PROGRESS
Promoting Green Deal Readiness in the Eastern Partnership Countries

On behalf of:

Federal Ministry for the Environment, Climate Action, Nature Conservation and Nuclear Safety

of the Federal Republic of Germany

IKI INTERNATIONAL CLIMATE INITIATIVE

STUDY ON GREEN AMMONIA USE IN SMALL-SCALE AGRICULTURAL BUSINESSES IN GEORGIA

On behalf of:

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Study on Green Ammonia Use in Small-Scale Agricultural Businesses in Georgia

Final Study

Promoting Green Deal Readiness in the Eastern Partnership Countries (PROGRESS)

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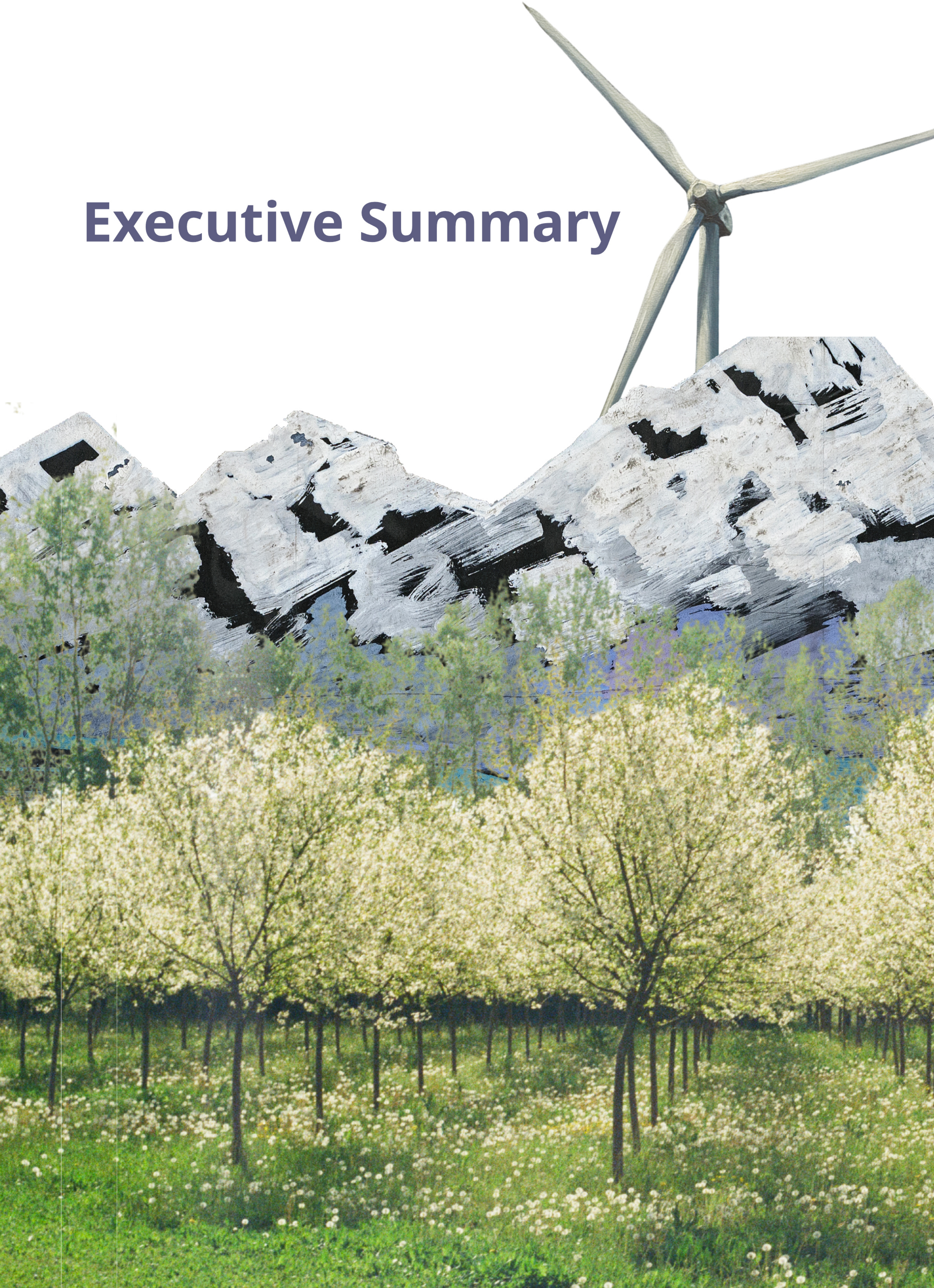
ABBREVIATIONS

AWPA	Georgian Almonds and Walnuts Producers Association
BAU	Business as Usual
BMUKN	Ministry for the Environment, Climate Action, Nature Conservation and Nuclear Safety
CAPEX	Capital Expenditure
CBAM	Carbon Border Adjustment Mechanism
Co	Company
CO_2	Carbon dioxide
DCFTA	Deep and Comprehensive Free Trade Area
EaP	Eastern Partnership Initiative
EBRD	European Bank for Reconstruction and Development
EGD	European Green Deal
EEA	European Economic Area
ENP	European Neighbourhood Programme
ENPARD	EU-supported European Neighbourhood Programme for Agriculture and Rural Development
ESG	Environmental, Social and Governance
EU	European Union
FAO	Food and Agriculture Organization of the United Nations
GA	Green Ammonia
GBGA	Georgian Blueberry Growers Association
GCF	Green Climate Fund
GDP	Gross domestic product
GEDF	Georgian Energy Development Fund
GEL	Georgian Lari
GeoStat	National Statistics Office of Georgia
GEOSTM	Georgian National Agency for Standards and Metrology
GFA	Georgian Farmers' Association
GHG	Greenhouse Gas
GIZ	Deutsche Gesellschaft für Internationale Zusammenarbeit
GNERC	Georgian National Energy and Water Supply Regulatory Commission

ha	Hectare (10,000 m^2 = 0.01 km^2 = 2.471 acres)
H2	Hydrogen
IEA	International Energy Agency
IRENA	International Renewable Energy Agency
ISO	International Organization for Standardization
IPCC	Intergovernmental Panel on Climate Change
LCA	Life Cycle Assessment
LLC	Limited Liability Company
LTD	Limited Company
LTS	Long-Term Low Emissions Development Strategy
MEPA	Ministry of Environmental Protection and Agriculture
MoESD	Ministry of Economy and Sustainable Development
MRV	Monitoring, Reporting, and Verification
NAMA	Nationally Appropriate Mitigation Action
NDCs	Nationally Determined Contributions
NECP	National Energy and Climate Plan
NH_3	Ammonia
OECD	Organisation for Economic Co-operation and Development
OPEX	Operating Expenditure
PROGRESS	Promoting Green Deal Readiness in the Eastern Partnership Countries
PSA	Pressure Swing Adsorption
PPP	Public Private Partnership
RDA	Rural Development Agency
R & D	Research and Development
RMI	Rocky Mountain Institute
ROI	Return on Investment
SDC	Swiss Agency for Development and Cooperation
SMR	Steam methane reforming
SRCA	Scientific Research Centre of Agriculture
TVET	Technical Vocational Education and Training
UN	United Nations
UNFCCC	United Nations Framework Convention on Climate Change
UNDP	United Nations Development Programme
US	United States

USAID	United States Agency for International Development
USD	United States Dollar
VCs	Value Chains

Executive Summary



Context and Objectives

Agriculture remains a critical pillar of Georgia's economy employing a substantial share of labour force and forming the backbone of rural livelihoods. However, the sector faces persistent structural challenges, including smallholder fragmentation, limited mechanisation and high reliance on fossil-based fertilisers. These factors constrain productivity and render Georgian agriculture vulnerable to global price shocks and input supply disruptions.

In this context, the study explores the feasibility and potential of decentralised Green Ammonia (GA) production as a sustainable fertiliser solution for Georgia's smallholder farmers – predominantly within the almond and blueberry value chains. Commissioned by the PROGRESS programme, which aims to foster green economic transformation across the Eastern Partnership region, this research provides a policy-anchored, evidence-based roadmap to support climate-smart agriculture through renewable energy integration.

Georgia's Fertiliser Challenge and Green Ammonia Potential

The Georgian fertiliser market is dominated by imported nitrogen-based products, which are fossil fuel-intensive and subject to price volatility - fertiliser costs rose by over 70% between 2022 and 2023. These inputs are essential for productivity in crops of almonds and blueberries yet expose farmers to financial risk and undermine sustainability goals.

Green Ammonia as a renewable nitrogen-based fertiliser made by combining hydrogen (from water via electrolysis) with nitrogen (from air) using clean electricity instead of fossil fuels, offers a transformative solution. It eliminates carbon emissions associated with traditional Haber-Bosch ammonia production, enhances domestic input security and enables integration of decentralised energy systems in rural areas.

For Georgia, this aligns well with the country's national strategies such as the Agriculture and Rural Development Strategy, the Low-Emission Development Strategy and the overarching EU Green Deal objectives alluded to its EU-association process.

Focus Value Chains: Almond and Blueberry

Using ValueLinks 2.0 methodology, the study identifies almonds and blueberries as the most promising sectors for Green Ammonia deployment. These high-value export crops combine:

> Strong market growth: e.g., >4,500 tons of blueberries exported in 2024
>
> High nitrogen demand, with fertiliser costs of €1,000–1,300 per hectare annually
>
> Environmental and gender co-benefits, including employment for women and relevance to organic/agroecological standards

Both crops are increasingly important for rural incomes and export competitiveness, and their sustainability footprint is critical for access to premium international markets.

Technical and Institutional Feasibility

The study applies a mixed-method approach, integrating:

- Fieldwork in Kakheti and Imereti with almond and blueberry farms
- Stakeholder interviews (experts, associations, exporters)
- Cost-benefit analysis, life cycle assessments and regulatory gap mapping

What can be said, findings indicate strong interest among farmers - particularly for cost-stable, local alternatives to imported fertilisers - but also identify significant barriers:

- Lack of enabling regulations for small-scale ammonia production
- Limited technical awareness and training in ammonia handling
- Absence of investment mechanisms or tailored financial products
- Inadequate grid reliability and renewable infrastructure in rural areas

Nonetheless, early pilot sites (e.g. the ones referred to in this study), and Georgia's solar potential provide strong foundations for decentralised production models.

Policy, Investment and Capacity Recommendations

To unlock the potential of Green Ammonia, the study recommends a multi-branched strategy:

1. Policy and Regulatory Reform

- Develop a legal framework for small-scale ammonia units (<50 kg/day), enabling licensing, zoning and environmental compliance.
- Embed Green Ammonia in fertiliser, energy and land-use policies.
- Define "green fertiliser" under national standards to enable certification and subsidy access.**2. Finance and Incentives**

2. Finance Incentives

- Introduce CAPEX subsidies, matching grants and performance-based financing for early adopters.
- Leverage green finance tools from GCF, EBRD, and donor facilities.
- Extend risk-sharing instruments to de-risk farmer investments and support cooperative procurement models.

3. Infrastructure and Skills

Create demonstration hubs in key value chain regions to build trust and technical familiarity.

Develop vocational training, university modules, and updated extension curricula on ammonia fertigation and electrolysis systems.

Promote solar-integrated systems under rural energy programmes and pilot agrivoltaics applications.

4. Market Development

Integrate Green Ammonia into traceability and certification schemes (e.g., organic, GlobalG.A.P.).

Position green-fertilised exports as compliant with EU Carbon Border Adjustment Mechanism (CBAM) and attractive to Gulf markets.

Launch a national "green fertiliser origin" registry or QR-based verification tool.

5. Monitoring and Research

Support universities and labs in conducting life-cycle assessments, soil and emissions monitoring.

Develop geospatial models and nutrient budgeting tools to support system siting, sizing, and precision application.

Roadmap and Timeline (2025–2035)

A phased deployment strategy is further proposed by the study:

Short-term (0-2 years): 2-3 pilot deployments, interim regulatory guidance, technical training.

Medium-term (3-5 years): Scale to 50+ farms, formal certification, MRV integration

Long-term (6-10 years): Institutionalisation, market integration, regional replication

This roadmap aligns with Georgia's National Energy and Climate Plan and Long-Term Strategy 2050, positioning Georgia as a regional leader in green fertiliser innovation.

Lastly, Green Ammonia represents a strategic lever for transforming Georgia's agri-food systems - enhancing sustainability, resilience, and market access. With coordinated reforms and targeted investments, Georgia can pioneer decentralised fertiliser models that support rural livelihoods and international climate commitments. This study outlines practical considerations and contributes a technically guided perspective to support this transition.

1. Introduction

1.1 Agriculture and Rural Development in Georgia

Agriculture continues to be a cornerstone of Georgia's economy, shaping rural livelihoods and contributing to food security, export potential and employment. Although the sector's share in GDP has gradually declined - from over 10% in 2010 to just under 7% in 2023[1] - it still provides jobs for nearly one-fifth of the national labour force and is the main source of income for the rural population.[2] However, structural challenges are related to the facts, that 97% of all farms are smaller than three hectares and more than three-quarters operate on less than one hectare.[3]

This fragmentation constrains productivity, investment and access to technology. According to the United Nation (UN) Food and Agriculture Organization (FAO)'s assessment "Smallholders and Family Farms in Georgia," around 70% of all agricultural holdings are family farms, the majority of which operate on very small plots and produce largely for own consumption rather than for sustained market participation.[4] While this figure does not directly quantify subsistence farming in a narrow statistical sense, it strongly indicates that Georgia's agricultural structure is still dominated by semi-subsistence and low-commercialisation farming systems, with only a small fraction of producers engaged in fully commercial, export-oriented operations.

The Agriculture and Rural Development Strategy of Georgia (2021–2027) recognises these limitations and defines a strategic vision for transforming the sector into a competitive, sustainable and climate-resilient component of the economy. Its objectives include strengthening value-added production, improving natural resource management, enhancing access to finance and fostering innovation and renewable-energy integration in agriculture. The Strategy explicitly supports the transition toward green and climate-smart agricultural practices as a pathway to meet Georgia's commitments under the Paris Agreement and its EU-Association obligations.

1.2 Smallholder Dynamics and Value Chain Context

Georgia's agri-food system is dominated by smallholder farmers who rely on mixed, low-intensity production and often lack economies of scale. Limited access to irrigation, extension services and affordable credit result in modest yields and income volatility. Yet,

[1] The decline in agriculture's GDP share is largely attributed to the relative expansion of Georgia's industrial and services sectors over the past decade. Despite this, the sector continues to employ around 20% of the national labour force, highlighting the persistently low capital intensity, productivity and prices within Georgian agriculture, especially among smallholders engaged in semi-subsistence or low-input farming. This structural mismatch underscores the importance of improving input efficiency and value chain integration to raise rural incomes.

[2] See: https://iset-pi.ge/en/indexes/3-agri-review/3496-june-2024-agri-review.

[3] "Value Chain Analysis of Blueberry, Almond, Strawberry and Tangerine in Georgia," PROGRESS, January 2025.

[4] See: https://www.fao.org/family-farming/detail/en/c/1455458/.

several value chains show strong potential for competitiveness and sustainable upgrading.

The GIZ-commissioned Value Chain Analysis (2025) identified blueberry and almond production as the most promising value chains for climate-oriented and green economic development based on ten selection criteria under the ValueLinks 2.0 methodology. In practice, decentralised green ammonia systems are likely to be most viable for medium-sized commercial farms (approximately 50–200 hectares) or cooperative clusters rather than smallholder farms, as these operations typically possess the technical capacity, electricity demand, and managerial structure required to operate small ammonia production systems.

Both crops achieved the highest composite scores (Blueberry 4.20 / Almond 4.09) that reflect their favourable environmental performance, export potential and institutional maturity:

Almonds: concentrated in Kakheti and Shida Kartli, are suited to Georgia's drier eastern regions and have experienced rapid expansion under the Plant the Future programme. Almond production is less labour-intensive but has strong export prospects and offers opportunities for mechanisation and post-harvest high value-add processing.

Blueberries: primarily grown in Western Georgia (Guria, Samegrelo, Adjara and Imereti), where acidic soils and a humid subtropical climate provide optimal conditions. The area under cultivation exceeds 3 000 ha and exports reached 4 564 tons in 2024, with most production oriented toward high-value export markets such as the US and EU.

Labour intensity is high, with 90% of pickers being women, making the crop relevant for gender-inclusive growth discussions.

These two sectors combine strong market performance with high environmental vulnerability, making them ideal candidates for testing innovative, low-carbon inputs such as Green Ammonia.

1.3 Rationale for Exploring Green Ammonia

Fertiliser use is one of the key productivity drivers for both crops. Yet, Georgian farmers depend almost entirely on imported, fossil-fuel-based nitrogen fertilisers, leaving them exposed to volatile international prices and supply chain disruptions. In 2022–2023, fertiliser prices increased by over 70%, significantly reducing profit margins, especially for smallholders.

Traditional ammonia production via the Haber–Bosch process accounts for around 1% of global GHG emissions and 2% of total energy consumption, relying heavily on natural gas as a feedstock (see **Annex 1** for additional information about the Haber-Bosch process).

Transitioning toward Green Ammonia, produced through renewable-powered electrolysis of water, can drastically reduce these emissions while enhancing energy security and rural self-sufficiency. A side-by-side comparison of Brown vs. Green Ammonia and the mass of greenhouse gases (CO_2e) produced per mass of ammonia (NH_3) can be seen in the image below. The **Annex 5** also has more information on the differences between the two methods of ammonia production.

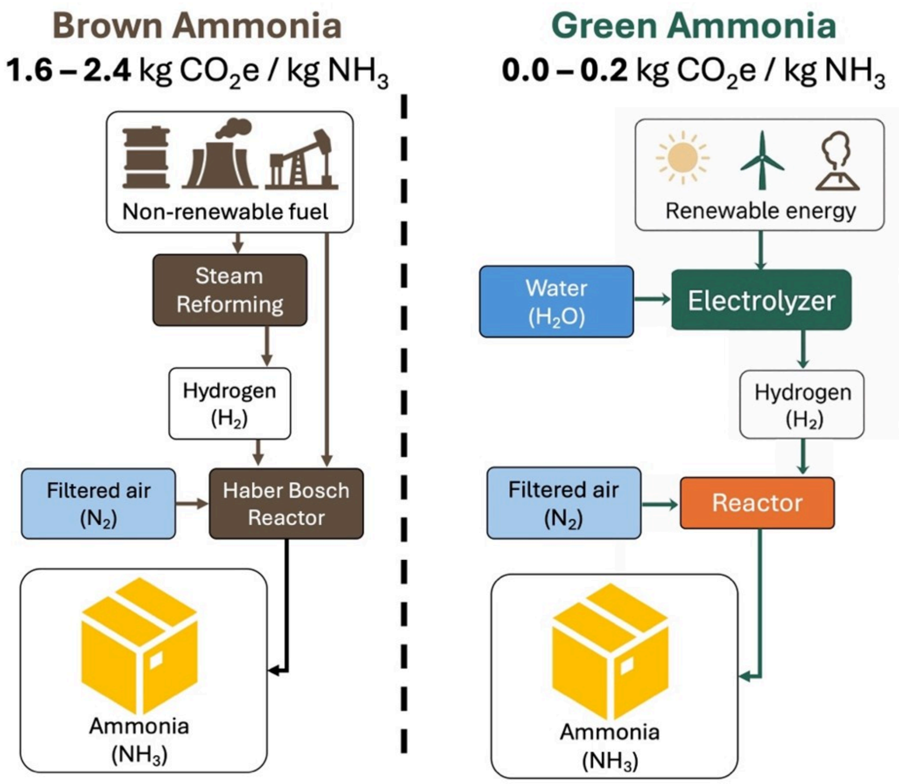


Figure 1. Comparison of Brown and Green Ammonia Productino Pathways and Emissions Intensity

Distributed, small-scale Green Ammonia systems have the potential to:

> Provide stable fertiliser supply for smallholders and cooperatives at lower long-term cost
>
> Serve as a flexible energy storage medium by converting surplus renewable electricity into chemical energy
>
> Reduce Georgia's dependence on imported nitrogen fertilisers or natural gas
>
> Strengthen climate-smart and decentralised rural energy systems in line with the Green Deal principles

For the almond and blueberry value chains, Green Ammonia could become a cornerstone input supporting productivity growth, improved soil management and reduced carbon footprints in export-oriented farming.

1.4 Problem Statement

Despite Georgia's favourable renewable-energy potential, the adoption of low-carbon fertiliser solutions remains very limited. The agricultural sector continues to depend almost entirely on imported nitrogen-based fertilisers, leaving farmers exposed to volatile global prices and logistical disruptions (see **Annex 2**). This reliance on external supply chains increases production risks for smallholders and weakens the competitiveness of domestic agriculture.

At the same time, rural infrastructure in many regions lacks the capacity to support innovative solutions such as electrolysis-based Green Ammonia production. Electricity access in farming areas is often insufficient or unreliable, making it difficult to pilot decentralised renewable energy systems. An additional benefit of decentralised ammonia pilots is their potential to accelerate solar adoption in agriculture, a technology that currently remains underutilised by Georgian farmers despite strong resource potential. Furthermore, awareness of new fertiliser technologies among farmers, cooperatives and even extension services remain low and technical knowledge on Green Ammonia production or application is virtually absent.

Regulatory uncertainty further constrains progress. Georgia's legal and institutional frameworks are not yet equipped to support decentralised fertiliser production or renewable-based agricultural inputs. The current legislation does not define conditions for small-scale ammonia generation, storage, or distribution and coordination between energy and agricultural authorities is still limited.

Compounding these challenges is the lack of dedicated investment mechanisms. Financial institutions and public programmes have not yet developed instruments tailored to green input production and farmers have limited access to affordable credit for adopting innovative technologies. Jointly, these factors create a structural barrier to the uptake of sustainable fertiliser alternatives.

As a result, Georgia's agriculture remains dependent on conventional inputs, with limited capacity to decouple productivity from fossil-based fertiliser use. Addressing these challenges requires a structured assessment of technical feasibility, economic viability, environmental benefits and farmer readiness to guide future interventions and reforms. Moreover, understanding the willingness of farmers to adopt, produce, or utilize green ammonia will be essential in creating a demand.

1.5 Legal, Regulatory and Institutional Gaps

Georgia's legal and policy environment is gradually evolving to support sustainable agriculture, climate mitigation and renewable energy integration. However, decentralised Green Ammonia production, particularly at the farm or cooperative level, remains a regulatory blind spot. Current legal and regulatory frameworks do not yet provide clear guidance or enabling conditions for integrated fertiliser-energy systems, despite increasing relevance to climate-aligned agriculture. Fertiliser regulation in the country is primarily governed by the Law of Georgia on Agricultural and rural development (2024), Law of Georgia on Ownership of Agricultural Land (2019), Law of Georgia on Pesticides and Agrochemicals (1998),[5] the Law on Food/Feed Safety, Veterinary and Plant Protection Code (2017), which cover import, registration, and quality control of fertilisers.

These laws are driven toward conventional fertiliser products and lack specific provisions for locally produced nitrogen-based inputs such as Green Ammonia, especially in gaseous or aqueous form. Note to mention, legal barriers may exist in licensing and permitting a Green Ammonia facility/site creating an unforeseen hinderance for adoption in contrast to imported ammonia. These legal gaps present a barrier for recognising or certifying decentralised production facilities.

Simultaneously, decentralised energy systems fall under the Law on Energy and Water Supply (2019) and the Law of Georgia on Promotion of Production and Use of Energy from Renewable Sources (2019), which outline support mechanisms for small-scale renewable energy projects. However, these laws focus on electricity generation rather than on coupling renewable energy with chemical production. Green Ammonia sits at the intersection of energy and agriculture, yet there is no dedicated regulatory interface to govern cross-sectoral initiatives.

Additionally, the institutional fragmentation between the Ministry of Environmental Protection and Agriculture (MEPA), the Ministry of Economy and Sustainable Development (MoESD), the Georgian National Energy and Water Supply Regulatory Commission (GNERC), and the Georgian Energy Development Fund (GEDF) on integrated, green fertilizer-energy systems - hampers coordinated policy action. While each entity plays a role in the ammonia value chain (e.g. MEPA for fertilisers, MoESD for renewable energy promotion), there is currently no unified framework to support innovations like decentralised Green Ammonia systems.

Moreover, fertiliser importers and their established logistical infrastructure would serve as a needed partner in distributing Green Ammonia across the value-chain in place of the revenue they stand to lose through decentralization. Future regulatory frameworks

[5] Latest consolidated version (N1696): 05.07.2018.

should ensure that producing green ammonia domestically is administratively simpler than importing conventional fertilisers, thereby encouraging local production and strengthening national fertiliser security.

Public extension services and agricultural training institutions in Georgia are still in the early stages of integrating sustainable fertiliser management and green technologies into their programming. According to the “Georgian Agricultural Sector: Transformation and developments over the past decade (2023) report,” extension officers often lack technical knowledge on renewable-powered technologies and modern nutrient management approaches.[6] This knowledge gap will make it difficult to scale decentralised ammonia systems unless addressed proactively through:

> **Curriculum reform** in vocational colleges and agricultural universities to include electrolysis-based fertiliser production and sustainable nitrogen management
>
> **Capacity-building** of public extension services through pilot project exposure and international exchange
>
> **Demonstration farms or living labs**, supported by state or donor funds, to showcase viable applications of decentralised fertiliser-energy systems.

A potential deployment model involves medium-sized farms producing green ammonia locally while smaller neighbouring farms access the product through shared distribution networks or subsidised supply programmes. Such an approach could accelerate adoption while avoiding the technical and financial barriers associated with installing production systems on very small farms.

In addition to this, Georgia’s draft Green Hydrogen Strategy (2024) identifies hydrogen derivatives, particularly ammonia, as important elements of a future hydrogen value chain. Ammonia is highlighted as a well-established hydrogen carrier that can facilitate the storage, transport and international trade of hydrogen-derived energy. Because hydrogen is difficult to transport directly over long distances, converting renewable hydrogen into derivatives such as ammonia provides a practical pathway for moving hydrogen-based energy between production centres and international markets. The strategy, therefore, recognises ammonia as a promising option for enabling hydrogen trade and supporting the integration of hydrogen into global energy systems.

According to the Strategy, ammonia production is already linked to the fertiliser industry, where hydrogen is currently produced from natural gas and used as a feedstock. The strategy notes that this existing industrial base provides relevant technical experience in ammonia production, storage and handling, creating a potential foundation for future

[6] See: https://webapi.parliament.ge/storage/files/shares/Komitetebi/agraruli/publikacia/transformacia. pdf.

low-carbon or green ammonia production based on renewable hydrogen. In the longer term, the gradual substitution of conventional hydrogen with renewable hydrogen could enable the production of low-carbon fertilisers and other hydrogen-based chemical products, contributing to industrial decarbonisation and supporting Georgia's climate objectives.

The strategy also highlights Georgia's geographic position and existing infrastructure as potential advantages for participating in regional hydrogen and hydrogen-derivative value chains. Hydrogen derivatives such as ammonia could be exported through Black Sea ports using established maritime transport systems, while transit flows from neighbouring regions could also utilise Georgian transport corridors. At the same time, the strategy emphasises that the hydrogen sector in Georgia is at an early stage of development. It calls for the gradual establishment of an appropriate regulatory and policy framework, including legislation covering hydrogen as an energy carrier, certification schemes compatible with EU standards, and pilot projects that can build technical capacity and support the emergence of viable hydrogen and hydrogen-derivative markets

1.6 Reform and Investment Opportunities

To create an enabling environment for Green Ammonia deployment, several reform directions emerge:

> **Establish** regulatory standards for small-scale renewable ammonia units to ensure environmental compliance and safety
>
> **Integrate** green fertilisers into national agricultural and climate strategies, aligning with Georgia's Low-Emission Development Strategy and Nationally Determined Contributions
>
> **Promote** pilot projects and fiscal incentives through MEPA and Rural Development Agency (RDA) programmes, targeting cooperatives and export-oriented farms
>
> **Encourage** blended-finance mechanisms combining donor support, concessional loans and carbon credit schemes
>
> **Strengthen** technical education and extension services to improve farmer knowledge of climate-smart inputs and on-farm renewable integration.
>
> Rather than waiting for comprehensive regulatory reform, policymakers could **introduce** temporary regulatory exemptions for pilot projects, allowing controlled demonstration of decentralised green ammonia systems under simplified licensing conditions.
>
> In addition to public extension services, farmer associations and international organisations such as FAO and UNDP may play an important role in **communicating** new

technologies to growers, as these organisations often maintain strong direct engagement with farming communities.

These measures would advance productivity as well as sustainability, supporting Georgia's broader agricultural transition.

1.7 Alignment with the PROGRESS Programme

The present study directly contributes to the PROGRESS programme, funded by Ministry for the Environment, Climate Action, Nature Conservation and Nuclear Safety (BMUKN) and implemented by a consortium with GIZ as a lead agency, which supports green economic transformation and climate resilience across the Eastern Partnership (EaP)[7]. Within its framework, the present study explores how renewable-energy-based fertiliser production can serve as a catalyst for sustainable agricultural growth in Georgia.

By focusing on the almond and blueberry sectors, the study aligns with PROGRESS's core objectives to:

Promote green and climate-resilient value chains

Facilitate cross-sectoral linkages between agriculture and renewable energy

Support evidence-based policymaking through feasibility and impact assessments

Encourage replicable, decentralised and innovative models for sustainable rural development.

Ultimately, this research aims to provide practical recommendations that connect farmers' needs with national reform agendas and regional sustainability goals under the European Green Deal (EGD).[8]

The EGD sets a transformative agenda for climate neutrality in the EU by 2050, including stricter sustainability requirements across agriculture, trade and energy. In case of Georgia, aligning with the EGD is not only a strategic ambition tied to the Deep and Comprehensive Free Trade Area (DCFTA), but also a practical necessity to future-proof its agri-export sectors. In this context, Green Ammonia emerges as a crucial solution, which may offer a low-emission, locally producible nitrogen fertiliser that supports both climate-smart farming and compliance with emerging EU standards such as CBAM.

[7] For more details on the Eastern Partnership please see: https://www.eeas.europa.eu/eeas/eastern-partnership_en.

[8] https://commission.europa.eu/strategy-and-policy/priorities-2019-2024/european-green-deal_en.

2. Methodology

The study applies a mixed-method approach integrating quantitative and qualitative research, technical and economic modelling and participatory stakeholder engagement. This combination ensures analytical accuracy, contextual relevance and alignment with both the PROGRESS programme objectives and national agricultural policies. The approach is designed to generate insights into the feasibility, benefits and implementation conditions for decentralised Green Ammonia production in Georgia's almond and blueberry value chains.

2.1 Desk Research

Comprehensive desk research combines quantitative and qualitative evidence to establish the analytical foundation for the study. Statistical data on agricultural production, trade, fertiliser use, and renewable energy potential are complemented by a systematic review of national policies, legal frameworks, and international literature.

The review encompasses a broad set of national and strategic documents, including the Agriculture and Rural Development Strategy of Georgia 2021–2027 and its Action Plans (2021–2023 and 2024–2027), the 2030 Climate Change Strategy of Georgia and corresponding Action Plan, and Georgia's Updated Nationally Determined Contribution (NDC) under the Paris Agreement and Long-term strategy document. It also analyses the Code of Good Agricultural Practices and national regulations on fertilisers and plant protection products issued by MEPA and relevant sectoral authorities. These documents frame the policy and institutional environment for the transition to sustainable agricultural inputs and climate-smart technologies.

The desk research also draws on key analytical and development publications, such as the World Bank report "Georgia - Towards Green and Resilient Growth", including related agriculture and rural investment projects (e.g., the GRAIL Irrigation and Land Management Project). Complementary insights are derived from UN's FAO guidance materials on sustainable fertiliser management and international energy studies by the International Energy Agency, World Bank, World Resources Institute, and UN agencies on Green Ammonia, hydrogen-to-ammonia conversion, and renewable energy integration.

Further to this, the national evidence is incorporated from the Primary and Secondary legislation as well as the publications, like "Georgian Agricultural Sector: Transformation and Developments Over the Past Decade", providing data on structural changes, productivity trends, and investment dynamics in the agri-food sector.

The findings from this multi-source review inform the design of fieldwork instruments, support the formulation of analytical hypotheses, and guide the selection of technical tools for subsequent tasks. They also provide the baseline for evaluating the coherence between Georgia's agricultural transformation agenda, climate commitments, and emerging opportunities for Green Ammonia deployment.

2.2 Interviews and Fieldwork

Fieldwork was carried out during October–November 2025 and combined qualitative and observational methods to complement the desk research and technical analysis. The main objectives were to gather first-hand information on farmers' experience with fertiliser use, their perception of innovative and climate-smart solutions such as Green Ammonia, and to understand value-chain linkages and institutional readiness for such technologies.

A total of five stakeholder interviews and two field visits were conducted. The interviewed parties included:

> **Georgian Blueberry Growers Association**, representing the majority of commercial blueberry producers and exporters
>
> **Almond and Walnut Producers Association**, providing insights on fertiliser use and productivity trends in Kakheti
>
> **Organic Almond Growers Farm**, a pioneering small enterprise transitioning toward sustainable and organic fertiliser practices
>
> **Georgian Farmers Association,** offering a cross-sectoral view of farmer challenges and institutional support needs.

The field visits took place in:

> **Nuts Cultivation Company's** organic almond orchards in Kvemo Bodbe (Kakheti), managing around 200 hectares of certified organic almond orchards, where discussions focused on fertiliser regimes (primarily organic inputs), pest control, and the broader potential for on-site renewable energy solutions. While synthetic ammonia is not currently permitted under organic standards, the viability of Green Ammonia as a future low-emission input was explored hypothetically, contingent on evolving certification frameworks.

Figure 2. Nuts Cultivation Co. Organic Almond Site in Kvemo Bodbe

LTD “Khoni Plantations” (Imereti) – This 20-hectare commercial blueberry farm provided insights into the operational dynamics of small-scale high-value fruit production in western Georgia. The field visit focused on understanding the farm's fertiliser application regimes, including types, quantities, and timing of nitrogen-based inputs used throughout the growing season. Additionally, the team observed the farm's irrigation infrastructure, which relies on electricity-driven systems, and discussed how this energy requirements intersect with fertiliser management practices - particularly during peak application periods. The visit also shed light on operational constraints, such as input costs, labour availability, and climate-related challenges (e.g., drought), helping contextualize the potential for integrated solutions like renewable-powered decentralised Green Ammonia systems. The farm manager shared valuable perspectives on the economic viability of adopting new fertiliser technologies, interest in ESG-compliant practices to attract premium buyers, and openness to cooperative approaches if they offered cost-sharing benefits or improved access to sustainable inputs.

Figure 3. LTD “Khoni Plantations” Co. Site in Imereti

Interviews followed a semi-structured format designed to balance consistency with flexibility. Each interview was guided by a pre-developed questionnaire aligned with the study's analytical tasks, covering themes such as fertiliser use patterns, cost and availability, environmental perceptions, and openness to new technologies. This format allowed respondents to elaborate freely on practical challenges and local innovations while ensuring comparability across stakeholders.

The interviews were conducted online, with participation from two researchers (a moderator and a note-taker) to ensure accurate documentation and triangulation. Interviews typically lasted 45–60 minutes, and responses were later coded thematically using qualitative content analysis. Confidentiality and informed consent procedures were strictly applied.

The fieldwork included direct observations of infrastructure, irrigation systems, storage facilities, and renewable-energy use, which were documented through field notes and photographs. These observations support the technical and economic analyses conducted under Tasks 1 and 2, particularly for identifying infrastructure bottlenecks and cost parameters relevant to decentralised Green Ammonia deployment.

Finally, the fieldwork outcomes will be validated through consultations with GIZ to ensure consistency with ongoing programmes and to integrate local feedback into the study's conclusions.

2.3 Technical and Analytical Methods

The technical component evaluates the feasibility of decentralised Green Ammonia production and its integration into the almond and blueberry value chains. Analytical methods include:

> Value Chain Integration Analysis, Cost-Benefit Analysis and Sensitivity & Scenario Analysis to assess economic viability
>
> Infrastructure Gap Analysis, Technology Readiness Assessment and Life Cycle Assessment (LCA) to evaluate technical and environmental aspects
>
> Capacity Needs and Policy Gap Assessments to identify institutional and regulatory bottlenecks
>
> Trade Competitiveness and Market Demand Forecasting to assess export and sustainability potential.

2.3 Stakeholder Engagement

A wide range of stakeholders - including farmers, agronomists, donor agencies, private sector actors and technical experts - were actively involved throughout the study (See Figure 8.) Engagement methods included semi-structured interviews, focus group discussions, consultations, and validation meetings (excl. the forthcoming Validation Workshop).

This inclusive and participatory approach ensures that the study reflects real-world agricultural conditions, market dynamics and technical capacities. Moreover, it aligns the research with national priorities and fosters ownership among key actors, increasing the likelihood of uptake and implementation of the recommendations.

2.4 Data and Validation

The study combines primary data collected through field visits, stakeholder interviews, and farm-level assessments, with secondary data from GeoStat, the Ministry of Environmental Protection and Agriculture (MEPA) and leading international datasets. Findings were triangulated across data sources to ensure a high degree of reliability, internal consistency, and contextual relevance.

Throughout the process, draft outputs were shared and refined in collaboration with GIZ, allowing for the integration of feedback and final alignment with sectoral strategies.

2.5 Stakeholder Validation Workshop

A validation workshop for the study "Green Ammonia Use in Small-Scale Agricultural Businesses in Georgia" was held in Tbilisi on 24 February 2026. The workshop brought together a broad group of stakeholders representing different segments of the agricultural, energy, and policy landscape in Georgia. Participants included representatives of farmer associations, agricultural producers and exporters, technical experts, government institutions, development partners and private sector actors involved in renewable energy and agricultural inputs.

The workshop was designed as a participatory validation exercise to review the preliminary findings of the study and to gather stakeholder perspectives on the feasibility, challenges, and opportunities related to the potential deployment of green ammonia systems in Georgia's agricultural sector. In line with the objectives outlined in the concept note, the workshop aimed to validate the study findings, identify key barriers and enabling conditions, and support the transition from analytical work to potential pilot initiatives.

The event began with a presentation of the study's objectives, methodology, and key preliminary findings by the project team. This provided participants with a common understanding of the concept of decentralised green ammonia production and its potential application within agricultural value chains in Georgia, particularly for crops such as almonds and blueberries. The presentation was followed by a plenary discussion that allowed participants to clarify aspects of the study and provide initial reactions.

To ensure more focused engagement and the collection of concrete inputs, participants were subsequently divided into three working groups addressing specific thematic questions related to the deployment of green ammonia systems in Georgia.

Group A – Technical Feasibility and Infrastructure

Group A discussed the question: What is needed to make green ammonia work at farm or cooperative level in Georgia within the next 3–5 years?

The discussion focused on the practical technical requirements and risks associated with implementing decentralised ammonia production and application systems. The group explored several guiding questions, including:

> What are the technical bottlenecks at farm or cooperative level?
>
> What is the minimum viable setup for a first pilot?
>
> What are the biggest technical risks to avoid early on?

Group participants highlighted that significant technical consultations and feasibility assessments will be necessary before pilot deployment. The group emphasized the importance of localising parts of the supply chain, including equipment procurement, technical maintenance, and service provision, in order to ensure operational reliability. Participants also noted that technical infrastructure and operational capacity at the farm or cooperative level remain key considerations.

Another important point raised was the need for risk-sharing mechanisms, particularly among farmers participating in potential pilot projects. Given that green ammonia systems represent a new and relatively unfamiliar technology, participants stressed that farmers would require confidence that technical and financial risks are adequately managed. Additionally, the group identified awareness raising and technical training as critical prerequisites for successful implementation.

Group B – Farmer Readiness and Adoption Conditions

Group B addressed the question: Under what conditions would farmers and cooperatives switch to green ammonia?

The discussion explored adoption dynamics and the factors that would influence farmers' willingness to engage with green ammonia technologies. The group considered the following guiding questions:

> Which farmer types are most likely to adopt first?
>
> What are the top concerns or barriers for farmers?

> What would convince farmers and cooperatives to try green ammonia systems?

Participants indicated that farmer stability and predictability of input supply are critical factors influencing adoption decisions. Farmers are generally cautious about adopting new technologies that may affect crop yields or input reliability. Therefore, ensuring stable production systems and reliable supply chains will be essential.

The group also noted that cooperative structures could play a key role in enabling adoption. Participants pointed out that cooperative models and collective purchasing mechanisms have historically been used in the region, including during the post-Soviet transition period, and such experiences could be leveraged for joint investments or shared operation of new technologies.

Furthermore, participants emphasized that economic incentives and clear benefits would be necessary to motivate farmers to participate in pilot initiatives. Demonstration projects, peer learning, and early adopter examples were considered important tools to build confidence among farmers.

Group C – Policy, Regulatory and Institutional Framework

Group C focused on the question: What must change in the policy and institutional setup to move from study findings to pilot projects?

> The group discussed the following guiding questions:
>
> Which regulatory gaps are currently blocking action?
>
> Which institutions must be involved from the start?
>
> What is the minimum policy setup needed for a pilot?

Participants highlighted that green ammonia sits at the intersection of agricultural, energy, and environmental regulation, which may require coordination among several government bodies. The group noted that clarity around regulatory frameworks, licensing procedures, and safety standards will be necessary before pilot projects can be implemented.

Another key discussion point concerned the role of public institutions and development partners in facilitating early-stage pilots. Participants suggested that pilot projects could benefit from institutional coordination mechanisms, potentially involving ministries responsible for agriculture, energy, and environmental protection.

The group also emphasized the importance of creating an enabling environment for experimentation, where pilot projects can be tested without excessive administrative burden. This could include simplified procedures for demonstration projects and targeted support mechanisms for innovative agricultural technologies.

Stakeholder Feedback and Integration into the Study

In addition to the discussions during the workshop, the draft study was made available to participants and other relevant stakeholders for written feedback following the event. The study remained open for comments for one week after the workshop. Some stakeholders provided detailed and insightful comments, reflecting both technical expertise and practical experience from the agricultural sector. These inputs contributed to refining the analysis, clarifying assumptions, and strengthening the practical relevance of the study's recommendations. The feedback received during the consultation period was reviewed and integrated into the final version of the study wherever appropriate.

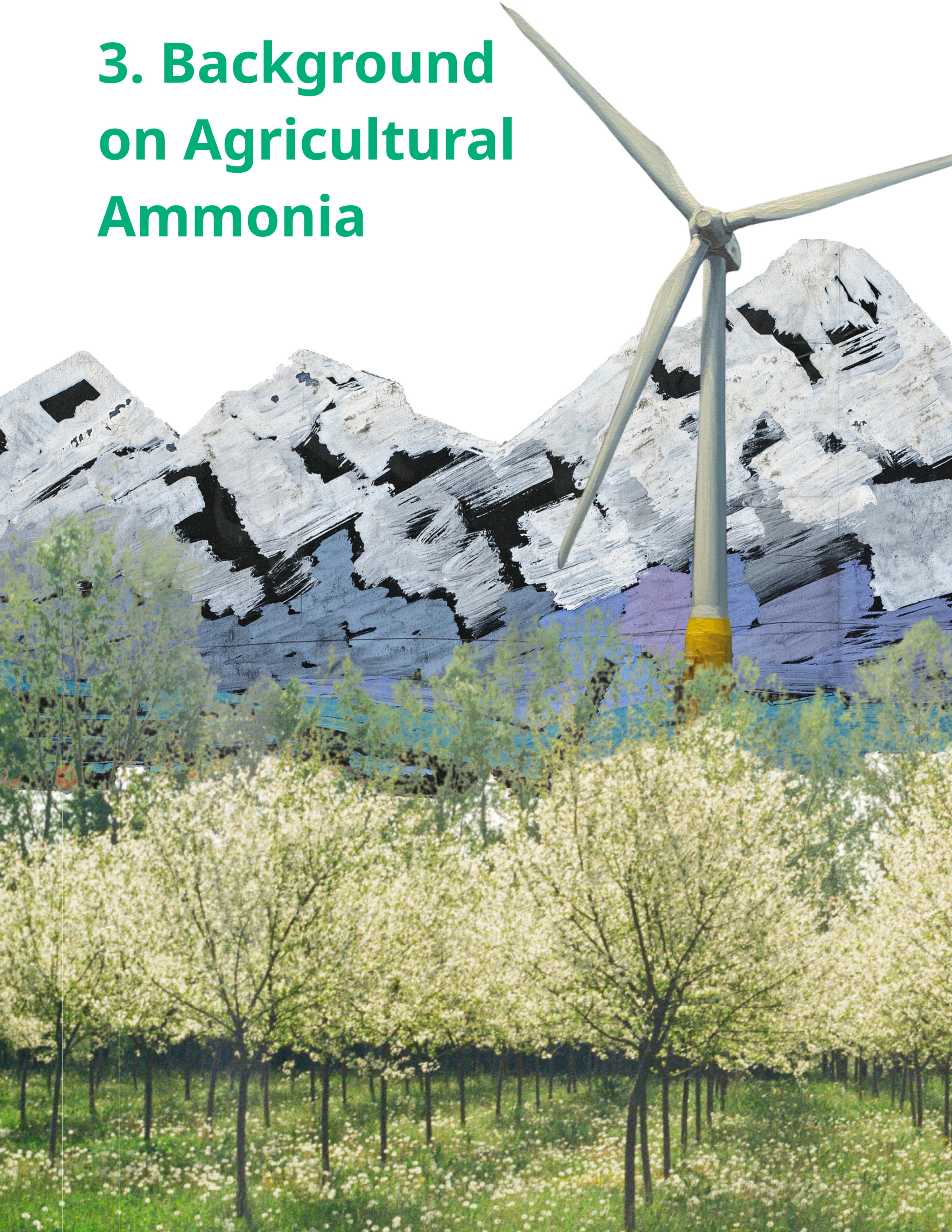
Overall Conclusions from the Validation Workshop

The validation workshop confirmed strong stakeholder interest in exploring innovative and low-emission solutions for agricultural inputs in Georgia. Participants generally acknowledged the potential of green ammonia to contribute to the decarbonisation of fertiliser supply chains and to support the country's broader climate and agricultural strategies. At the same time, discussions highlighted several critical conditions that must be addressed before implementation. These include technical readiness, farmer awareness and trust, appropriate cooperative structures, and a supportive policy and institutional environment. The insights gathered during the workshop and the subsequent written feedback process provided valuable input for refining the study and identifying potential next steps, particularly regarding the design of pilot projects and the further exploration of green ammonia solutions in Georgia's agricultural sector.

2.6 Coordination and Quality Assurance

The study maintained continuous coordination with GIZ from inception to finalization, ensuring consistency with programmatic goals and responsiveness to stakeholder needs. The team adhered to ethical research principles, including informed consent, confidentiality and transparent data handling. An internal quality assurance mechanism was in place, incorporating multi-disciplinary review across technical, environmental, policy, and socio-economic dimensions. This ensured that the findings and recommendations were evidence-based, methodologically sound and strategically actionable within Georgia's evolving agricultural and climate policy landscape.

3. Background on Agricultural Ammonia



Ammonia is the foundational molecule behind all synthetic nitrogen fertilisers - powering yields across global food systems[9]. Today, over 150 million tonnes of ammonia are produced annually, with ~71% going directly into fertilisers such as urea, ammonium nitrate, and NPK blends. As illustrated in the Sankey diagram below, adapted from Mingolla et al.[10], this vast flow of ammonia is still overwhelmingly tied to fossil fuel feedstocks - natural gas accounts for over 70% of global ammonia production, with coal and oil filling much of the remainder. Less than 1% of ammonia today is made using renewable electricity, and even that is mostly at pilot scale.

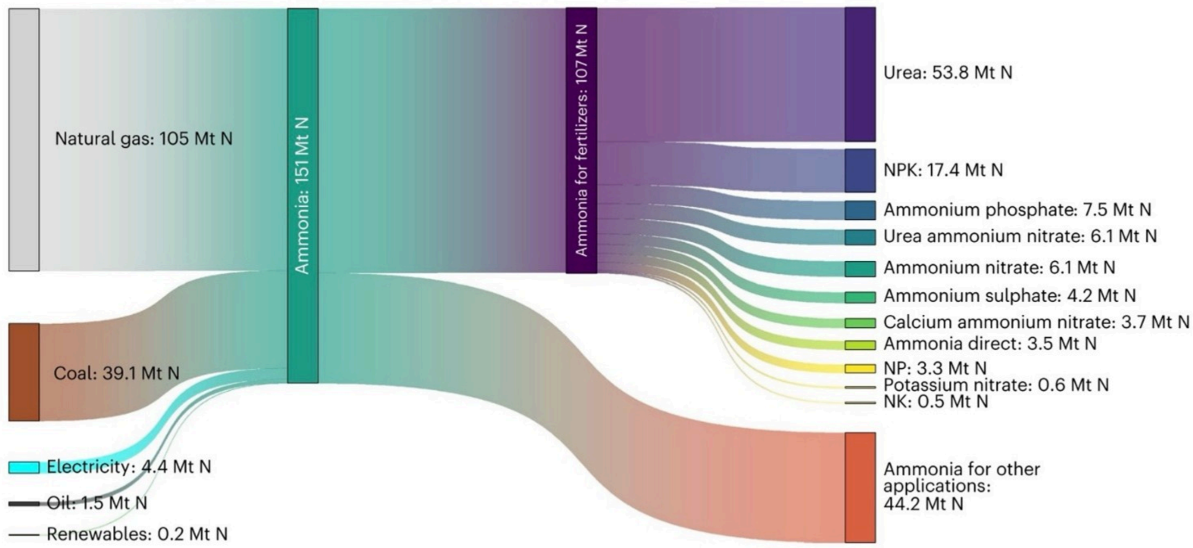


Figure 4: Global Nitrogen Flow from Feedstock to Ammonia-Based Fertiliser Products

The conventional Haber–Bosch process is not only centralized and capital-intensive, but it also generates approximately 2 tonnes of CO_2 per tonne of NH_3, making it one of the most carbon-intensive industrial processes in the world. However, as shown in the below figure, new research from *Nature Food*[11] suggests that distributed, electrochemical ammonia production systems, particularly those powered by local renewables, could become increasingly price-competitive by 2030–2050, depending on the scenario.

In agrivoltaics and grid-tied systems, distributed ammonia could serve smallholder clusters, export farms, and cooperatives, bypassing traditional supply chains and associated volatility.

[9] On average, nitrogen fertilisers, primarily in the form of ammonia-based compounds, account for 30% to 50% of global yield increases in staple crops over the past century. Without synthetic nitrogen inputs, it is estimated that global food production would decline by up to 50%, highlighting the critical role of fertiliser in supporting food security and land-use efficiency.
(Source: Erisman et al., 2008, "How a century of ammonia synthesis changed the world", Nature Geoscience)

[10] Mingolla, S., & Rosa, L. (2025). Low-carbon ammonia production is essential for resilient and sustainable agriculture. Nature Food, 6(6), 610–621. .

[11] Tonelli, D., Rosa, L., Gabrielli, P., Parente, A., & Contino, F. (2024). Cost-competitive decentralized ammonia fertilizer production can increase food security. Nature Food, 5(6), 469–479. .

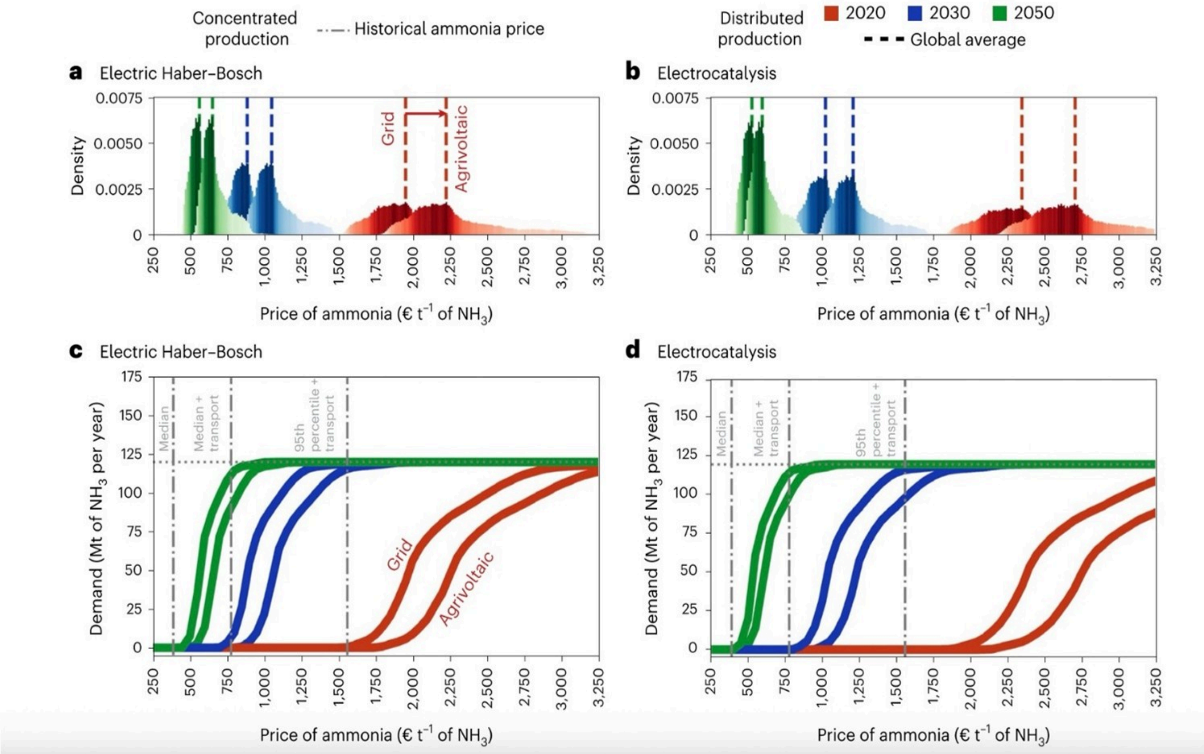


Figure 5: Ammonia Cost Distribution and Market Demand Across Production Routes and Timeframes

This shift offers a unique opportunity for countries like Georgia. Instead of importing urea or nitrate from abroad, farms could generate ammonia on-site using solar electricity, store it in liquid form, and apply it directly via fertigation.

Georgia hosts a key industrial site - Rustavi Azot - that forms the backbone of its domestic ammonia and fertiliser production. The facility is reported to have an annual production capacity of approximately 220,000 metric tonnes of ammonia and up to 550,000 metric tonnes of ammonium nitrate.[12,13]

Despite this, nitrogen fertiliser imports remain significant: in 2023, Georgia imported nitrogenous fertilisers valued at approximately €10.1 million, with additional imports from earlier years consistently exceeding €18–25 million, depending on energy prices and demand cycles.[14,15]

[12] FMO (2021). Rustavi Azot project briefing. https://ewsdata.rightsindevelopment.org/projects/FMO-47819/.

[13] EBRD (2025). EBRD supports modernisation of fertiliser production in Georgia. https://www.ebrd.com/home/news-and-events/news/2025/ebrd-supports-modernisation-of-fertiliser-production-in-georgia.html.

[14] Trendeconomy (2024). Georgia nitrogenous fertiliser imports (HS Code 3102). https://trendeconomy.com/data/h2/Georgia/3102.

[15] Enterprise Georgia (2015). Fertiliser Market Overview. https://www.enterprisegeorgia.gov.ge/uploads/files/publications/5b4dd99bcc88d-5.pdf.

While Georgia also exports nitrogen fertilisers, reaching over 75,000 metric tonnes in just the first two months of 2025, the extent to which these exports originate from domestic synthesis versus reprocessed imports remains unclear.[16]

As no fully disaggregated national data on actual production volumes over time are publicly available, it remains difficult to establish a precise domestic-versus-import ratio. However, the import volume and ongoing investment in Rustavi Azot underscore both the strategic importance and the xvulnerability of Georgia's nitrogen input supply chain.

In addition to eliminating supply risk and import premiums, this model dramatically cuts carbon emissions, enables integration with solar infrastructure, and could support new revenue streams through carbon credits or sustainable certifications. Given rising fertiliser costs, shifting EU buyer preferences, and ongoing geopolitical input disruptions, the case for decentralised Green Ammonia in agriculture is no longer theoretical - it's rapidly becoming strategic.

[16] BM.ge (2025). Georgia earned €21.6 million from nitrogen fertiliser exports in Jan–Feb 2025. https://bm.ge/en/news/georgia-earned-up-to-24-mln-in-revenue-from-nitrogen-fertilizer-exports-in-2m25.

4. Study Findings

4.1 Technical Feasibility

Decentralised Green Ammonia production for small-scale agricultural use in Georgia is technically feasible under specific infrastructural and operational conditions. Farm-level energy access, water availability, and fertiliser application methods vary significantly across regions and crop types, shaping the practical scope for deploying such system. As shown below, Green Ammonia adoption readiness can be considered as a combination of these factors. Farms with access to already installed renewable energy, abundant water supply, and that currently use nitrogen-based fertilisers are more ready to adopt than farms lacking any of these 3 resources at the farm-level.

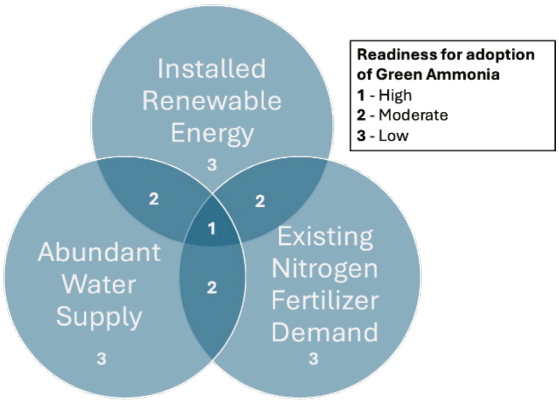


Figure 6: Farm Category Performance Comparison

Farms that possess a high readiness for adoption of Green Ammonia, may still be challenged by the core feasibility of efficiently and cost effectively converting atmospheric nitrogen into ammonia. At present, no published material or system has demonstrated high electrical efficiency for prolonged use-cases at generating ammonia from renewable energy at scales needed by a farm.[17] Moreover, the produced ammonia requires careful handling and storage through on-site infrastructure.

The Organic Almond Farm in Kakheti, for instance, demonstrates strong baseline readiness. Despite its rural location, the farm independently builds a 28-kilometre private electricity line, securing stable grid access and laying the groundwork for integrating on-site solar.

This infrastructure could support a ~1 MW solar installation, making renewable-powered electrolysis a plausible option. Additionally, the farm has space and systems in place for storing liquid organic inputs, including tanks up to 2,000 litres, which could be adapted for ammonia-based fertilisers. See **Annex 3** for further information on how to calculate expected production of hydrogen and ammonia by provided renewable energy.

[17] Kaur, G., Zhu, H., Dhawale, D. S., Ju, H. K., Biswas, S., Kim, J. H., Yoon, H. C., & Giddey, S. (2025). A review on intermediate temperature electrochemical synthesis of ammonia. Applied Energy, 393. https://doi.org/10.1016/j.apenergy.2025.126092.

In contrast, many nut and berry farms in Georgia use advanced drip irrigation systems that are incompatible with particulate or unfiltered fertilisers. For these farms - especially blueberry producers in western regions - Green Ammonia would need to be delivered in a highly purified, water-soluble format suitable for fertigation systems. This sets a higher technical bar for filtration and distribution mechanisms.

Machinery readiness also varies. Most large producers have tractors and sprayers capable of applying liquid fertiliser across 100+ hectares, and some already manage on-farm fermentation or composting. However, smaller producers lack the capacity to install and maintain complex production units. In these cases, cooperative-based deployment or mobile ammonia systems may be more appropriate.

Electricity access remains a limiting factor in certain rural zones. While Georgia's national grid is 70% hydro-powered - providing an inherently low-carbon baseline - many farmers report inadequate local transmission infrastructure, voltage fluctuations, and limited renewable generation nearby. Without targeted investment in rural solar infrastructure or battery storage, adoption of Green Ammonia systems may be delayed outside of pilot clusters.

Overall, technical feasibility is highest for:

> Export-oriented farms looking to show reduction in greenhouse gases created by their farm with robust (perhaps on-site) energy and water infrastructure
>
> Organic or regenerative growers already using non-synthetic nitrogen sources
>
> Farmer associations or cooperatives with interest in shared input solutions
>
> Further feasibility studies will be needed to define optimal system sizes (e.g. 50 kg/day units), energy inputs (e.g. 5–10 kWh/kg NH_3), and purification requirements based on end-user equipment.

Despite growing technical interest, Georgia lacks a permitting framework tailored to decentralized ammonia production. Electrolysers and ammonia storage are not explicitly covered under current agricultural or energy regulations, creating legal uncertainty for farmers or cooperatives exploring on-site systems. Globally, countries like Germany and Australia have introduced differentiated licensing tiers or pilot exemptions for small-scale ammonia projects. These often include safety protocols, simplified environmental assessments, and temporary operating licenses tied to renewable energy use. In Japan, rural cooperatives testing on-farm ammonia systems have been granted limited zoning exemptions under national innovation pilots, provided they meet operator training and leak prevention standards (See **Annex 4**).

Georgia could adopt similar enabling mechanisms to unlock early adoption. This includes developing permitting fast-tracks for systems under defined production thresholds, issuing temporary regulatory sandboxes for pilot deployments, and embedding ammonia system safety into vocational training. Cross-ministerial coordination between MEPA, the Ministry of Economy, and the Georgian National Agency for Standards and Metrology (GEOSTM) will be critical to avoid regulatory bottlenecks and ensure alignment with both agricultural and energy transition goals.

4.2 Economic and Social Benefits

Globally, the transition to Green Ammonia offers farmers multiple economic and social advantages that go beyond environmental gains. Chief among these is the potential for price stability and input independence. In markets with high exposure to imported fertilisers, such as sub-Saharan Africa, Southeast Asia, and Latin America, on-farm or cooperative-level ammonia production has been proposed as a way to shield farmers from volatile global nitrogen markets. Projects in Kenya (e.g., KOKO Networks) and Chile (e.g., Enaex-Puerto Mejillones) illustrate early-stage models where decentralised ammonia or hydrogen production is being paired with renewables to stabilise fertiliser or industrial input supply.

On top of that, decentralised Green Ammonia systems support local value creation and employment. Unlike conventional fertilisers, which are produced in large, centralised plants with minimal rural economic linkages, small-scale Green Ammonia units require local operators, technicians, and maintenance providers. This translates into job creation and aligns with just transition goals under frameworks like the EU Green Deal and the African Green Stimulus Programme.

Socially, access to clean nitrogen inputs can also support equity and inclusion. In India, for example, pilot projects exploring Green Ammonia in dairy and pulse value chains have shown potential to improve the livelihoods of women-led cooperatives, who face higher fertiliser prices due to smaller purchase volumes and poor local delivery infrastructure. When embedded in cooperative or shared-ownership models, Green Ammonia systems can democratise access to technology, reduce input dependency, and improve bargaining power for smallholders.

Green Ammonia systems offer potential long-term economic benefits for Georgian farmers, primarily through reduced fertiliser cost volatility, import substitution, and alignment with sustainability standards of high-value export markets.

For conventional producers (e.g., blueberries, almonds, walnuts), nitrogen fertilisers make up a significant share of production costs. Blueberry farms report spending 3,000-4,000 GEL/ha annually on fertilisers, with nitrogen accounting for 40% of that amount. Given recent price spikes of over 70% (2022–2023), producers are actively exploring alternatives - particularly if amortised production costs under decentralised Green Ammonia systems fall below market imports.

In contrast, a localised Green Ammonia system would have initially high projected ammonia costs as a result of CAPEX costs. Following amortization of the capital, ammonia costs would decrease and be mostly composed of OPEX costs (water, energy, upkeep, permitting, etc.). The table below compares on average what the current spending on nitrogen fertilizer is for a Georgian farmer versus a decentralised plant servicing ~100 ha, with a production cost ~US$500/t NH_3, and an initial CAPEX of ~GEL6.2M.[18,19,20] Green Ammonia costs would be roughly double that of the current market costs until the full cost of the CAPEX is sunk. At which point, the projected Green Ammonia costs would be ~155 GEL/ha/year on going which is roughly 1/60th of the current market cost.

Metric	Current spends (Georgian farmer)	Projected decentralised green NH_3 system
Typical nitrogen fertiliser cost	3,000-4,000 GEL/ha	-
OPEX (green NH_3)	-	~155 GEL/ha/year (after CAPEX amortised)
CAPEX amortised cost	-	~6,355 GEL/ha (year 1)
Total "first-year" cost	~3,000-4,000 GEL/ha	~6,510 GEL/ha (CAPEX + OPEX)
Subsequent years cost	~3,000-4,000 GEL/ha	~155 GEL/ha/year (assuming CAPEX sunk)

Organic producers such as almond farm interviewed in Kakheti already rely on fermented manure but face high costs (25% of total OPEX) for supplemental organic inputs, mostly imported from Italy. For these producers, self-generated nitrogen from Green Ammonia could significantly reduce dependence on expensive imports while

[18] Fernández, C. A., Chapman, O., Brown, M. A., Alvarez-Pugliese, C. E., & Hatzell, M. C. (2024). Achieving Decentralized, Electrified, and Decarbonized Ammonia Production. Environmental Science and Technology, 58(16), 6964–6977. https://doi.org/10.1021/acs.est.3c10751.

[19] AMMPOWER. (2022). Market-ready Solution for Decentralized Ammonia Production. https://www.ammoniaenergy.org/wp-content/uploads/2022/10/AEA-2022-AmmPower-final.pdf.

[20] Zetomica. (2025). Green Ammonia Production with Nuclear Power. https://zetomica.com/articles/green-ammonia-production-with-nuclear-power/.

maintaining organic certification - if certification pathways evolve to include low-carbon ammonia from renewable sources.

Social benefits include:

- Job creation for ammonia system operators, especially in remote areas
- Skills development in renewable energy and sustainable input production
- Increased resilience among rural communities through localised input autonomy

However, feasibility depends on cost parity with synthetic nitrogen. Most farmers indicate they are open to adopting new systems only if the return on investment (ROI) is clearly positive and maintenance is minimal. For example, larger farms are willing to dedicate staff to ammonia systems if it offsets existing fertiliser budgets or improves their ESG profile.

Cooperative models may amplify these benefits. Shared ammonia production units could reduce per-farmer capital outlays, enable knowledge transfer, and strengthen input bargaining power - particularly among smallholders who are otherwise priced out of organic or low-carbon inputs.

4.3 Environmental and Sustainable Impact

Traditional ammonia production via the Haber–Bosch process is one of the most carbon-intensive chemical processes in the world. Alone, traditional ammonia production accounts for 1.8–2.0 tonnes of CO_2-equivalent emissions per tonne of ammonia produced. The high emissions are largely due to Haber-Bosch's reliance on natural gas as both a hydrogen source and energy input. In contrast, Green Ammonia, synthesized using electrolysis powered by renewable electricity, has the potential to reduce life cycle emissions by up to 90%, achieving emission intensities as low as 0.1–0.2 tonnes CO_2 per tonne under optimal renewable energy use and system efficiency. These differences are particularly relevant for countries like Georgia seeking to decarbonize their agri-export value chains and align with EU's climate neutrality aspirations and potential future extensions of the CBAM.[21]

Beyond emissions, Green Ammonia could also offer significant co-benefits for soil and water quality. Conventional nitrogen fertilisers, such as urea and ammonium nitrate, are prone to leaching and runoff, which contribute to eutrophication and groundwater contamination - particularly in areas with shallow aquifers or runoff-sensitive ecosystems. Locally produced Green Ammonia can help address these risks by enabling more controlled, timely, and efficient fertiliser application near farm sites throughout the growing season.

[21] https://taxation-customs.ec.europa.eu/carbon-border-adjustment-mechanism_en.

This more sustainable nitrogen source presents a transformative opportunity for Georgia's agriculture, which currently relies heavily on imported fossil fuel–based fertilisers. These inputs not only carry high embedded emissions but also contribute to soil degradation and nutrient runoff, especially under poorly managed application regimes.

A recent study by Mingolla et al.[22], compared the trade-offs of 7 different factors between natural gas "business as usual" (BAU) and decentralized renewable electrolysis. As shown in the below adapted figure from their report, fossil-fuel dependence, GHG emissions, and supply chain complexity have a high impact on the production of methane based ammonia production. Much lower impact on each of these factors can be found in implementation of decentralized renewable electrolysis (Green Ammonia), however, cost and electricity use remain a high impact trade off.

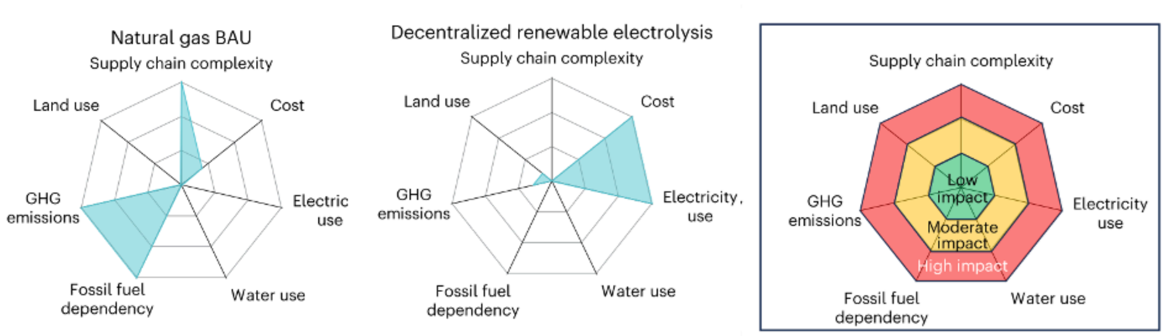


Figure 7: Environmental and Supply Chain Trade-Offs Between Natural Gas and Renewable Ammonia Pathways

Transitioning to locally produced Green Ammonia could yield several environmental benefits:

Reduction of GHG emissions from both fertiliser production and transport

Lower nitrate runoff if application is properly matched to crop uptake

Improved soil health, especially if integrated with organic or regenerative practices

While ammonia itself is not a pesticide, its usage patterns influence broader input strategies, particularly in regenerative or organic systems. Farms integrating Green Ammonia with biofertilisers, compost, or cover crops may reduce dependency on synthetic pesticides by improving plant health and soil microbiota balance. Moreover, unlike conventional fertiliser supply chains, decentralised ammonia systems could

[22] Mingolla, S., & Rosa, L. (2025). Low-carbon ammonia production is essential for resilient and sustainable agriculture. Nature Food, 6(6), 610–621. https://doi.org/10.1038/s43016-025-01125-y.

support on-demand application, reducing nutrient surpluses that often lead to pest population booms.

Indirectly, this transition supports biodiversity preservation, especially in zones adjacent to high-value natural areas or riparian corridors. For example, lower nitrogen runoff into rivers can improve aquatic biodiversity, while reduced chemical accumulation in soils benefits pollinators and below-ground species critical to long-term soil fertility.

In sum, Green Ammonia's environmental advantage extends beyond carbon metrics to encompass water quality, soil regeneration, and potential synergies with low-input farming practices - supporting both productivity and ecological resilience in Georgian agriculture.

The almond and blueberry value chains - already geared toward premium export markets - stand to benefit from emissions tracking and lifecycle transparency. Some buyers, such as German supermarkets, have already begun requesting voluntary carbon reporting, and organic farms like the one in Kakheti are preparing for mandatory carbon footprint disclosures.

Moreover, farms with waste biomass (e.g., almond shells, husks) may explore coupling Green Ammonia systems with pyrolysis or biochar production. While energy-intensive, these closed-loop systems can enable carbon-negative farming models under the right conditions. Integrating solar energy systems, green ammonia production and soil carbon technologies such as biochar could also create opportunities for carbon credit generation, provided appropriate monitoring and verification systems are developed.

However, the overall environmental benefit depends heavily on the source of electricity used in ammonia synthesis. Without solar or hydro-based power, the "green" label may not hold up under EU-level scrutiny or certification frameworks.

Key constraints include:

> Lack of regulatory clarity on certifying low-carbon ammonia as organic
>
> Limited knowledge among farmers and extension services about ammonia's role in nitrogen cycling
>
> Energy intensity of production (~9–11 kWh/kg) requiring clean, low-cost power to remain competitive

What is more, Green Ammonia aligns well with Georgia's climate strategy and EU approximation goals. If supported by policy, pilot investment, and carbon tracking systems, it can enable a shift toward more sustainable, resilient fertilisation across the agri-value chains.

The environmental benefits of Green Ammonia production and use are well aligned with Georgia's national climate and energy ambitions as outlined in the NECP (2023), Long-Term Low Emissions Development Strategy (LTS, 2023), and Updated Nationally Determined Contribution (NDC, 2021). Georgia's NECP explicitly identifies agriculture as a priority sector for climate action and promotes the reduction of emissions from fertiliser use through innovation and enhanced nitrogen management. Green Ammonia systems - particularly those powered by solar and hydro - can directly support these goals by replacing fossil-based nitrogen inputs with low-emission alternatives, while also creating new synergies with decentralised renewable energy deployment.

The LTS outlines a vision for 2050 where low-emission agricultural practices and climate-smart technologies are widely adopted, including a transition toward decarbonised inputs, integrated land use, and energy efficiency across the food system. Green Ammonia fits into this paradigm by offering a circular fertiliser solution that can reduce dependence on imported urea and ammonium nitrate, while also opening pathways for closed-loop farming systems that improve soil health and reduce water pollution. In addition to mitigation, decentralised Green Ammonia production can also strengthen Georgia's adaptive capacity. By enabling more predictable and locally controlled fertiliser supply chains, farmers are better insulated from global disruptions, extreme price volatility, and geopolitical risks—factors that can otherwise undermine production and planning, particularly in the face of climate shocks.

Further, Georgia's NDC emphasizes adaptation co-benefits, environmental integrity, and emission reductions in the land-use and agricultural sectors. The adoption of Green Ammonia technology would contribute to achieving Georgia's target of reducing GHG emissions by 35% below 1990 levels by 2030, especially through mitigation measures that address non-CO_2 emissions in agriculture, such as nitrous oxide from fertiliser overuse. At the same time, by promoting efficient nutrient use and potentially reducing over-application of synthetic fertilisers, Green Ammonia systems can lessen soil and water degradation and, thus, support long-term agricultural productivity and resilience to climate impacts like drought or soil salinization.

In this sense, Green Ammonia aligns not only with mitigation targets but also with adaptation goals outlined in all three strategic documents — strengthening the resilience of the agricultural sector and ensuring continuity of agri-export value chains in a changing climate.

Incorporating Green Ammonia into Georgia's policy toolkit not only reinforces these strategic documents but also enables early alignment with EU sustainability requirements such as the European Green Deal and the Carbon Border Adjustment Mechanism, which are expected to influence agri-export markets in the near future.

4.4 Farmer Readiness and Adoption Potential

The global agricultural landscape is increasingly recognising the potential of decentralised, low-carbon fertiliser systems. Regions especially burdened by high import dependence, volatile input prices and unreliable supply chains stand to benefit the most form Green Ammonia. For example, in sub-Saharan Africa the shift toward on-farm or community-level production of green nitrogen sources is being considered as a way to mitigate supply shocks and improve food security.[23,24]

In North America, U.S. states such as Minnesota are already preparing roadmaps for "distributed Green Ammonia" systems that could bring fertiliser production closer to farms and reduce logistic premiums.[25] Meanwhile, in the Asia-Pacific region countries like Thailand, India and Japan are advancing both large-scale Green Ammonia projects and actionable strategies for localised use, signalling wider readiness for adoption.[26,27]

These global precedents provide a strong backdrop for understanding how farmers' readiness - shaped by factors such as technology cost, farm-level integration capacity, supply chain disruptions and institutional support - is evolving. The implication for the context of this study is clear: adoption will depend not just on the availability of Green Ammonia systems, but on how well they fit within the farmer's business model, local infrastructure and regulatory environment.

Farmer readiness for adopting Green Ammonia in Georgia varies significantly by farm size, crop type, and existing energy and fertiliser practices. While technical awareness remains limited, there is strong interest in cost-saving, low-carbon alternatives to imported nitrogen fertilisers - especially from export-oriented and organic producers.

Large-scale producers, such as members of the Georgian Blueberry Growers Association (GBGA) and the Organic Almond Farm in Kakheti, have the operational scale and management capacity to consider on-farm production systems. GBGA farmers already use computer-controlled fertigation systems and spend approximately 3,000–4,000 GEL per hectare annually on fertilisers. While unfamiliar with Green Ammonia per se, they expressed a strong willingness to adopt in-house nitrogen production if systems prove

[23] Sameer Parvathikar. (2023, October 31). Green Ammonia's Potential to Improve Food Security and Mitigate Climate Change Across Africa. RTI International - Insights Blog.

[24] Alho, S., Rombach, A., & Zeppenfeldt, L. (2024). Decentralized Green Ammonia Quick Guide. https://clim-eat.org/wp-content/uploads/2024/10/Quick-Guide-Decentralized-green-ammonia.pdf.

[25] Kirk, T., Krimer, A., Munasinghe, S., Rodriguez, E., Rosas, J., & Homann, Q. (2024). Roadmap for Distributed Green Ammonia in Minnesota. https://rmi.org/roadmap-for-distributed-green-in-Minnesota.

[26] Bidwai, S., & Shivarkar, A. (2025, September 2). Asia Pacific Green Ammonia Market: Demand, Production, and Future Projections. Towards Chem and Materials. https://www.towardschemandmaterials.com/insights/asia-pacific-green-ammonia-market.

[27] DNV Energy systems, & GIZ Thailand. (2024). Green Ammonia Market Study in Thailand and SEA Region. https://www.thai-german-cooperation.info/wp-content/uploads/2024/06/Ammonia-market-study-report_final-version.pdf.

financially viable and technically robust. For such farms, the primary motivator is economic: savings on input costs and reduced supply risk.

Among organic producers, the motivation also includes alignment with ESG and certification standards. The manager of Georgia's first certified organic almond operation sees Green Ammonia as a potential way to meet growing EU buyer expectations for carbon tracking - provided certification pathways exist for its use within organic systems.

However, smallholders and conventional nut producers showed limited awareness of ammonia-based fertilisers and remain risk-averse. Most rely on external fertiliser suppliers and lack the labour or technical capacity to operate new systems. Some are open to cooperative models if cost savings are proven, but uptake would likely require government support or external facilitation.

While farmer segmentation by capacity (infrastructure, export focus, crop type) remains the primary lens for adoption, it is worth noting that Green Ammonia systems may also intersect with inclusion dynamics in labour-sensitive value chains like blueberries. In Georgia, for example, women make up the majority of seasonal labour in blueberry production.

If Green Ammonia systems are introduced through cooperatives or require trained operators, there may be opportunities to upskill rural youth and women in system management, fertiliser application, or carbon tracking. However, targeted training and access-to-technology programs would be necessary to avoid reinforcing existing disparities. Inclusion is not a precondition for adoption, but a design opportunity for broader social benefit.

Key readiness indicators include:

> High (Export-focused, ESG-aligned, large-scale farms)
>
> Moderate (Blueberry farms with fertigation systems)
>
> Low (Smallholders, fragmented nut producers)

Education and demonstration projects will be critical. Farmer understanding of "Green Ammonia" remains minimal; most reference "nitrogen" without distinguishing source or synthesis method. Building literacy around ammonia production, application, and certification potential will shape future adoption.

Infrastructure and Capacity Barriers to Adoption

While high-capacity, export-oriented farms may possess the baseline infrastructure to integrate Green Ammonia production (e.g. stable electricity, irrigation systems, input storage), most Georgian farms do not. Critical infrastructure gaps include reliable power supply, modular input storage, and precision application equipment compatible with ammonia solutions. For instance, many smallholders operate on low-voltage rural grids prone to fluctuation, making electrolysis units infeasible without additional investment in stabilisation, on-site generation, or battery backup. Furthermore, a significant number of farms lack the tank capacity or pumping systems required for safe ammonia handling and fertigation.

Beyond hardware, the soft infrastructure, such as knowledge, training, service networks, is equally underdeveloped. Currently, extension services and vocational programs do not provide instruction on decentralized ammonia-based fertiliser systems, their operation protocols, or system maintenance. Farmer associations are largely unfamiliar with decentralised fertiliser production models, and there is no established pipeline of system integrators or technicians. This lack of human capital represents a major bottleneck for technology adoption.

Risk Perception and the Investment Hesitation Hypothesis

The core hypothesis of this study is that: *"Farmers who have a low barrier to adoption will be interested in Green Ammonia, but hesitant to invest in new technology unless sufficient risk mitigation is provided on their behalf."* This is strongly supported by field insights. Even among well-equipped producers, such as members of the Georgian Blueberry Growers Association, there is notable hesitation around early-stage investment. Concerns include system downtime, uncertain ROI, and potential certification hurdles for crops treated with a "new" input.

This hesitation reflects a classic "first-mover disadvantage." Farmers are not unwilling to adopt; they are unwilling to shoulder the entire risk burden of early adoption. To overcome this, risk-mitigating mechanisms such as pilot cost-sharing, capital subsidies, technical guarantees, or performance-based incentives must be introduced. Additionally, establishing demonstration farms and embedding Green Ammonia use into public extension curricula can help reduce uncertainty and normalise the technology.

The segmentation model of advanced vs. low-capacity farms remains a useful tool to guide early deployment. However, within each segment, perceived risk and trust in support structures will ultimately shape adoption more than infrastructure alone. This underscores the need for a systems-based approach that combines technical feasibility with capacity-building, financial de-risking, and strong institutional coordination.

4.5 Institutional and Financial Ecosystem

Around the world, governments and industry are beginning to deploy and pilot decentralised and Green Ammonia solutions. For example, in sub-Saharan Africa countries like Kenya and Malawi are exploring modular Green Ammonia units to reduce dependency on imported nitrogen fertilisers and improve resilience in high-import regions.[28,29] In North America and Europe the firm Rocky Mountain Institute (RMI) has published roadmaps for "distributed Green Ammonia" systems aiming to stabilise fertiliser supply chains and reduce emissions.[30] Furthermore, academic work such as the study by D. Tonelli et al., "Cost-competitive decentralised ammonia fertilizer production," highlights that in favourable locations decentralised Green Ammonia could become cost-competitive against conventional fertilisers by 2030.[31, 32]

Each of these examples underscores three important lessons:

- Regions with high import dependence and high logistic/fuel cost premiums tend to be early hotspots for decentralised ammonia.
- The combination of renewable energy availability, localised production need, and supportive policy/regulatory frameworks is critical.
- The evolution of cost-competitiveness depends strongly on transport/supply chain disadvantage of conventional fertilisers, which gives green systems an early entry edge.

The current institutional and financial environment in Georgia is not yet equipped to support decentralised Green Ammonia adoption at scale. Fertiliser import, distribution, and safety are governed under agricultural quality regulations, while renewable energy systems fall under a separate energy-sector framework. No legal provisions yet exist for on-farm ammonia generation, storage, or safety protocols - creating regulatory ambiguity for potential adopters. Moreover, there is minimal coordination between the MEPA, the Ministry of Economy and Sustainable Development, and the GEDF on decentralised green alternatives systems. This lack of cross-sector integration hinders efforts to link renewable energy and sustainable agriculture in a cohesive way.

The table below outlines key policy instruments, their current status in Georgia, and what anticipated changes are needed to better adopt Green Ammonia.

[28] Kirk, T., Krimer, A., Munasinghe, S., Rodriguez, E., Rosas, J., & Homann, Q. (2024). Roadmap for Distributed Green Ammonia in Minnesota. https://rmi.org/roadmap-for-distributed-green-ammonia.

[29] Alho, S., Rombach, A., & Zeppenfeldt, L. (2024). Decentralized Green Ammonia Quick Guide. https://clim-eat.org/wp-content/uploads/2024/10/Quick-Guide-Decentralized-green-ammonia.pdf.

[30] Sameer Parvathikar. (2023, October 31). Green Ammonia's Potential to Improve Food Security and Mitigate Climate Change Across Africa. RTI International - Insights Blog.

[31] Tonelli, D., Rosa, L., Gabrielli, P., Parente, A., & Contino, F. (2024). Cost-competitive decentralized ammonia fertilizer production can increase food security. Nature Food, 5(6), 469–479. https://doi.org/10.1038/s43016-024-00979-y.

[32] Fernández, C. A., Chapman, O., Brown, M. A., Alvarez-Pugliese, C. E., & Hatzell, M. C. (2024). Achieving Decentralized, Electrified, and Decarbonized Ammonia Production. Environmental Science and Technology, 58(16), 6964–6977. https://doi.org/10.1021/acs.est.3c10751.

Policy Instrument	Current Status in Georgia	Needed for Green Ammonia Adoption
Agro-credit Lines	Available for conventional inputs; no dedicated lines for Green Ammonia or general green agricultural practices	Dedicated Green Ammonia credit windows via RDA or concessional donors
Input Subsidy Schemes	Focused on traditional fertilisers; green inputs not included	Subsidies for ammonia production units or localised systems
Safety Standards for Ammonia Systems	Not yet defined for decentralised ammonia generation or storage	Clear national standards for safety, storage, operator licensing
Renewable Energy Integration Incentives	Limited to solar irrigation; no fertiliser-energy linkage[33]	Bundled energy-input investment schemes tied to renewables
Risk Insurance for Input Innovations	Unavailable; no tailored risk instruments for new tech	Pilot insurance tools to de-risk adoption of fertiliser innovation
Cross-Ministerial Coordination Frameworks	Fragmented; no joint planning between MEPA, MOESD, GEDF	Inter-agency taskforce or joint roadmap development

[33] Renewable energy incentives in Georgia remain relatively limited, and recent restrictions on net metering have reduced the attractiveness of small-scale solar investments for agricultural producers.

TVET Training on Green Inputs	TVET includes basic fertiliser training; no Green Ammonia modules	Curriculum upgrades + national training programs for ammonia handling
Certification Standards for Low-Carbon Fertilisers	Organic standards unclear on eligibility of Green Ammonia	Pathways to include renewable-based ammonia under organic/EU-GAP standards

In addition to conventional agricultural financing instruments, the Rural Development Agency (RDA) has already implemented several programmes that incorporate elements of resource efficiency and renewable energy use in rural production systems. For example, the UNDP-supported Green Mobility Grant (GMG) programme financed solar-powered heating systems, demonstrating the potential for integrating renewable energy technologies into agricultural operations.

Energy efficiency has also been promoted through the Energy-Efficient Stove component under the Preferential Agro Credit programme and the Agro-Processing and Storage Enterprises Co-Financing Project. Furthermore, the Agency operates a dedicated Energy-Efficient Stove Co-Financing Programme that supports both the partial financing of improved stove technologies and the testing costs required for energy-efficient stove manufacturers.

Furthermore, through the Program for Promoting Agricultural Production on Irrigated Land Plots, the RDA offers financial assistance in certain regions to support projects that improve climate-resilient agricultural production. Eligible activities include the construction of greenhouses; installation of drip and sprinkler irrigation systems (including fertigation and filtration systems) for crops such as strawberries and alfalfa; development of small solar power plants; and establishment of agro-meteorological stations to support primary agricultural production. These initiatives demonstrate increasing institutional attention to sustainable and resource-efficient agricultural practices. However, they remain sector-specific and do not yet address the integration of renewable energy with fertiliser production technologies such as decentralised Green Ammonia systems.

While several RDA programmes already support energy efficiency and renewable energy integration in agriculture, none currently target decentralised fertiliser production technologies such as Green Ammonia.

From a financial perspective, there are no dedicated credit lines, subsidies, or insurance instruments for green input production. Public programmes like the RDA ones[34] offer preferential agrocredits, but these are aimed at conventional inputs. Private banks are not yet familiar with the business model of decentralised ammonia production, limiting access to investment capital.

Multilateral development banks such as EBRD and ADB generally focus on larger infrastructure or industrial projects and rarely finance primary agricultural investments, which may limit their relevance for farm-level ammonia systems. However, carbon finance mechanisms generally require large project scale or specialised mitigation technologies, meaning that aggregation of multiple farms may be necessary. The limited availability of agricultural equipment leasing and specialised financing instruments in Georgia also highlights the need for innovative financing structures to support adoption.

However, foundations exist for improvement:

- Georgia's Agriculture Strategy (2021–2027) explicitly supports innovation and renewable energy integration in farming.
- Georgia's Low Emission Development Strategy and NDCs provide an umbrella for climate-smart agriculture.
- Technical Vocational Education and Training (TVET) institutions[35] and the Scientific Research Center of Agriculture (SRCA) are starting to include green practices in their curriculum.

To enable adoption, future measures could include:

- Establishing ammonia system safety standards
- Integrating green inputs into national agro-subsidy schemes
- Launching pilot projects via MEPA, RDA, GIZ etc
- Developing blended-finance mechanisms for early adopters

Such financial mechanisms/instruments, their availability in Georgia, and suggested action or framework are shown in the table below.

[34] https://www.rda.gov.ge/programs.

[35] Including the ones listed: https://mes.gov.ge/content.php?id=215&lang=eng.

Financing Instrument	Availability in Georgia	Suggested Action or Framework
Preferential Agro-Credit (RDA)	Available but not tailored to Green Ammonia or fertiliser tech	Introduce a dedicated Green Ammonia sub-window within RDA
Green Innovation Grants (MEPA/SDC/etc)	Available but limited in scale; no ammonia-specific focus	Create ammonia pilot funding calls under existing donor grant schemes
Blended Finance Facilities	Not established for fertiliser production technologies	Develop donor-backed blended finance platforms for shared CAPEX projects
Carbon Credit Access Mechanisms	Emerging but not accessible to smallholders or input systems	Enable farmers to access voluntary carbon markets via group certification
Technology Risk Insurance Products	Absent; no insurance tools for tech or input failure risks	Design insurance schemes covering input failure or system breakdown
Leasing Options for On-Farm Systems	Rare; limited ag-tech leasing mechanisms in place	Partner with banks or vendors to pilot ammonia leasing models

Cooperative Financing Programs	Limited; mostly oriented to marketing, not input infrastructure	Revise cooperative funding to include decentralised input systems
Private Sector Venture Investment	Very limited; ag-tech VCs do not currently target ammonia	Engage green venture funds or impact investors in ag-tech ammonia pilots

4.6 Market Integration

Georgia's almond and blueberry sectors are export-driven and closely aligned with high-value European markets - creating a strategic entry point for Green Ammonia integration. Buyers such as, for example, REWE, EDEKA, and Lidl increasingly scrutinize supply chain emissions and input sustainability. Already, producers are being asked to report carbon emissions voluntarily, and mandatory certification is anticipated in the near future.

Large retail and commodity buyers are increasingly embedding low-carbon fertiliser criteria into their procurement frameworks. For example, agribusiness supply-chain analyses show that food-industry buyers adopt sustainability instruments - such as green sourcing, reduced input footprints, and buyer-farmer bilateral programmes - to both reduce supply risk and capture premium positioning.[36,37]

In the fertiliser-input domain, projects in Kenya offering trade-credit guarantees for "green fertiliser" operators illustrate how input supply chains are beginning to respond to buyer and donor pressure rather than just price competition.[38] These shifts suggest that for a farmer or cooperative deploying Green Ammonia-based inputs, there is growing market leverage - especially where export pathways to Europe or the U.S. emphasise input sustainability.

[36] Benitez-Altuna, F., Materia, V. C., Bijman, J., Gaitán-Cremaschi, D., & Trienekens, J. (2024). Farmer–buyer relationships and sustainable agricultural practices in the food supply chain: The case of vegetables in Chile. Agribusiness, 40(1), 3–30. https://doi.org/10.1002/agr.21829.

[37] Rueda, X., Garrett, R. D., & Lambin, E. F. (2017). Corporate investments in supply chain sustainability: Selecting instruments in the agri-food industry. Journal of Cleaner Production, 142, 2480–2492. https://doi.org/10.1016/j.jclepro.2016.11.026.

[38] Isaac Jumba, Dr. Nicholas Korir, Louka Commu, & Aisha Langat. (2024). THE BUSINESS CASE AND STRATEGIES TO SCALING LOCAL MANUFACTURING OF ORGANIC FERTILIZER.

During a recent site visit to LTD "Khoni Plantations" (20 ha, West Georgia), the project team observed a forward-leaning, export-oriented blueberry farm with characteristics ideally suited for early-stage Green Ammonia deployment. The farm supplies premium markets like Germany, Poland and United Arab Emirates and operates a 150-kW solar system - producing excess electricity and signalling potential for energy–fertiliser integration. Irrigation and water infrastructure are self-sufficient, and storage capacity exists for liquid ammonia handling (2,000+ L).

The farm's annual fertiliser expenditure (see attached XLS) stands at ~24,900 GEL per year, or ~1,245 GEL/ha, significantly lower than almond farm benchmarks (~3,000–4,000 GEL/ha). While this suggests lower total demand, the export premium and ESG alignment pressures from EU buyers make Khoni a high-leverage pilot site for decentralised Green Ammonia. The owners expressed strong interest but lack technical knowledge, highlighting the need for targeted capacity-building, risk mitigation mechanisms, and supply chain demonstration.

For certified organic and GlobalG.A.P.-compliant farms,[39] Green Ammonia offers a competitive advantage. If recognised by certification bodies, low-carbon nitrogen inputs could support brand differentiation and price premiums. This is particularly relevant for Georgia's organic almond producers targeting markets in Germany and Switzerland.

On the domestic market, price sensitivity and limited consumer awareness reduce immediate demand for green-labelled inputs. Conventional farmers prioritize affordability and ease of use, and the fertiliser market remains dominated by imports from Russia, and Turkey.

Nonetheless, regional cooperatives or demonstration hubs could serve as early test beds for showcasing the market impact of input localization and environmental traceability.

In the broader region, Turkey has begun scaling green hydrogen and ammonia initiatives, positioning itself as a potential future exporter of low-carbon inputs within the Eastern Mediterranean. Meanwhile, Armenia and Azerbaijan remain heavily dependent on conventional imports, with limited visible progress toward fertiliser decarbonisation. This creates a first-mover opportunity for Georgia.

Meaning, not just in sustainable production, but in shaping regional norms around input traceability and low-emissions sourcing. As neighbouring markets begin aligning with EU Green Deal standards, Georgia's early piloting of decentralised Green Ammonia could become a strategic differentiator in the South Caucasus and wider EaP region.

In parallel, carbon market developments - such as voluntary carbon credits (as well as compliance carbon markets) or supply chain Scope 3 accounting - may create

[39] See https://www.globalgap.org/.

monetizable benefits for Green Ammonia system adopters. Exporters who decarbonize fertiliser use could benefit from improved buyer access or emissions-based incentives.

4.7 Stakeholder Development

Creating a functional Green Ammonia ecosystem in Georgia requires strategic, multi-level engagement across farmers, government, industry, research, and development partners. Each stakeholder brings unique capacities and constraints, and their alignment will determine the speed and sustainability of adoption.

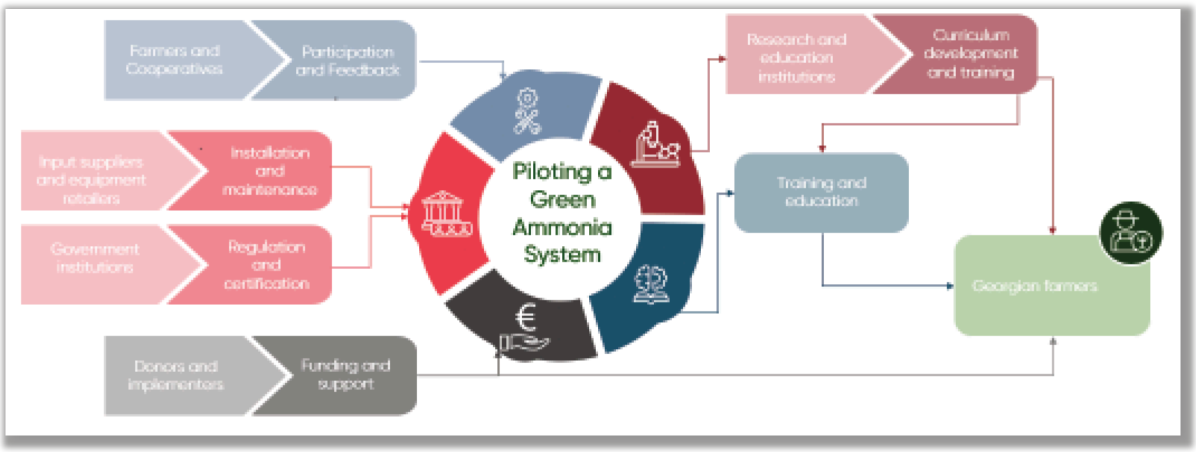


Figure 8: Stakeholder Flowchart

The journey begins with farmers and cooperatives, the ultimate end-users. Their willingness to engage depends on clear, tangible benefits: lower fertilizer costs, higher yields, and access to premium export markets. Cooperative ownership models reduce barriers for smallholders, enabling shared investment in decentralized production units. Community-led demonstration farms serve as proving grounds, showcasing how ammonia fertilization can integrate with renewable energy systems.

Supporting them are input suppliers and equipment retailers, who today remain largely import-focused. As pilots scale, their role evolves into maintaining decentralized systems, building distribution networks, and offering training services for safe ammonia handling. Over time, they can transform into local technology integrators, bundling ammonia systems with solar or wind solutions — making the technology practical and accessible.

MEPA and the Rural Development Agency lead policy integration, but require new regulatory tools for ammonia safety, certification, and market incentives. The GEDF and MoESD align grid infrastructure and renewable energy subsidies to support decentralized production. By embedding Green Ammonia into national energy security strategies and climate commitments, government actors ensure that pilots are not isolated experiments but part of a broader reform agenda.

To de-risk early investments, donors and implementers such as GIZ, SDC, and/or other donor step in. They provide funding, support business model innovation, and convene cross-sector actors. The PROGRESS programme offers a platform to align Green Ammonia with climate-resilient rural development. Donors also enable knowledge-sharing exchanges with countries further advanced in ammonia application, ensuring Georgia learns from global pioneers.

Meanwhile, research and education institutions prepare the human capital. TVET colleges, SRCA, and universities expand curricula to include ammonia handling, renewable integration, and low-carbon farming. Certified training modules equip technicians, farmers, and cooperative managers with the skills needed to operate safely and effectively. A Green Ammonia Innovation Hub could serve as a focal point for applied research, pilot testing, and industry-academic collaboration.

New actors add depth to the ecosystem. Financial institutions and investors design green credit lines for farmers and cooperatives, while impact investors back scalable business models tied to carbon credits and sustainable agriculture branding. Civil society and consumer groups advocate for safe practices, raise community awareness, and help build eco-labels that strengthen trust in export markets.

Altogether, these stakeholders form a web of relationships: farmers provide feedback, suppliers keep systems running, government sets the rules, donors fund and convene, educators train, financiers support, and civil society builds trust. Their interplay ensures that piloting Green Ammonia is not just a technical exercise, but a coordinated national effort to give Georgian farmers a real-world shot at sustainable, climate-smart agriculture.

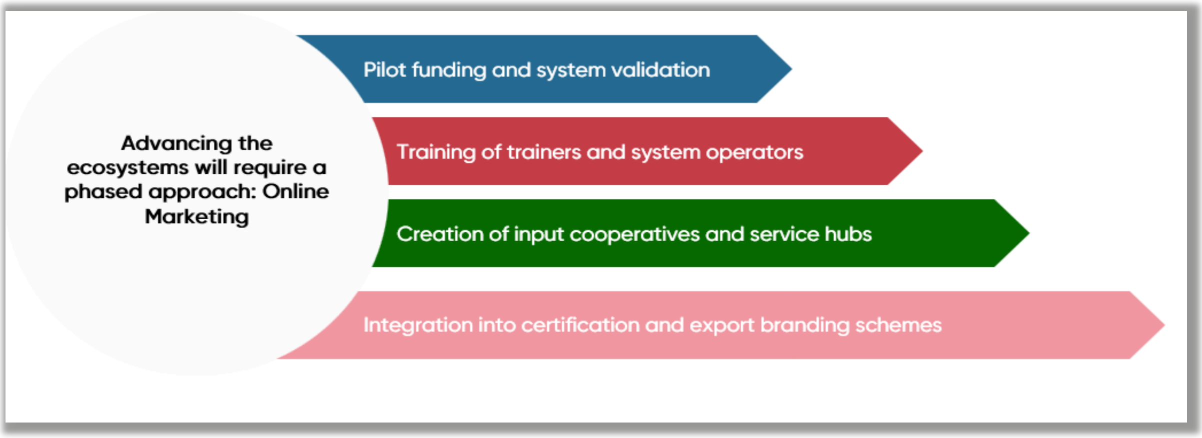


Figure 9: Phased Approach Diagram

Georgia's Green Ammonia ecosystem will grow step by step. It starts with pilot funding and system validation, where donor and government support enables demonstration projects that prove both technical feasibility and farmer acceptance. Next comes training of trainers and system operators, building certified expertise across colleges and cooperatives to ensure safe handling, renewable integration, and sound business practices. With skills in place, input cooperatives or service hubs emerge to manage production, storage, and distribution, lowering barriers for smallholders and embedding shared ownership models. Finally, the system matures through integration into certification and export branding schemes, linking ammonia use to organic and low-carbon standards and positioning Georgian agriculture under a “climate-smart farming” brand.

5. Targeted Recommendations

Green Ammonia offers a strategic opportunity for Georgia to address critical vulnerabilities in its agricultural and energy sectors. As this study has shown, transitioning to decentralized, renewable-based fertiliser production can enhance food system resilience, reduce exposure to import price shocks, and align domestic practices with emerging international sustainability rules and standards. However, unlocking this potential requires coordinated policy, financing, infrastructure, and market development efforts. The following recommendations are structured to guide government agencies, development partners and the private sector in building an enabling ecosystem for Green Ammonia deployment at scale.

5.1 Policy and Regulatory Reform

5.1.1 Develop a Legal Framework for Decentralized Ammonia Production

Georgia currently lacks a permitting regime adapted to the unique characteristics of decentralized ammonia systems. To unlock deployment, a dedicated regulatory tier for small-scale, renewable-powered ammonia units should be introduced - defining licensing thresholds (e.g., <50 kg/day production), clarifying zoning and land-use eligibility for farms, and outlining safety and environmental protocols. Ammonia should also be formally recognised as an agricultural input, rather than defaulting to industrial chemical classifications, to reduce regulatory friction.

In practice, this will require amendments to existing laws covering chemical handling, land-use planning, and renewable energy deployment. Lessons can be drawn from jurisdictions such as Germany and Australia, which have adopted pilot-friendly regulations for small-scale ammonia systems. For example, temporary exemptions for innovation pilots, simplified environmental review processes, and limited-site safety licenses have proven effective at accelerating field trials without compromising environmental or community safety. Establishing such a conducive environment in Georgia is a foundational step toward unlocking farmer-led innovation.

5.1.2 Align Fertiliser Policy with Green Transition Goals

Green Ammonia must be embedded into national agriculture and climate policies. This includes formal integration into sustainable fertiliser strategies under MEPA, enabling access to green finance under climate-related taxonomies, and permitting use of ammonia units on agricultural land under land-use and building codes. A phased policy roadmap should be developed with benchmarks for recognising, piloting, and scaling GA systems.

Additionally, a clear definition of “green fertiliser” within national standards is necessary to support procurement, certification, and subsidy allocation. This would enable local producers to access premium markets and ESG-aligned finance mechanisms. The alignment of agricultural and energy policy under a shared sustainability framework is essential for enabling cross-sectoral planning and investment.

5.2 Financial Incentives and De-Risking Mechanisms

5.2.1 Subsidies and Pilot Funding

Field visits to almond and blueberry farms in regions such as Imereti and Kakheti revealed that farmers currently spend approximately €1,000–1,300 per hectare annually on nitrogen-based fertilisers - typically imported, untraceable, and subject to volatile global prices. These inputs represent a significant share of annual production costs. Yet, farmers expressed hesitancy toward investing in unfamiliar and capital-intensive technologies without clear technical support or payback assurances. To lower this barrier, the government—through MEPA, RDA, or donor-aligned programmes - should establish targeted CAPEX support schemes for decentralised ammonia systems.

This support could take the form of matching grants for early adopters or a rebate scheme tied to specific outcomes such as reduced nitrate runoff, verified GHG reductions, or improvements in nitrogen-use efficiency. Subsidy tiers might be differentiated based on farm size, crop type, or cooperative engagement to ensure equitable access. Public funds could also underwrite demonstration units at selected regional sites to anchor the first deployments and provide real-time cost-performance benchmarks.

Beyond domestic funding, international donors and green finance instruments (e.g., GCF, EBRD's Green Economy Financing Facility) could be mobilised to support technology localisation and field trials. Financing should also consider the full ecosystem: pre-feasibility assessments, installer training, maintenance planning, and seasonal storage solutions.

5.3 Technical Capacity and Infrastructure

Low-cost insurance mechanisms or guarantee funds could improve bankability of farmer investments in Green Ammonia. For cooperatives or agri-processors, Public-Private Partnership (PPP) models may support pooled procurement of ammonia systems, with public entities underwriting early market risk. Instruments from Georgia's agricultural leasing or sovereign guarantee toolkit could be extended to GA systems.

Furthermore, pilot projects could incorporate performance-based payment mechanisms that reward verified fertiliser replacement, yield improvement, or GHG abatement. This could build a results-based finance track record for future scaling under international climate finance mechanisms such as the GCF[40] or NAMA Facility (current: Mitigation Action Facility).[41]

5.3.1 Demonstration Hubs and Knowledge Transfer

Piloting decentralised systems in real farming contexts is key to overcoming technical hesitancy and unfamiliarity with ammonia handling. Demonstration farms - such as the Khoni blueberry site or almond orchards in Kakheti - can be equipped with modular Green Ammonia systems and serve as regional field schools. These hubs would validate ammonia application methods (e.g., fertigation), evaluate seasonal performance, and build trust among farmers, technicians, and agri-input distributors.

To scale knowledge, a structured capacity-building framework should be established that spans vocational, academic, and advisory tiers. This includes:

- **Vocational Training Programs:** Develop certificate-based technician training programs through technical colleges or rural skills centres, focusing on electrolyser operation, safety protocols, maintenance, and ammonia fertigation techniques.
- **University Partnerships:** Integrate Green Ammonia modules into agricultural engineering, energy systems, and agri-economics curricula at major institutions such as the Georgian Technical University and Agricultural University of Georgia. Collaborative research projects and summer field placements could further bridge theory and practice.
- **Extension Services Upgrade:** Equip MEPA extension officers with updated materials and diagnostic tools to guide farmers on GA integration. This should include guidance on water sourcing, system sizing, fertigation timing, and safety monitoring.

Building this ecosystem of technical knowledge and local service provision will be essential to transition beyond isolated pilots. It also ensures that deployment is not overly dependent on foreign engineers or external vendors, reinforcing local job creation and long-term system sustainability.

5.3.2 Green Energy-Agri Synergies

The integration of renewable energy with ammonia production is central to the Green Ammonia model. Solar-powered systems, in particular, offer a compelling opportunity in Georgia's rural regions with high irradiance and unreliable grid access. Where

[40] https://www.greenclimate.fund/.

[41] https://mitigation-action.org/about/nama-facility/.

opportune, on-farm solar installations should be co-located with ammonia units to reduce transmission losses and maximise control over input costs.

To operationalise this, national rural energy programmes under the Ministry of Economy and Sustainable Development should include decentralised ammonia production as an eligible use-case for solar or hybrid mini-grid systems. Infrastructure upgrades - such as voltage regulation, smart metering, and water purification systems - should be co-funded alongside GA systems to ensure end-to-end operability.

Innovative configurations such as agrivoltaics (dual land use for solar and agriculture) and ammonia-powered irrigation systems could also be explored as part of applied R&D tracks with academic partners. These integrated systems not only improve energy and fertiliser self-sufficiency but also offer replicable models for climate-smart farming across the region.

Farmers can assess on-farm solar potential, explore co-locating renewable energy with fertiliser needs, and collaborate through cooperatives or pilots to reduce costs and improve energy and input self-sufficiency.

5.4 Market Development and Demand Creation

5.4.1 Certification and Traceability

To unlock premium export opportunities, Green Ammonia fertiliser should be formally integrated into national organic and low-emission certification schemes. This enables traceability of fertiliser-related emissions and aligns production practices with global buyers demanding ESG-compliant inputs.

In the context of Georgia's Deep and Comprehensive Free Trade Area with the European Union, traceability and emissions transparency are increasingly critical for maintaining access to high-value markets.

Retailers such as Lidl, REWE, and EDEKA already impose strict Scope 3 emissions scrutiny on their suppliers.[42] By certifying GA use within the supply chain, Georgian producers -

particularly those exporting fruit, nuts, or herbs - can position themselves as early movers aligned with EU Green Deal goals and the emerging Carbon Border Adjustment Mechanism. National authorities should support the development of a "green fertiliser origin" registry or QR-based tool, allowing buyers to verify environmental credentials at the input level.

To avoid duplication and keep certification costs manageable for smallholders, Green Ammonia should be integrated into existing organic, GlobalG.A.P., and fair-trade frameworks. Farmers can support this by maintaining clear input records, adopting

[42] https://ghgprotocol.org/scope-3-calculation-guidance-2.

digital traceability tools and engaging with certification bodies on Green Ammonia's recognition. Participating in pilots or cooperative initiatives can reduce individual costs and streamline compliance. Those already certified should explore how Green Ammonia aligns with evolving sustainability standards. Early adoption and proactive engagement will position farmers to benefit from premium markets increasingly requiring low-emission practices and Scope 3 emissions traceability across the entire supply chain.

5.4.2 EU and Gulf Market Leverage

Georgia's proximity to and preferential trade access with the EU presents a clear opportunity for green-labelled fertiliser inputs to serve as a differentiator in the bloc's increasingly sustainability-driven markets. Green Ammonia use in fertilisation could offer measurable advantages in CBAM compliance and organic labelling, particularly for export crops where fertiliser provenance is becoming part of market verification processes.

Similarly, in the Gulf region, agricultural importers are increasingly attentive to sustainability, water efficiency, and soil health. Highlighting GA adoption within bilateral agricultural trade dialogues could elevate Georgia's brand and support long-term positioning as a supplier of climate-smart, traceable produce. Government support for aligning GA production and certification standards with both EU and Gulf market requirements will be key to expanding export competitiveness.

5.5 Research, Data, and Monitoring

5.5.1 Life-Cycle and Emissions Data

A comprehensive evidence base is essential to validate the environmental and agronomic benefits of Green Ammonia in the Georgian context. Establishing baseline data for conventional nitrogen fertiliser use - including life-cycle emissions, nitrate runoff, and soil health impacts - will provide a foundation for comparing the performance of decentralised ammonia systems.

To support this, partnerships should be established with local academic institutions such as the Agricultural University of Georgia, Ilia State University, Georgian Technical University or other. These institutions are well-positioned to conduct field trials, emissions sampling, and soil quality assessments using credible methodologies. International donors and development partners should be invited to co-fund and co-design early monitoring efforts, particularly where Green Ammonia pilots are being deployed.

Avoiding over-reliance on direct coordination with central state authorities at this stage allows for greater flexibility and reduces potential bottlenecks due to political or administrative sensitivities. Instead, collaboration can be anchored through research consortia, independent labs, or donor-backed innovation platforms.

Farmers can – in essence - participate in field trials, share fertiliser and yield data, allow soil and water monitoring on their land, and collaborate with researchers to generate evidence that supports adoption and future incentives.

5.5.2 Adaptive Planning Tools

To guide efficient deployment, data-driven planning tools should be developed - such as geospatial models for mapping Green Ammonia production potential based on crop type, solar irradiance, and water access. These tools can support system sizing, siting, and infrastructure investment decisions at the farm and regional level.

Digital twin models and mobile-based nutrient budgeting apps tailored to Georgian conditions would further enable precision fertiliser application and optimisation of ammonia output. Monitoring, reporting, and verification (MRV) protocols should be aligned with international standards (e.g., IPCC Tier 2+) but adapted for farm-level application.

By anchoring these tools in the country’s academic and innovation ecosystem, Georgia can build technical independence while also aligning with international climate reporting frameworks and donor expectations.

6. Roadmap for Scaling Green Ammonia in Georgia

This roadmap presents a sequenced, phased approach for the deployment of Green Ammonia solutions in Georgia, aligned with the country's evolving technical capacity, the readiness of the farming sector, and the maturation of supportive policy frameworks. Each stage - from pilot projects to nationwide scale-up - has been structured to reflect real-world implementation dynamics, including farmer adoption potential, regulatory evolution, and infrastructure development.

Importantly, the timeline is designed to integrate with and reinforce key national frameworks, such as Georgia's NECP and LTS for 2050. These strategies prioritize emissions mitigation, enhancement of rural resilience, and the transition to sustainable agricultural inputs - all of which are directly supported by the rollout of decentralised Green Ammonia systems. The accompanying Gantt Chart below provides a visual summary of the roadmap's key milestones and activities.

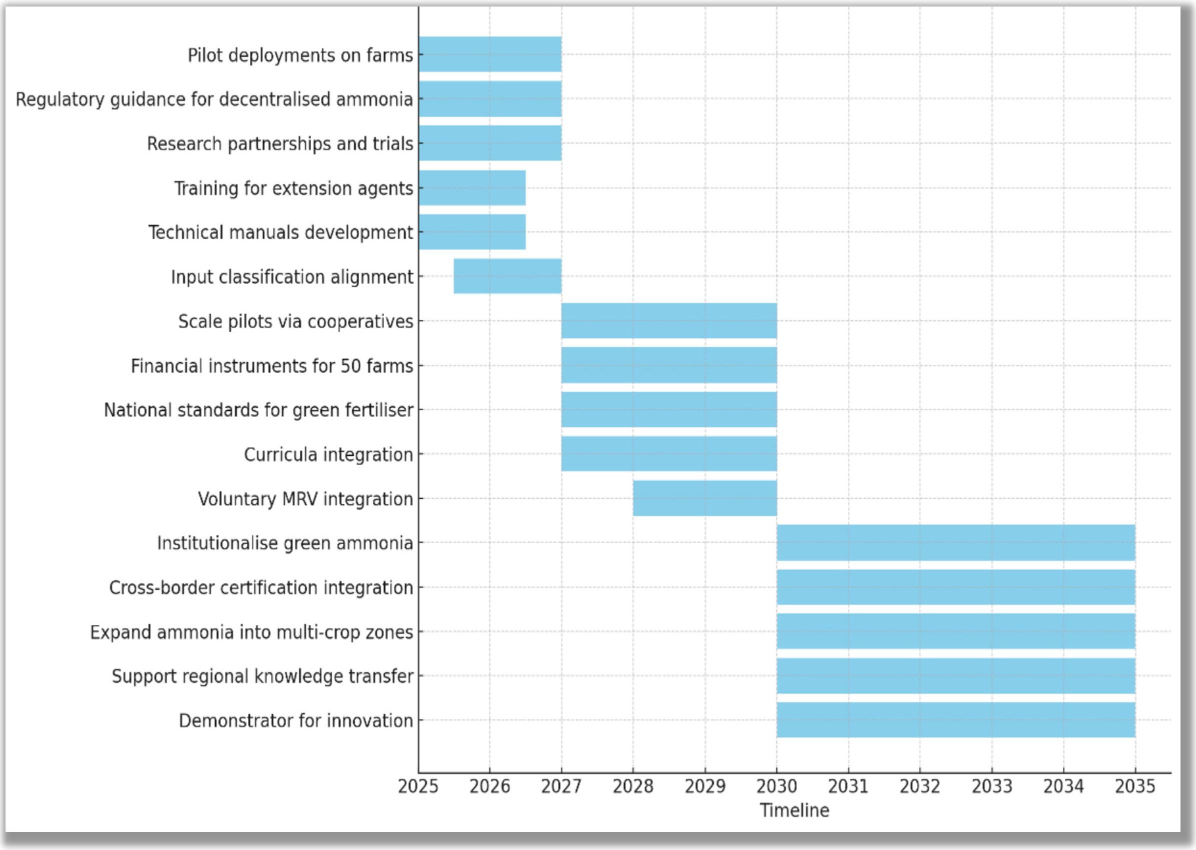


Figure 10: Gantt Chart: Georgia GA Roadmap.

6.1 Near-Term (0–2 years)

In the initial phase, the focus is on creating the basic building blocks for Green Ammonia deployment. This includes launching pilot projects, establishing enabling regulatory guidance, training technical personnel and initiating research partnerships.

These early efforts aim to test feasibility, build technical familiarity, and position GA within existing national frameworks such as the NECP/NDC etc.

- Launch 2-3 pilot deployments on almond and blueberry farms in high-N regions
- Develop interim regulatory guidance for decentralised ammonia units (aligning with NECP action area: agriculture decarbonisation pilots)
- Initiate partnerships with local research institutions for field trials, LCA studies, and emissions benchmarking
- Train MEPA/RDA extension agents and vocational instructors on ammonia fertigation and basic safety
- Draft simplified technical and operational manuals for small-scale Green Ammonia systems
- Begin aligning ammonia input classification with green taxonomy definitions to enable future financing access

6.2 Mid-Term (3–5 years)

This phase emphasizes expansion and institutional embedding. Successful pilot models are scaled through cooperatives and regional hubs, while national standards for emissions, safety, and certification are formalised. Education systems are updated to include Green Ammonia training and the technology begins integration into Georgia's greenhouse gas monitoring systems — paving the way for sector-wide adoption.

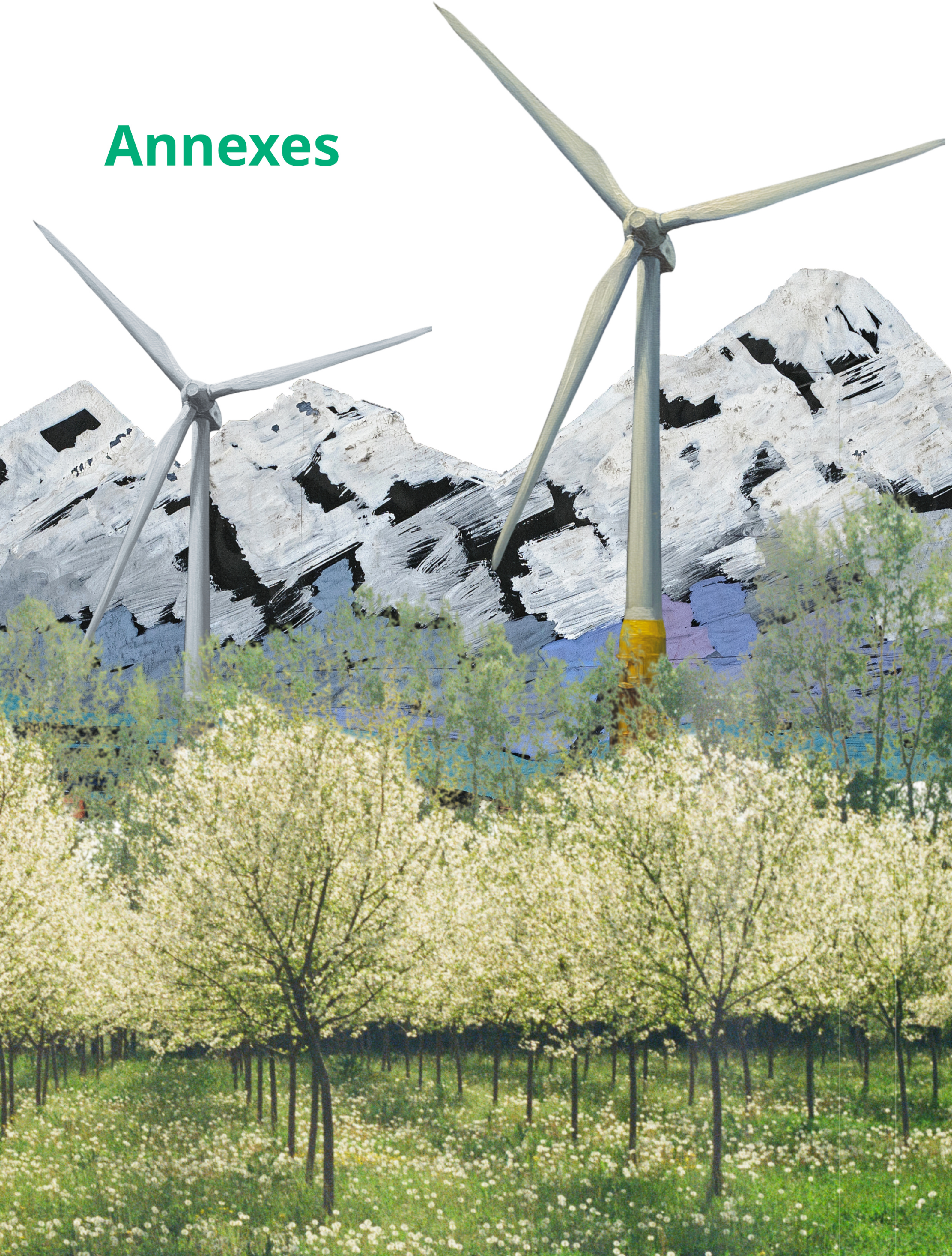
- Scale pilot models through cooperatives and regional demonstration hubs
- Extend CAPEX support and financial risk instruments to at least 50 farms across key export value chains
- Finalise national standards for green fertiliser emissions, safety protocols, and environmental traceability
- Embed GA modules into formal agricultural and vocational education curricula (supporting NECP goals for capacity-building in climate-smart agri-tech)
- Begin voluntary MRV integration of GA-based fertilisation into national GHG inventory frameworks

6.3 Long-Term (6–10 years)

The final phase seeks full institutionalisation and international alignment. Green Ammonia is incorporated into national subsidy schemes and trade frameworks, enabling broader use *across crops and energy systems. Georgia also begins exporting its expertise, contributing to regional knowledge exchange and positioning itself as a South Caucasus leader in climate-smart fertiliser innovation.*

- Institutionalise GA in agricultural input, fertiliser subsidy, and renewable energy policies
- Enable integration with cross-border certification schemes in EU and Gulf markets (aligning with LTS ambitions for sustainable exports and low-carbon trade)
- Expand decentralised ammonia production into multi-crop zones and energy storage applications
- Support regional knowledge transfer and technology demonstration under Georgia's international climate cooperation commitments
- Establish Georgia as a demonstrator for green fertiliser innovation in the South Caucasus and Black Sea regions.

Annexes



Annex 1: Understanding Conventional Ammonia Production (Haber–Bosch Process)

Overview

Ammonia (NH_3) is primarily produced via the Haber–Bosch process, a method developed in the early 20th century that revolutionized global food production by enabling the mass synthesis of nitrogen fertilisers. It remains the industrial standard today, with more than 180 million tonnes produced annually worldwide. This process converts atmospheric nitrogen (N_2) and hydrogen (H_2) into ammonia using high temperature and pressure in the presence of a catalyst. The figure below is provided as an overview of the Haber Bosch process and key aspects of its implementation in the current global economy.

Figure 11: Haber-Bosch Process: Value Chain & Emissions.

Inputs and Feedstocks

The Haber–Bosch process requires two main inputs:

1. **Nitrogen (N_2)**: Extracted from the atmosphere (78% of air is nitrogen).
2. **Hydrogen (H_2)**: Typically derived from natural gas (methane, CH_4) through a method known as steam methane reforming (SMR). In some plants, coal gasification or naphtha reforming is also used.

Hydrogen Extraction Reactions

To extract hydrogen from natural gas (CH4), a steam reforming method is used providing 3 molecules of hydrogen gas (H2) for every molecule of water (H2O) put in. The remaining molecule of carbon monoxide (CO) then reacts with water to further yield more hydrogen gas eventually yielding carbon dioxide (CO2) as a green-house gas byproduct.

- $CH_4 + H_2O$ (steam) → $CO + 3H_2$ (via steam methane reforming)
- $CO + H_2O \rightarrow CO_2 + H_2$ (via water-gas shift reaction)
- The hydrogen gas (H2) is then reacted with atmospheric nitrogen (N2) at a 3:1 ratio, respectively, in a specialized reactor capable of high temperature and high pressure to yield 2 molecules of ammonia (NH3):
- $N_2 + 3H_2 \rightarrow 2NH_3$ (exothermic reaction, facilitated by an iron-based catalyst)

Process Conditions

> **Temperature:** 400–500°C
>
> **Pressure:** 150–300 bar
>
> **Catalyst:** Iron-based (with potassium and aluminum oxides)
>
> **Energy Use:** The process is extremely energy intensive, requiring 8–12 MWh per tonne of ammonia produced.

Environmental and Economic Implications

- CO_2 Emissions: Producing 1 tonne of ammonia emits ~1.6 to 2.4 tonnes of CO_2, depending on the feedstock.
- Fossil Fuel Dependency: ~70% of global ammonia is made from natural gas; ~25% from coal (mainly in China).
- GHG Footprint: Ammonia production accounts for ~1% of total global GHG emissions and ~2% of global energy use.

- Cost Drivers: Ammonia prices are heavily influenced by fossil fuel prices, especially natural gas

Role in Fertiliser Production

The ammonia produced via Haber–Bosch is further processed into nitrogen-based fertilisers:

- Urea ($CO(NH_2)_2$)
- Ammonium nitrate (NH_4NO_3)
- Ammonium sulfate ($(NH_4)_2SO_4$)
- UAN (urea ammonium nitrate)

These fertilisers are key to intensive crop production but also contribute to N_2O emissions and eutrophication when over-applied.

Pathways to Decarbonisation

The conventional ammonia industry is exploring the following approaches to reduce its carbon footprint:

> **Blue ammonia:** Uses natural gas with carbon capture and storage (CCS)
>
> **Green Ammonia:** Uses renewable electricity to electrolyze water (H_2O) into hydrogen (H_2), replacing fossil-based hydrogen entirely
>
> **Process efficiency:** Incremental gains in catalyst performance and heat recovery

Understanding this baseline is essential to assess the environmental, economic, and technical benefits of decentralised Green Ammonia in agricultural systems like Georgia's.

Annex 2: Price Evolution of Nitrogen Fertiliser

Fertiliser prices have become increasingly volatile over the past few years, largely due to the strong link between nitrogen fertiliser production and global energy markets. Urea and ammonium nitrate are highly energy-intensive products, and when natural gas prices rise, production costs quickly feed through to international fertiliser prices. This volatility has been amplified by additional shocks, including disruptions to global logistics, export restrictions, and the general inflation of industrial inputs, resulting in sharp and often sudden price movements.

Between mid-2020 and mid-2022, international benchmark prices for key nitrogen products more than doubled, peaking above US $900/tonne in some markets. In Georgia, this translated into major cost increases for commonly used nitrogen inputs, with reported price spikes in the range of 70-120% during 2022-2023. Although prices eased somewhat afterward, they have not returned to a stable pre-2020 baseline and remain sensitive to further energy shocks and geopolitical developments. For Georgian farmers - especially smaller producers and export-oriented farms - this uncertainty creates planning challenges, squeezes profit margins, and increases exposure to input supply risks.

For Georgia, this volatility is compounded by import dependence and exposure to regional supply dynamics. Because most nitrogen fertilisers are sourced from external markets, exchange-rate movements, transport costs, and sudden changes in export availability can quickly translate into higher farmgate prices. In periods of tight supply, distributors may reduce volumes or shift to short-term contracting, leaving farmers with limited bargaining power and forcing purchases at short notice. In practice, this encourages coping strategies such as applying less-than-optimal nutrient rates, postponing application windows, or switching to cheaper blends—choices that can reduce yields, lower nutrient-use efficiency, and increase production costs per unit of output.

Longer-term outlooks from international organisations (including FAO and the World Bank) suggest that fertiliser markets are likely to remain exposed to periodic shocks rather than returning to sustained price stability. This makes input-price risk an increasingly central constraint for farm competitiveness and for the adoption of improved agronomic practices that depend on reliable nutrient supply. In this context, alternatives that reduce dependence on imported, fossil-based fertilisers, such as decentralised Green Ammonia production, longer-term supply contracts, or cooperative procurement models, can help buffer farmers against volatility while supporting Georgia's wider climate and resilience objectives.

Annex 3: Energy-to-Ammonia Conversion Example and Crop Demand Analysis

Overview

This annex provides a practical example of how renewable electricity (solar PV) can be converted into hydrogen and subsequently into Green Ammonia, with indicative input/output ratios. It also estimates the ammonia fertiliser demand per hectare for two key crops, blueberry and almond, and the associated water requirements for electrolysis.

Energy Conversion Efficiency

- 1 MWh of electricity can produce approximately 20 kg of hydrogen via electrolysis (assuming 50 kWh/kg H_2).
- To produce 1 tonne (1,000 kg) of ammonia (NH_3), around 180 kg of hydrogen and 825 kg of nitrogen (from air) are required.
- Therefore, 1 MWh of electricity yields ~110 kg of ammonia.

Note: This efficiency figure reflects current real-world performance from commercial and demonstration-scale systems. While the theoretical maximum yield could approach 135–140 kg NH_3 per MWh, most operational plants (e.g. Haldor Topsøe, Siemens, Fertiberia) report net yields of 90–115 kg NH_3/MWh once electrolysis, air separation, synthesis, and compression losses are included.

Cost Estimate:

> Based on current electricity prices (~€50–70/MWh for solar in emerging markets1) and average system-level costs (CAPEX, OPEX, maintenance), the levelised cost of Green Ammonia production typically ranges between €600 and €900 per metric tonne.
>
> This is significantly higher than fossil-based ammonia (~€200–400/tonne in pre-2020 markets), but future cost parity is expected by 2030–2035 with falling electrolyser costs and rising carbon pricing.

Solar PV System Yield

- A 1 MW solar PV system in a location like Georgia (South Caucasus) with ~1,400–1,600 full load hours/year will generate ~1.4 to 1.6 GWh annually.
- This yields approximately 154 to 176 tonnes of ammonia per year under optimal conditions.

Ammonia Demand by Crop Type

Blueberries:

> Typical nitrogen requirement: ~50 kg N/ha/year
>
> Ammonia contains ~82% nitrogen by weight (i.e., ~60.9 kg NH_3 needed per ha/year)
>
> For a 20-ha blueberry farm: ~1.2 tonnes of ammonia per year

Almonds:

> Nitrogen requirement: ~150–200 kg N/ha/year
>
> Equivalent to ~183–244 kg NH_3/ha/year
>
> For a 20-ha almond orchard: ~3.7 to 4.9 tonnes of ammonia per year

Electrolysis Water Use

> Producing 1 kg of hydrogen via electrolysis requires ~9 liters of purified water
>
> To produce 1 tonne of ammonia (~180 kg H_2), ~1.6 m^3 of water is required
>
> For 1 MW of solar capacity (generating ~154 tonnes of ammonia/year), annual water demand for electrolysis would be ~246 m^3/year

Summary

This example illustrates that a 1 MW solar PV installation can meet the annual ammonia needs of 30–50 ha of high-value crops, such as blueberries and almonds, with manageable water input requirements. Such decentralised systems offer real potential for on-farm fertiliser autonomy and insulation from fossil-fuel-driven price volatility in the global fertiliser market.

Annex 4: Legal Requirements Permitting and Legal Considerations for Decentralized Green Ammonia Systems

Overview

Deploying decentralized Green Ammonia systems requires not only technical readiness but also a tailored permitting and regulatory environment. In Georgia, as in many countries, the legal classification of small-scale ammonia production is ambiguous, often falling between energy, agricultural, and industrial codes. This annex outlines the typical permitting requirements and policy gaps that must be addressed to enable safe, scalable deployment.

Core Regulatory Domains Affected

Electrolyser Installation

> Falls under electrical and industrial equipment codes.
>
> Typically requires connection approval, grounding, and EMI compliance.
>
> May be subject to industrial safety inspections, even at farm scale.

Ammonia Synthesis Equipment

> May require hazardous process permits depending on national classification of ammonia as a chemical or fertiliser.
>
> If operated below a defined threshold (e.g. <10 tonnes), many jurisdictions allow simplified permits.

Ammonia Storage

> Pressurised or refrigerated tanks often trigger safety and zoning reviews.
>
> Permits typically require:

- Risk assessments (leak/fire/explosion)
- Operator training protocols
- Spill containment and ventilation systems

Zoning and Land Use

> Agricultural zones may prohibit on-farm chemical processing unless classified under agri-processing or renewable energy.
>
> Pilot waivers or innovation zones can facilitate initial deployment.

Environmental Licensing

> Small-scale systems may fall below thresholds for full environmental impact assessments (EIAs).
>
> Simplified environmental declarations or exemptions are possible for <1 MW systems.

International Practices

> Germany: Modular ammonia pilots are licensed under renewable demonstration exemptions tied to regional energy transition strategies.
>
> Australia: Off-grid ammonia units benefit from fast-track permitting through its National Green Hydrogen Strategy.
>
> Japan: Rural ammonia pilot projects receive zoning flexibility via Ministry of Agriculture innovation designations, provided safety standards are met.
>
> USA: In states like California, ammonia-as-fuel projects must comply with both EPA and OSHA thresholds for hazardous materials, even at small scale.

Recommendations for Georgia

> Define ammonia synthesis below 10 tonnes/year as a non-industrial, low-risk process.
>
> Create a specific permitting track under MEPA or MOESD for electrochemical agri-input production.
>
> Integrate ammonia production into renewable energy pilot schemes.
>
> Issue guidelines for storage and handling of decentralised ammonia volumes.

Conclusion

Without clear permitting pathways, even technically viable decentralised systems face deployment delays or outright legal barriers. A tiered framework, tailored to small-scale agricultural use, is critical for unlocking early adoption and ensuring safety without regulatory overburden.

Annex 5: Comparing Traditional and Green Ammonia Production Pathways

This annex outlines the key differences between conventional (fossil-based) ammonia production via the Haber–Bosch process and emerging Green Ammonia systems powered by renewable energy. It also explains the system configuration of decentralized Green Ammonia production, highlighting the use of water electrolysis and renewable electricity to generate hydrogen.

Traditional Haber–Bosch Process vs. Green Ammonia

Attribute	Traditional Haber–Bosch	Green Ammonia (Decentralized)
Hydrogen Source	Steam methane reforming (SMR) from natural gas	Electrolysis of water using renewable electricity
Nitrogen Source	Atmospheric air (via PSA or cryogenic separation)	Atmospheric air (via PSA or cryogenic separation)
Primary Energy Input	Fossil fuels (thermal + electrical)	Renewable electricity (solar, wind, hydro)
Carbon Intensity	1.6–2.0 tonnes CO_2 / tonne NH_3	~0–0.2 tonnes CO_2 / tonne NH_3 (near-zero with RES)
System Efficiency	~55–60% (including feedstock energy)	~40–55% (including electrolysis and synthesis losses)

Typical Plant Size	>1,000 tonnes/day (centralized)	10s of kg/day to several tonnes/day (modular)
Ammonia Storage	Bulk cryogenic tanks (industrial)	Pressurised or cryogenic tanks (farm-scale or coop-level)
End Uses	Primarily for industrial-scale fertiliser production	Fertiliser, on-farm energy carrier, or microgrid balancing
Environmental Impact	High GHG footprint; fossil dependency	Near-zero emissions; aligns with decarbonization goals
Infrastructure Model	Centralized, capital-intensive, high transport costs	Distributed, locally adaptable, transport-light
Scalability	Economies of scale only	Highly modular and replicable
Grid Integration	Rigid baseload plant	Flexible load; supports grid balancing

System Architecture of Green Ammonia

1. Renewable Energy Source (e.g., Solar PV, Wind)

Supplies direct current (DC) or alternating current (AC) to power electrolysers

2. Electrolyser Unit

Splits purified water into H_2 and O_2 using electricity

Common types: Alkaline, PEM, Solid Oxide (future)

3. Nitrogen Separation Unit

Extracts N_2 from ambient air

Technologies: PSA or cryogenic distillation

4. Ammonia Synthesis Reactor

Combines H_2 and N_2 at elevated temperatures and pressures over a catalyst

Operates in cycles for small-scale systems or continuously in modular designs

5. Ammonia Storage and Handling

Stored in pressurised tanks (8–10 bar) or cryogenic vessels (-33°C)

Ready for direct use in fertigation or downstream conversion (e.g., ammonium nitrate)

Comparative Advantages of Green Ammonia

> Environmental: Eliminates direct CO_2 emissions from hydrogen production
>
> Energy Security: Utilises local renewable energy instead of imported natural gas
>
> Scalability: Enables distributed production close to end-users (e.g., farms)
>
> Grid Support: Can operate as a flexible load to absorb surplus or supply renewable generation during high demand
>
> Multi-use Potential: Serves as a fertiliser, energy carrier, and potential fuel

Conclusion

While Green Ammonia systems currently operate with lower overall energy conversion efficiency compared to traditional Haber–Bosch plants, their broader advantages make them a transformative option for sustainable fertiliser production. Most notably, they eliminate carbon emissions from hydrogen generation by using renewable electricity and water electrolysis, aligning directly with global decarbonisation goals.

Their modularity and flexibility in scale allow for deployment in rural and remote areas, making decentralised, near-farm fertiliser production not only feasible but economically and environmentally viable.

In Georgia's context, this means reducing dependence on volatile fertiliser imports, increasing farmer self-sufficiency, and supporting the transition to climate-smart agricultural practices. These systems can also support renewable energy grid integration and serve as multi-functional assets - providing fertiliser, storing energy, or even powering farm operations.

As such, Green Ammonia holds the potential to not only decarbonise agriculture but also enhance rural autonomy, contributing meaningfully to Georgia's national climate targets and agricultural resilience.

Annex 6: Interview Questions

The questionnaire presented in this annex was developed specifically for interviews with almond and blueberry farmers in Georgia. It serves as a structured tool to collect detailed information on farmers' fertiliser practices, input sourcing, cultivation approaches, access to energy, and perceptions of emerging sustainable technologies such as Green Ammonia. It also examines economic, technical, and environmental considerations influencing fertiliser-related decisions, including willingness to adopt decentralised or renewable-based fertiliser production systems. The insights gathered through this instrument form the analytical foundation for assessing the feasibility, barriers, and opportunities for introducing Green Ammonia into Georgia's small-scale agriculture sector.

Questions

1. Do you use fertilizer on your farm?
1.1 If 'yes' continue to Section 1.3
1.2 If 'no' continue to Section 1.4

1.3 Farmers Using Fertilizer
1.3.1 Who provides your fertilizer?
1.3.2 How many suppliers of fertilizer do you currently use?
1.3.3 How many suppliers of fertilizer have you used to date?
1.3.4 Are these suppliers private businesses, other farmers, or co-operatives?
1.3.5 Do you purchase, trade, or receive for free your fertilizer?
1.3.6 What is the rough annual cost of fertilizer?
1.3.7 Do you use manure, synthetic fertilizer, or a combination of both?
1.3.8 Do you use specifically nitrogen fertilizer on your farm?
1.3.9 Do you use ammonia-based nitrogen fertilizer on your farm?
1.3.10 Do you use urea-based nitrogen fertilizer on your farm?
1.3.11 How much fertilizer do you use?
1.3.12 How much do you pay for fertilizer?
1.3.13 Do you have access to renewable energy sources like solar, wind, or geothermal?
1.3.14 How far would you be willing to travel to purchase fertilizer?
1.3.15 At what price would you opt not to use fertilizer?
1.3.16 Would you have interest in making your own fertilizer?
1.3.17 How much money would you be willing to spend on a system that produced fertilizer?
1.3.18 How many hours per week would you be able to spend operating and maintaining a system that produces fertilizer?
1.3.19 Would you prefer another person operates and maintains this system?
1.3.20 Do you use or have access to renewable energy?

1.3.21 Do you have concerns about using synthetic fertilizer?

1.4 Farmers Not Using Fertilizer

1.4.1 Have you ever used fertilizer?
1.4.2 What has prevented you from using fertilizer?
1.4.3 Do you know other farmers that do use fertilizer?
1.4.4 Would your farm be improved if it had access to fertilizer?
1.4.5 Where do you usually acquire consumables needed for your farm?
1.4.6 How far from your farm is that?
1.4.7 Do you use or have access to renewable energy?
1.4.8 If a system you own produced fertilizer you could both use and sell, would that be of interest to you?
1.4.9 Do you have environmental concerns about using synthetic fertilizer?

Annex 7: Validation Workshop - Concept & Agenda

Context

Georgia's agricultural sector is undergoing structural transformation, with a growing emphasis on climate-smart practices, renewable energy integration and export competitiveness. This transition is underscored by national and international policy frameworks - Georgia's National Energy and Climate Plan (NECP), Long-Term Low Emissions Development Strategy (LTS) and Updated Nationally Determined Contribution (NDC), which call for innovative and low-emission solutions in agriculture and energy.

In this context, the study "Green Ammonia Use in Small-Scale Agricultural Businesses in Georgia" represents one of the first national explorations of decentralised green ammonia production and use. It examines the technical, economic, environmental and institutional feasibility of deploying green ammonia systems - particularly within the almond and blueberry value chains - to substitute imported, fossil-based nitrogen fertilisers with low-carbon, locally produced alternatives powered by renewable energy.

As global trade frameworks evolve, the findings of this study are also highly relevant for Georgia's economic integration efforts. Instruments such as the Deep and Comprehensive Free Trade Area (DCFTA) with the European Union's Carbon Border Adjustment Mechanism (CBAM) are reshaping agri-export standards, particularly around emissions traceability and sustainable input sourcing.

To ensure that the study's recommendations are anchored in practical realities and aligned with national priorities, this Validation Workshop convenes key stakeholders from farmer associations, agri-exporters, technical experts, and development partners. The event will facilitate a structured validation of findings, strengthen stakeholder ownership and support alignment with Georgia's agricultural, climate and renewable energy strategies.

PROGRESS programme

The project "Promoting Green Deal Readiness in the Eastern Partnership Countries" (PROGRESS) supports Armenia, Azerbaijan, Georgia, Moldova, and Ukraine in their transition toward climate-oriented, resilient, and green economic development, aligning agricultural and environmental practices with the principles of the European Green Deal. By fostering innovative technologies, tools, and methodologies, PROGRESS accelerates sustainability, strengthens climate resilience, and enables long-term greenhouse gas mitigation, all underpinned by improved framework conditions. Its vision is to contribute to long-term climate mitigation and sustainable development in line with the EU Green Deal objectives and the Paris Agreement's 1.5°C pathways across the Eastern Partnership countries.

The project 'Promoting Green Deal Readiness in the Eastern Partnership Countries' (PROGRESS) is implemented on behalf of the International Climate Initiative (IKI) of the Federal Government of Germany. Within the Federal Government, the IKI is anchored in the Federal Ministry for the Environment, Climate Action, Nature Conservation and Nuclear Safety (BMUKN). Selected project is also the responsibility of the Federal Foreign Office (AA). PROGRESS is implemented by the Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH, as the lead agency, in partnership with the Organisation for Economic Co-operation and Development (OECD), the Regional Environmental Centre for the Caucasus (REC), the European Business Association (EBA) Moldova and the Institute for Economics and Forecasting of the National Academy of Sciences of Ukraine (IEF).

Main Purpose of the Workshop

The workshop aims to:

> Validate the draft study findings with national stakeholders.
>
> Discuss and refine the feasibility assessment, challenges and opportunities for green ammonia in Georgia.
>
> Identify roles and responsibilities among key actors for moving from study to action.
>
> Strengthen stakeholder buy-in for future pilot projects and policy processes.
>
> Gather input on potential pilot site criteria and deployment sequencing.

Relevance of the Workshop

This workshop is essential because it:

> Ensures the study findings are accurate, realistic, and aligned with the Georgian context.
>
> Builds cross-sectoral consensus, especially important since green ammonia sits at the intersection of agriculture, energy and environmental policy.
>
> Provides a platform for farmer associations and value chain actors to express their practical needs and constraints.
>
> Helps identify policy gaps, pilot opportunities, financing options, and capacity-building before scaling the technology.

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