. Our estimates suggest that reaching cost parity would require a carbon price of $0.43 per kilogram of carbon, markedly higher than current carbon prices of $0.07 per kilogram of carbon (Ember 2024). The estimate does not account for the mandated 40 percent share of carbon credit revenue designated for local communities, as detailed below.

Carbon markets may not provide full cost parity, but they could contribute to reducing the cost gap between green and gray fertilizer production. As the global carbon market matures and prices potentially increase, this mechanism could become increasingly important for the economic viability of green fertilizer projects in Kenya.

The Climate Change Act also instills a community development provision, which could help address the equity and other non-cost considerations identified. The Act requires that carbon credit projects must sign a Community Development Agreement (CDA) which must include project stakeholders, annual social contribution of earnings to be disbursed towards the benefit of the community, a community engagement plan, and proposed socioeconomic developments around community priorities (Oraro and Otieno 2023). Alongside this plan, landbased projects must disburse at least 40 percent of the revenue generated from carbon credits back to the local community. For example, the Wildlife Works' Kasigau Redd+ project in Taita Taveta County was structured to direct a substantial portion of its revenue into community development initiatives—such as funding scholarships, healthcare, and water infrastructure—through locally managed committees (WildlifeWorks 2023). However, critics have questioned whether the benefits are equitably distributed, arguing that the funds may disproportionately favor local elites rather than broadly enhancing community welfare (Farand 2023). Together, a project's CDA and revenue disbursement could provide communities with the ability to manage the environmental or equity-related challenges a project may cause.

Beyond Kenya's carbon markets, a domestic green fertilizer project should capitalize on international clean fuel mandates by scaling hydrogen and ammonia production facilities beyond domestic fertilizer output. Excess green hydrogen and ammonia could be shipped and sold in international markets such as the EU, Japan, or South Korea, which require the use of clean fuels in sectors like maritime shipping and aviation. According to the EU's Renewable Energy Directive (RED III), industrial sectors like ammonia and steel must source at least 42 percent of their hydrogen from Renewable Fuels of Non-Biological Origin (RFNBOs) by 2030, with the target increasing to 60 percent by 2035 (European Parliament and the Council of the European Union 2023). These mandates are strict and require projects to transition regardless of cost.

Other geographies, such as Japan and South Korea, have incentivized clean hydrogen and ammonia offtake through a subsidy model, providing excess revenue to hydrogen importers. Japan has already outlaid over $19 billion in subsidies for locally produced and imported hydrogen through a CfD scheme (Collins 2024). Thus, a domestic green fertilizer project may be able to sell excess ammonia into higher-priced export markets. The additional revenue would help secure project financing and subsidize domestic selling prices, thereby reducing the financial burden on local agro-dealers, farmers, and other retailers.

Kenya's carbon market and international mandates represent possible additional sources of revenue but do not address the high estimated costs of production. Achieving competitive production costs will require reductions in the cost of capital and electrolyzer, plus renewable energy capital expenditures. A domestic green fertilizer project could achieve these reductions in two possible ways. First, high costs of capital in Kenya are due, in large part, to the currency risk associated with the Kenya shilling. While concessional financing tools such as grants, green bonds, and other mechanisms could catalyze private investment, the country could turn to a currency risk–specific solution such as The Currency Exchange's (TCX) local-currency bonds.

TCX does not issue the bonds directly, but rather hedges against the payment obligations from the local-currency bonds reducing the currency risk for its potential shareholders, the majority of which are development financing institutions (The Currency Exchange 2024). Accessing and implementing local-currency bonds could play a key role in reducing currency risk and, subsequently, the cost of capital of a project. In 2023, TCX hedged the currency risk on a loan between a financing institution and a digital bank in Uzbekistan meant to fund household energy-efficiency improvements. By issuing a three-year currency swap, TCX eliminated the currency risk from the digital bank, improving the economy of the project and contributing to its overall decarbonization impact. A similar approach could be taken to reduce the currency risk associated with a domestic green fertilizer plant. Reducing the currency risk and the cost of capital of the plant could also have a "catalytic" effect, making it easier for other private investors to finance the project.

Achieving cost parity is a necessary step to ensure that existing fertilizer market inefficiencies are not made worse. Kenya's fertilizer subsidy is straining, with inadequate distribution infrastructure and limited funding. If domestic production can be made affordable, it could be distributed directly, reducing the burden on Kenya's over-taxed subsidy scheme and avoiding a key barrier to market entry.

Kenya could also look to develop public-private partnerships (PPPs) to bring in the necessary technical knowledge, labor, and machinery at reduced cost, thereby lowering the overall production cost. A PPP is a contractual agreement between a public and private entity, in which the private entity agrees to perform a "public function" such as building public infrastructure and utilities (Office of the Deputy Prime Minister 2011). PPPs are often used to manage projects requiring private sector technical expertise or having risk profiles that public entities cannot safely manage. These agreements have several different forms, including Build-Own-Operate (BOO) and Build-Operate-Transfer (BOT) models. A BOO model allows the private sector to build, own, and operate a facility without transferring the facility back to the government or public entity. BOT models allow the private sector to build and operate the facility for a set time period and then transfer the project back to the government. A BOT model could provide a realistic development framework to create a domestic green fertilizer plant in Kenya, by aligning private sector efficiencies with public sector objectives. Companies and organizations, like Fertiglobe and Plug Power, with experience in renewable energy infrastructure, electrolyzer manufacturing and operation, and ammonia synthesis could likely complete construction quickly and efficiently. Facility management and operational upkeep would also be streamlined. Private sector operation could also allow for knowledge transfer domestically. Local communities could use the construction and operation phases as an upskilling opportunity, possibly providing high-value, industrial jobs. In doing so, once the facility is transferred back to the government, a portion of the local population could run plant operations, addressing concerns regarding community benefits. The private sector would likely need to recoup its investment through the structure described above, in which a portion of the hydrogen/ammonia/fertilizer is sold to international markets as domestic willingness-to-pay may not be enough to meet a company's requisite financial returns.

To adequately address the structural cost and non-cost challenges facing a domestic green fertilizer plant, a combination of external revenue addition and production cost reduction is necessary. A BOT PPP structure presents a framework in which plant development could take advantage of private sector learnings and efficiencies, reducing both technological and timeline risks and providing the ability for local upskilling. Utilizing organizations like TCX and currency exchange swaps can also reduce the currency risk. Taken together, these individual de-risking steps could create access to low-cost financing reducing the overall cost of capital associated with the project. Within this structure, project developers can look to couple low-cost financing with external revenue generation through both Kenya's carbon market and international clean fuel mandates. The growth of Kenya's carbon market directly monetizes the clean attributes of green hydrogen/ammonia/fertilizers, allowing them to compete against cheaper, less clean products. Similarly, a green fertilizer project could defray product costs for a domestic population by taking advantage of the higher willingness-to-pay of geographies with international mandates.

Kenya stands at a crucial juncture in its energy and emissions trajectory. The nation's commitment to integrating green hydrogen into its energy strategy represents a pivotal move towards sustainable development and emissions reduction. Green hydrogen–based fertilizer production offers a promising pathway to enhance domestic agricultural productivity, reduce reliance on volatile global fertilizer markets, and drive economic growth. However, this initiative faces significant economic and non-economic challenges.

Economically, the high costs of green hydrogen production, driven by capital expenditures on solar and electrolyzer technologies; plus, high costs of capital present substantial barriers. Comparatively, green hydrogen remains significantly more expensive than gray hydrogen, necessitating substantial cost reductions to achieve parity. Addressing the currency risk and leveraging concessional financing mechanisms like local-currency bonds and international clean fuel mandates could help bridge this gap. Additionally, public-private partnerships could play a crucial role in bringing the necessary technical expertise and investment to scale up production efficiently.

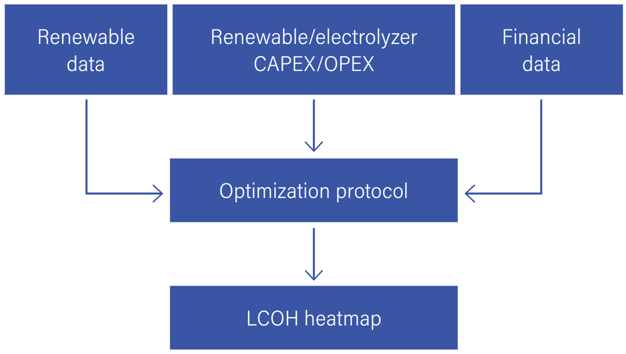
Non-economic barriers, including the lack of technical expertise and existing inefficiencies within Kenya's fertilizer value chain, further complicate the transition. The need for significant up-skilling of the local workforce and the potential displacement effects on the private fertilizer market due to government subsidies must be carefully managed. Policy measures such as Kenya's carbon market and community development agreements could provide additional revenue streams and address equity concerns, fostering a more inclusive and sustainable transition.

Although Kenya faces challenges in adopting green hydrogen, targeted policy measures, innovative financing solutions, and strong public-private partnerships can lay the foundation for a sustainable and economically viable green hydrogen future. A successful transition holds the potential to stabilize fertilizer supply and pricing, strengthen food security, generate employment, and support broader industrial growth, ultimately contributing to Kenya's long-term sustainable development goals.

Appendix A: Green hydrogen production cost parameters

The green hydrogen modeling conducted throughout this analysis averages 15 years of hourly wind speeds and solar irradiation values at a resolution of 0.25 degrees latitude by 0.25 degrees (550 km^2) longitude in order to account for yearly variations. Then, using the financial and technical inputs listed below, the model solves for the lowest levelized cost of hydrogen at each grid cell, simultaneously optimizing the ratio between renewable energy generation and electrolyzer nameplate capacity. In doing so, the model accounts for the largest and most indicative green hydrogen cost drivers. This approach has several limitations and uncertainties: construction time, water costs, and land availability are not considered. However, these factors could be included in future work. The model assumes renewable energy generation and electrolyzers are co-located, so transmission costs are not included.

Figure A-1. **Simplified block diagram of LCOH algorithm**



Source: Satnam Energy Calculation.

Table A-1. **Input data and assumptions for green hydrogen cost computations**

PARAMETER	VALUE
Kenya Cost of Capital (Discount Rate)[a]	8.4% → 20%
Electrolyzer Efficiency (kWh/kg)[b]	50
Solar Costs (for Kenya, \$/kW)[c]	(Global Weighted Average) Capital/Equipment Costs: 857 Operating Costs: 18.2
Wind Costs (for Kenya, \$/kW)[d]	(Africa Weighted Average) Capital/Equipment Costs: 1892 Operating Costs: 36
Electrolyzer Capital Costs (Low, Medium, High Scenarios 2022 \$/kW)[e]	1100, 1450, 1800
Electrolyzer Operating Costs (Low, Medium, High Scenarios 2022 \$/kW)[f]	17, 22, 28
Electrolyzer Operating/Capital Costs (Low, Medium, High Scenarios 2030 \$/kW)[g]	Capital: 650, 1225,1800 Operating: 10, 18, 28
Electrolyzer Operating/Capital Costs (Low, Medium, High Scenarios 2050 \$/kW)[h]	Capital: 200, 550, 900 Operating: 3, 9, 14
Lifetime (years)[i]	20
G20 Cost of Capital (Discount Rate)[j]	Varies
Global Solar Costs[k]	Varies
Renewable Energy Data (Solar Irradiance)[l]	Varies
Electrolyzer Stack Degradation Rate (% per year)[m]	2
Allowed Electrolyzer Degradation Before Replacement (%)	70
Electrolyzer Replacement Cost (% of Initial CAPEX)	30

Sources: a. IRENA 2022; b. CEEPR 2023; c. IRENA 2021; d. IRENA 2021; e. IEA 2019; f. IEA 2024b; g. IEA 2019; h. IEA 2019; i. Arfan et. al 2023; j. IRENA 2022; k. IRENA 2021; l. ERA5 2007-2022; m. Keddar et. al 2022.

Table A-2. **Hydrogen production cost breakdown from Figure 3, discount rate of 8.4%**

CATEGORY	SOLAR CAPEX	COST OF CAPITAL (SOLAR)	ELECTROLYZER CAPEX	COST OF CAPITAL (ELECTROLYZER)	SOLAR OPEX	ELECTROLYZER OPEX	TOTAL (ROUNDED)
Current costs	1.93	1.17	1.82	1.09	0.05	0.04	**6.10**
2030 costs	1.77	1.12	1.67	0.97	0.05	0.04	**5.60**
2050 costs	1.67	1.06	0.70	0.45	0.04	0.02	**3.90**

Source: Satnam Energy Calculations.

Table A-3. **Hydrogen production cost breakdown from Figure 3, discount rate of 15%**

CATEGORY	SOLAR CAPEX	COST OF CAPITAL (SOLAR)	ELECTROLYZER CAPEX	COST OF CAPITAL (ELECTROLYZER)	SOLAR OPEX	ELECTROLYZER OPEX	TOTAL (ROUNDED)
Current costs	2.08	2.21	1.96	2.10	0.07	0.05	**8.50**
2030 costs	2.04	2.21	1.71	1.87	0.07	0.05	**8.00**
2050 costs	1.73	2.04	0.73	0.85	0.06	0.03	**5.40**

Source: Satnam Energy Calculations.

Table A-4. **Hydrogen production cost breakdown from Figure 3, discount rate of 20%**

CATEGORY	SOLAR CAPEX	COST OF CAPITAL (SOLAR)	ELECTROLYZER CAPEX	COST OF CAPITAL (ELECTROLYZER)	SOLAR OPEX	ELECTROLYZER OPEX	TOTAL (ROUNDED)
Current costs	2.17	3.02	2.04	2.83	0.08	0.07	**10.20**
2030 costs	2.14	3.01	1.80	2.54	0.08	0.06	**9.60**
2050 costs	1.78	2.77	0.75	1.16	0.07	0.03	**6.60**

Source: Satnam Energy Calculations.

Appendix B: Ammonia modeling parameters

We model the financial implications of producing ammonia using two methods: steam methane reforming (SMR) or gray hydrogen and green hydrogen generated through electrolysis. The cost of hydrogen feedstock is the primary variable in production cost between these two methods, as the remaining portions of the synthesis loop are essentially equivalent in this model. We calculate the cost of hydrogen feedstock for gray ammonia by computing the capital and operational expenditures associated with an SMR unit. We use the median green hydrogen production cost as the cost of hydrogen feedstock for green ammonia. We assume the hydrogen production facility and ammonia synthesis loop are co-located, thus eliminating intermediate transportation or storage costs. Capital expenditure costs for the ammonia synthesis loop change with plant size, taking advantage of economies of scale. The results in this paper scale all requisite components of the ammonia production facility to 3,000 metric tons per day.

Table B-1. **Input data and assumptions for green ammonia cost computations**

PARAMETER	VALUE
Hydrogen Required in Ammonia Synthesis (kgH2/tNH_3)[a]	179.4
Nitrogen Required in Ammonia Synthesis (kgN2/tNH_3)[b]	830.7
SMR Efficiency (%)[c]	65
SMR Fixed OPEX (%)	5
Green Hydrogen Cost ($/kg)	6.10
Cost of Capital (%)	5
Air Separation CAPEX[d]	Scales Based on Capacity
Ammonia Synthesis Loop CAPEX[e]	Scales Based on Capacity
Ammonia Storage CAPEX[f]	Scales Based on Capacity
Lifetime (years)[g]	25
Electricity Cost ($/kWh)[h]	0.20
Natural Gas Price ($/MMBtu)	4

Sources: a. SAREP 2023; b. SAREP 2023; c. NYSERDA 2005; d. Jain et. al 2022; e. Jain et. al 2022; f. Nayak-Luke et. al 2021; g. SAREP 2023; h. Global Petrol Prices 2025.

Table B-2. **Green and gray ammonia production cost breakdown comparison**

COST COMPONENT ($/TON NH_3)	GREY AMMONIA (SMR)	GREEN AMMONIA (ELECTROLYSIS)
Fixed SMR OPEX	3.45	—
SMR CAPEX	68.96	—
Hydrogen Cost	251.16	1 094.34
Ammonia Storage CAPEX	7.14	7.14
Fixed OPEX	6.71	5.33
Air Separation CAPEX	225.91	225.91
Synthesis CAPEX	33.62	33.62
Electricity OPEX	140.22	140.22
Total (Rounded)	**737**	**1 507**

Source: Satnam Energy Calculations.

Abbreviations

AFAP	African Fertilizer and Agribusiness Partnership
AGHA	Africa Green Hydrogen Alliance
BNEF	Bloomberg New Energy Finance
BOO	Build-Own-Operate
BOT	Build-Operate-Transfer
CAN	Calcium Ammonium Nitrate
CAPEX	Capital expenditure
CBAM	Carbon Border Adjustment Mechanism
CEEPR	Center for Energy and Environmental Policy Research
CfD	Contract for Difference
CIF	Climate Investment Fund
DAP	Diammonium Phosphate
EIA	Energy Information Administration
EIB	European Investment Bank
ESMAP	Energy Sector Management Assistance Program
ETG	Export Trading Group
ETS	Emissions Trading System
EU	European Union
FID	Final Investment Decision
GHG	Greenhouse Gas
ICCT	International Council on Clean Transportation
IEA	International Energy Agency
IFDC	International Fertilizer Development Center
IFPRI	International Food Policy Research Institute
IRENA	International Renewable Energy Agency
ISA	International Solar Alliance
ITMO	Internationally Transferred Mitigation Outcomes
KBC	Kenya Broadcasting Corporation
KNTC	Kenya National Trading Corporation
KSh	Kenya shilling
Kt	kilotons
LCOA	Levelized Cost of Ammonia
LCOH	Levelized Cost of Hydrogen
MEA Ltd.	Manufacturing, Engineering & Agricultural Limited
MMBtu	Metric Million British thermal unit
Mt	megatonnes
MW	megawatts
NCPB	National Cereals and Produce Board
NDCs	Nationally Determined Contributions
NGO	Nongovernmental organization
NYSERDA	New York State Energy Research and Development Authority
OECD	Organisation for Economic Co-operation and Development
OPEX	Operating expenses
PEM	Proton Exchange Membrane
PPP	Public-Private Partnership
PtX	Power-to-X
R&D	Research and Development
RED III	Renewable Energy Directive III
REI	Renewable Energy Integration
RFNBO	Renewable Fuels of Non-Biological Origin
SAF	Sustainable Aviation Fuel
SAREP	South Asian Regional Energy Partnership
SMR	Steam Methane Reformation
SOEC	Solid Oxide Electrolyzer Cell
WACC	Weighted Average Cost of Capital
TCX	The Currency Exchange
TWh	Terawatt hours

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Satnam Energy supplies clear, data-driven guidance on grid expansion, energy policy, and climate finance for low-carbon technologies—including clean hydrogen, wind, solar, and low-carbon gases. The firm's modeling and market studies span green hydrogen and its derivatives, including ammonia and e-SAF, covering Kenya, India, Brazil, and the EU. Key partners include the World Resources Institute, the Center for Strategic and International Studies, and the Green Hydrogen Organization.

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