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BIO4AFRICA

Diversifying revenue in rural Africa through circular, sustainable and replicable biobased solutions and business models

Research and Innovation Action (RIA)
Grant Agreement 101000762

D1.2: Mapping of local forage agri-food systems

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Abbreviations

AFAAS	AFRICAN FORUM FOR AGRICULTURAL ADVISORY SERVICES
BPMN	Business Process Model and Notation
FAO	Food and Agriculture Organization of the United Nations
INP-HB	INSTITUT NATIONAL POLYTECHNIQUE FELIX HOUPHOUET-BOIGNY
KRC	KABAROLE RESEARCH AND RESOURCE CENTRE
SAVANET	SAVANNAH YOUNG FARMERS NETWORK
UASZ	UNIVERSITE ASSANE SECK DE ZIGUINCHOR

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1. Executive Summary

This report provides detailed business process maps of the agricultural supply network systems in West and East Africa to identify circular economy opportunities. Specifically, this reports details the supply chain mapping results for eight agri-food case studies across four West and East African countries, leveraging secondary evidence and multiple rounds of online interviews to capture current state scenarios. The two supply chains that were mapped, per country of interest, include: (i) Ghana – Cassava and Plant residues; (ii) Ivory Coast – Cassava and Cashew nuts; (iii) Senegal – Cashew nuts and Rice; and (iv) Uganda – Legumes and Cassava. The mapping process was based on the principles of Business Process Model and Notation (BPMN). In alignment with the BIO4AFRICA project's vision to promote technological interventions in rural production systems, the value of BPMN is encapsulated in the fact that it comprises a standardized business process modelling and notation technique that can be communicated and comprehended by technical developers.

Methodologically, this report first performed a review of the scientific and grey literature to develop an understanding of the rural systems in the four countries of focus. A series of eight literature-based maps were developed, two per country of interest. Thereafter, a total of 32 informants were engaged, representative of the eight investigated agricultural supply chains to validate the maps. In particular, throughout the mapping process, informants were systematically engaged through at least two rounds of online interviews. Additionally, we conducted several electronic mail communications to retrieve expert feedback, complement the literature-based maps and provide any 'known-unknowns' about the local systems' particularities. Overall, the primary and secondary evidence that was acquired was qualitative in nature.

Collating the literature on rural agricultural systems in Africa, in tandem with semi-structured interviews and expert panel engagements, involving industry and academic informants, resulted in a series of business processes maps. Such an output can guide the design of supply chain operations defined by the generated renewable feedstocks. In particular, this report provides a foundation for operational and future-state interventions for renewable feedstock valorisation. The provided eight maps are rather strategic in nature thus tending to capture uninterrupted flows. The main conclusion from the mapping in all eight cases is a set of crop-based added-value applications (e.g., cattle feed, bio-chemicals, textiles, food and biofuels) presented in detail in every map/section respectively and overall in Table 3.

This report acts as the deliverable (D1.2) that describes the activities carried out by DRAXIS for mapping agri-food supply network systems in West and East Africa as part of WP1, achieving Milestone 3 as per the BIO4AFRICA project. The work that is presented in this report has substantial linkages with other project strands, towards the common goal of leveraging the local forage agri-food systems in the selected countries to reveal pathways for sustainably introducing bio-based value chains.

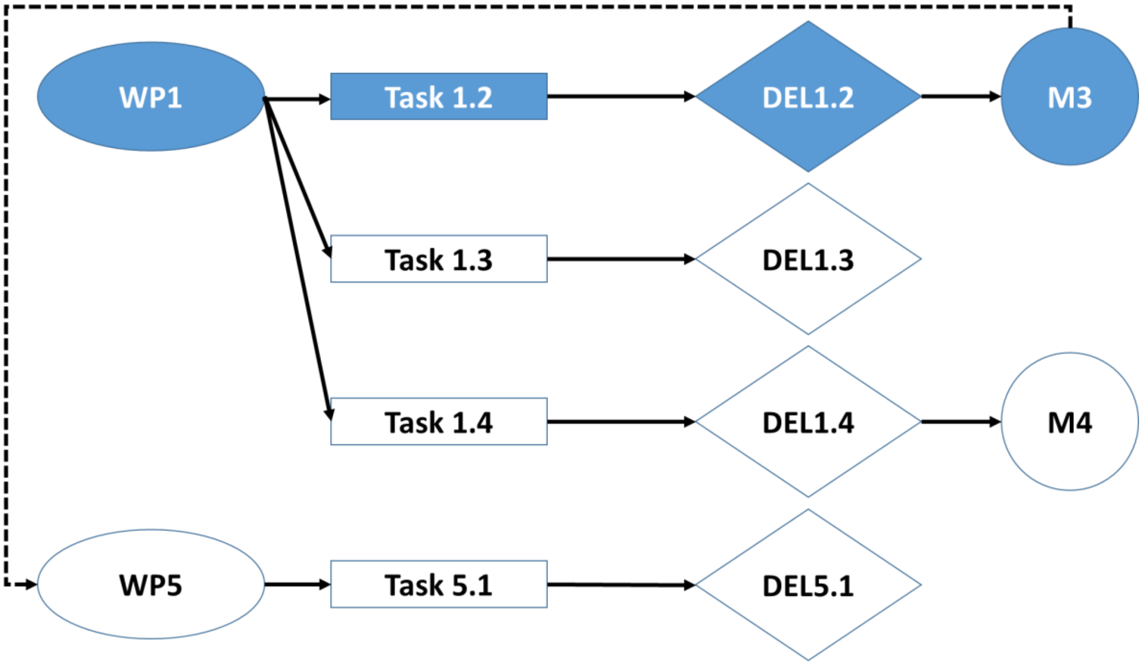
2. Introduction

In Africa, projections highlight the need to feed 1.2 billion people by 2030 and over 2 billion by 2050, while contemporarily coping with unprecedented demographic, socio-economic, environmental, climatic and health transitions (FAO, 2017). Contemporarily, African agri-food systems are uniquely positioned at the crossroads of major economic, environmental, human and policy challenges, but have the potential to address food and income security challenges whilst fostering inclusive and sustainable rural development (AGRA, 2018). In particular, this potential is pertinent to forage[1] agri-food systems as 60% of sub-Saharan African land is used by the rural population for farming and livestock production purposes (USAID, 2015). The valorisation of crop and animal residues stemming from forage agri-food systems can increase the circularity and sustainability of farming practices in rural Africa by recycling biomass and nutrients.

The BIO4AFRICA project will develop a catalogue of bio-based technologies adapted to the local needs and context, and it will train farmers in rural Africa to sustainably produce a variety of high value-added bio-based projects, such as animal feed, fertilisers, or biofuels. The farmers and rural communities in each of the BIO4AFRICA's pilot countries face unique challenges and opportunities. To this effect, D1.2: "Mapping of local forage agri-food systems" focuses on mapping the local agri-food systems, available feedstocks, actors, processes, resource flows, and value chains of the project's pilot cases in four participating countries, namely: (i) Ghana; (ii) Cote d'Ivoire; (iii) Senegal; and (iv) Uganda. The aim of the deliverable is to gain insights about the main features of the local forage agri-food systems, while also highlighting their dynamics and revealing pathways for sustainably introducing bio-based value chains. To address this objective, DRAXIS (DRAXIS ENVIRONMENTAL S.A. - Partner No. 21) carried out the project tasks which are schematically represented in Figure 1.

[1] "Forage" refers to plants eaten by animals as pasture, crop residue or immature cereal crops as well as plants cut/ processed for use as fodder (hay, silage, etc.).

Figure 1: Hierarchical representation of project activities within Task 1.2.



The hierarchilaa levels that are directly involved for D1.2 are highlighted in light blue. Links with the associated milestones ("M") and the affected deliverables ("DEL"), are also displayed. The dashed links denote an informal association that emerged in practice. [based on Grant Agreement, Figure 6]

The report is organised as follows: In Chapter 1 titled "Executive Summary", the key points of the report are summarised and presented. The purpose of the study is stated, major aspects are highlighted and results as well as conclusions drawn are presented. In Chapter 2 titled "Introduction" (the present chapter), the objective and the structure of the report are presented. In Chapter 3 titled "Materials and Methods", the overall methodology for identifying and mapping the crop supply systems is presented. In Chapter 4 titled "Mapping Agri-food Systems in West and East Africa", the mapping results that came out from the literature review and interviews conducted with experts from four countries are presented. In Chapter 5 titled "Conclusions", the conclusions are drawn. Finally, some issues for further discussion are raised. References are provided after the last chapter. Appendixes are provided at the end of the deliverable:

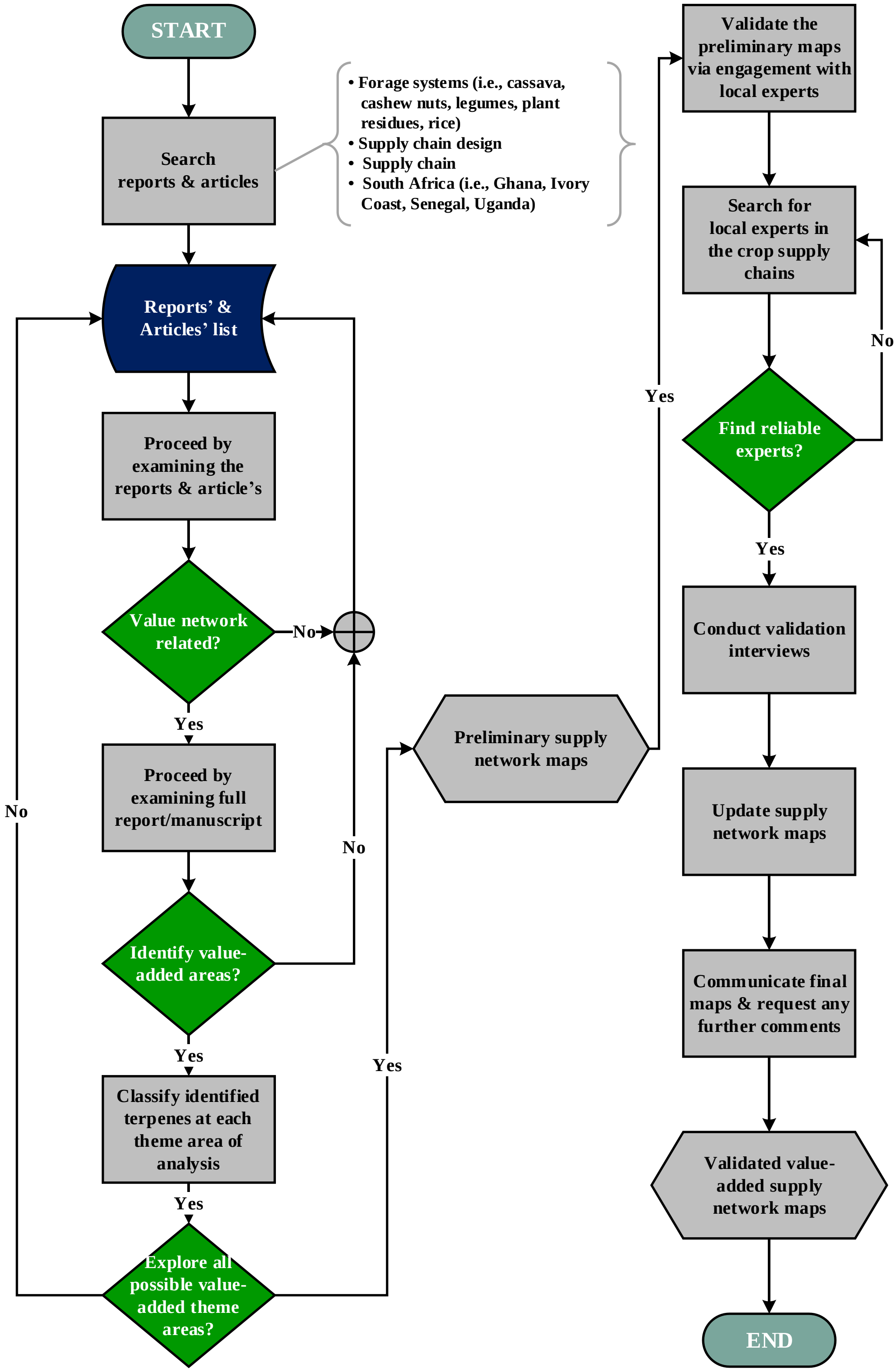
- Appendix I: BPMN Constructs & Symbols
- Appendix II: Main Mapping Sources
- Appendix III: Initial Draft Maps.

3. Materials and Methods

DRAXIS-led Task 1.2 (entitled “Mapping target local agri-food systems, available feedstocks and value chains”) was carried out within the context of WP1 “Needs analysis, technology screening and knowledge integration with rural African communities”. As illustrated in Figure 1, the milestone M3 – i.e., “Needs and agri-food systems of farmers and rural communities analysed” for the four countries of interest is essential for the identification of the current state of relevant crops’ and residues’ physical flows to inform future-state circular supply chains for the valorisation of any unwanted material for guiding the development of bio-based business opportunities.

In this regard, the object of scrutiny is a synthesis of both primary and secondary data. First, literature evidence was gathered to develop a coherent conceptual structure of major crops’ supply chains in the four African countries of interest to generate evidence informed management knowledge (Tranfield et al., 2003). Second, we investigated case studies on crops supply chain in Ghana, Cote d'Ivoire, Senegal, and Uganda. The multiple case study research provided unprecedented access to primary evidence (Yin, 1993) while the range of the involved informants allowed us to explore the supply network systems in depth (Gobbi and Hsuan, 2015). Figure 2 depicts the methodological approach and workflow for generating the supply network maps, enriched key data elements that have to be recorded at each echelon to assist operations’ synchronisation. The resulting mapping output informs the rigorous development of future-state interventions for exploiting the potential of crop residues and waste/by-products for empowering rural communities in Africa. The supply chain mapping methodology and the primary data gathering process employed as part of the D1.2 are discussed in the following subsections.

Figure 2: Methodology flowchart.



3.1 Supply Chain Mapping

In the extant body of the academic and practice literature, a range of reference frameworks exists for the mapping and modelling of business processes or workflows and the capturing of the underpinning material, data and information flows (Aalst and Hee, 2004). Such frameworks generally describe formal modelling principles that allow the conceptual representation of business processes in systems, which can then be used to guide quantitative analysis (e.g., simulation) at higher abstraction levels (Aguilar-Savén, 2004).

In the context of D1.2, the Business Process Model and Notation (BPMN) was chosen as the preferred approach to capture the business processes and associated material and data flows for the investigated crop supply chains. The details about BPMN are specified by the Standard ISO/IEC 19510:2013 and the OMG Specification v2.0.2 (OMG, 2014). A summary of BPMN's formalisms is provided by Rosing et al. (2015) and Chinosi and Trombetta (2012). A reference guide on key constructs and symbols used in BPMN is inserted in Appendix I.

Overall, BPMN provides the capability for the graphical representation of business processes in a business process model via leveraging a standard notation (Teixeira and Borsato, 2019). The design of BPMN necessitates that the business processes are captured in levels or layers. The technique is supported by open source and commercial graphical tools. The technique has been applied for mapping purposes in a range of sectors for understanding the complexity, supporting re-configuration options, identifying process bottlenecks, and prioritizing corporate resources, at the respective systems, including: (i) construction (Cheng et al., 2010); (ii) food for traceability purposes (Pizzuti et al., 2014); and (iii) healthcare for re-engineering processes (Chanpuypetch and Kritchanchai, 2018).

The selection of BPMN as a mapping method is due to the fact that:

i. BPMN helps to ensure consistency with established reference frameworks for the structured representation of business processes.
ii. BPMN helps to capture business processes and underpinning flows at a high level of abstraction.
iii. BPMN ensures the same standard mapping principles are applied across the range of crop supply chain systems being investigated in D1.2.
iv. BPMN is relevant to crop supply chains as it supports the identification and interactions between processes and business rules for determining an informed course of action.

An overview of software tools that are typically used for the development of BPMN is provided by Geiger et al. (2018). In this D1.2, the BPMN maps were created via the MS Visio Professional 2013 for visualisation purposes.

3.2 Case Studies

The aim of mapping local agri-food systems is to gain a deeper understanding and insights into the main features of the local forage agri-food systems in the selected countries. The case studies involve mapping of the processes, crops, renewable feedstocks, actors, and value chains to reveal pathways for sustainably introducing bio-based value chains. Specifically, every map breaks down the respective supply network system into different levels (e.g., procurement, farming, trading, valorisation, and retailing). In total, eight (8) maps were generated involving two (2) agri-food forage systems per each of the four (4) participating countries, i.e.: (i) Ghana; (ii) Cote d'Ivoire; (iii) Senegal; and (iv) Uganda.

Prior to the mapping process, a thorough examination of the BIO4AFRICA Grant Agreement document and a preliminary exploration of the pertinent literature were conducted to compile a list of agri-food supply networks per country that were deemed worth considering for further investigation. A list of main supply network mapping sources for the selected countries, that guided the initial selection of cropping systems, is inserted in Appendix II. The selection criteria involved the feasibility and value opportunities stemming for the potential valorisation of cropping by-products. The suggested list of potential agri-food supply networks to map was circulated to partners from each participating country. Ultimately, the selection of the cropping systems to map was based on the consent of the task leaders of the intended pilot cases. Table 2 tabulates the specific cases of crop supply network systems that were agreed to be mapped within the context of D1.2.

Table 1: Case study selection matrix.

	Crop				
Country	Legumes	Cassava	Plant Residues	Cashew Nuts	Rice
▪ Ghana		X	X		
▪ Cote d'Ivoire		X		X	
▪ Senegal				X	X
▪ Uganda	X	X			

The mapping process per crop involved two stages. At a first stage, a preliminary mapping of every existing value chain was performed based on secondary evidence retrieved from the academic, institutional and grey literature. The initial draft maps that were developed solely based on secondary evidence are inserted in Appendix III. Every map considers the system's boundaries and involved processes (e.g., farming inputs, crop varieties, processing stages, waste generation, retailing, and consumption), as well as value chain characteristics (e.g., types of inputs, valorisation options, and outputs). The generated maps were then communicated to the particular stakeholders who possess expertise and primary knowledge about each of the mapped supply network. At a second stage, a validation process occurred involving one online meeting, involving experts from every of the four countries of focus, and communication of the revised/validated map for final observations and comments. This two-stage process ensures a comprehensive and validated overview of each pilot case.

A vital action between the two stages described above, was providing practical instructions concerning the BPMN to familiarise the informants with the flowchart representation and key maps' elements. Therefore, we shared with the informants a tutorial explaining all the elements and the logic behind BPMN (available here https://www.youtube.com/watch?v=BwkNceoybvA&ab_channel=Lucidchart), building also a simple diagram to illustrate the key points. For example, the explanation of the four groups of elements or symbols (1) Flow Objects, that includes events [○], activities [□] and gateways [◊]; (2) Connecting Objects, that includes lines showing sequence in message flows [⟶]and associations [--------]; (3) Pools and Swim lanes, that represent major participants in a process [i.e. the main rectangles across the map]; (4) Artifacts, that bring an addition level of details [▭] (see Appendix I).

Overall, by the end of August 2021, a total of four online validation meetings were organised. The engagement with the informants academic and industry informants, from the local settings of the investigated West and East African case studies, helped to reduce bias and increase the reliability of the gathered data, thus informing the generated maps (Eisenhardt and Graebner, 2007). Table 2 sets out the specific expertise of the involved informants. For ensuring anonymity and due to privacy concerns, the names of the involved informants are not specified.

Table 2: Informants.

#	Country	Position	Occupation	Expertise	Interview Date
1	Senegal	Professor	UASZ	Agricultural production systems	28/07/2021
2	Senegal	Professor	UASZ	Agricultural potential of the Ziguinchor region (World Bank)	28/07/2021
3	Senegal	PhD	UASZ	Estimation of agricultural and energy potential of agro-resources	28/07/2021
4	Senegal	PhD student	UASZ	Estimation of agricultural and energy potential of agro-resources	28/07/2021

#	Country	Position	Occupation	Expertise	Interview Date
5	Senegal	Company manager	SCPL	Cashew value chain	28/07/2021
6	Senegal	Professor	UASZ	Estimation of agricultural and energy potential of agro-resources	28/07/2021
7	Senegal	Coordinator Office Upgrade	Senegal Chamber of Commerce	Agricultural production systems and value chain	28/07/2021
8	Senegal	Assistant	SCPL (Manufacturer)	Cashew value chain	28/07/2021
9	Senegal	Head of GIE	GIE DEMIIR (Famer, Trader)	Cereals, fruits and vegetables chains	28/07/2021
10	Senegal	PhD	Independent	Estimation of agricultural and energy potential of agro-resources	28/07/2021
11	Senegal	Senior technician	Contractor	Cereals, fruits and vegetables chains	28/07/2021
12	Senegal	Senior technician	Farmer	Agricultural production systems	28/07/2021
13	Senegal	College level	Trader	Cashew value chain	28/07/2021
14	Senegal	Manager	Transporter	Cashew value chain	28/07/2021
15	Ivory Coast	Assistant Professor	INP-HB		26/07/2021
16	Cote d'Ivoire	Assistant Professor	INP-HB		26/07/2021
17	Cote d'Ivoire	Assistant Professor	INP-HB		26/07/2021
18	Cote d'Ivoire	Professor	INP-HB		26/07/2021

#	Country	Position	Occupation	Expertise	Interview Date
19	Cote d'Ivoire	Professor	INP-HB		26/07/2021
20	Cote d'Ivoire	Director	DENIA Cashew Processing Factory	Cashew value chain	26/07/2021
21	Cote d'Ivoire	Cassava Producer and Processor	President, Association of Women Cassava Producers	Cassava value chain	26/07/2021
22	Ghana		SavaNet		23/8/2021
23	Ghana		SavaNet		23/8/2021
24	Ghana		0km.nomads		23/8/2021
25	Ghana		Farmer		23/8/2021
26	Ghana		Trader		23/8/2021
27	Uganda		AFAAS		24/8/2021
28	Uganda		AFAAS		24/8/2021
29	Uganda		AFAAS		24/8/2021
30	Uganda		KRC		24/8/2021
31	Uganda		KRC		24/8/2021
32	Uganda		KRC		24/8/2021

4. Mapping Agri-food Systems in West and East Africa

The mapping involved four countries from West and East Africa, involving two agri-food products per country, hence resulting in a total of eight maps. The mapping process allowed to capture the investigated agri-food supply network systems and their constituent flows hence recognising opportunities for valorising by-products and wasted/discarded material. The recognition of these material as renewable feedstocks inspires opportunities for valorisation interventions to deliver added-value to farmers and promote welfare and sustainable development to the local and regional communities. In the subsections that follow, the detailed maps along with a brief description are provided, per each considered agri-food forage system, including:

1. Ghana
    - Cassava
    - Plant residues
2. Cote d'Ivoire
    - Cassava
    - Cashew nuts
3. Senegal
    - Cashew nuts
    - Rice
4. Uganda
    - Legumes
    - Cassava.

4.1 Ghana

In the case of Ghana, the two agri-food forage systems that were mapped include: (i) cassava; and (ii) plant residues. The theoretical drafts are presented in the Appendix III and were based on scientific publications and reports (Angelucci, 2013; Naziri, et al., 2014; Anim-Somuah et al., 2013; Larsen et al., 2009; Pace, 2012; Poku et al., 2018; Kleih et al., 2013). The subsections that follow present the outputs of the mapping process.

4.1.1 Cassava

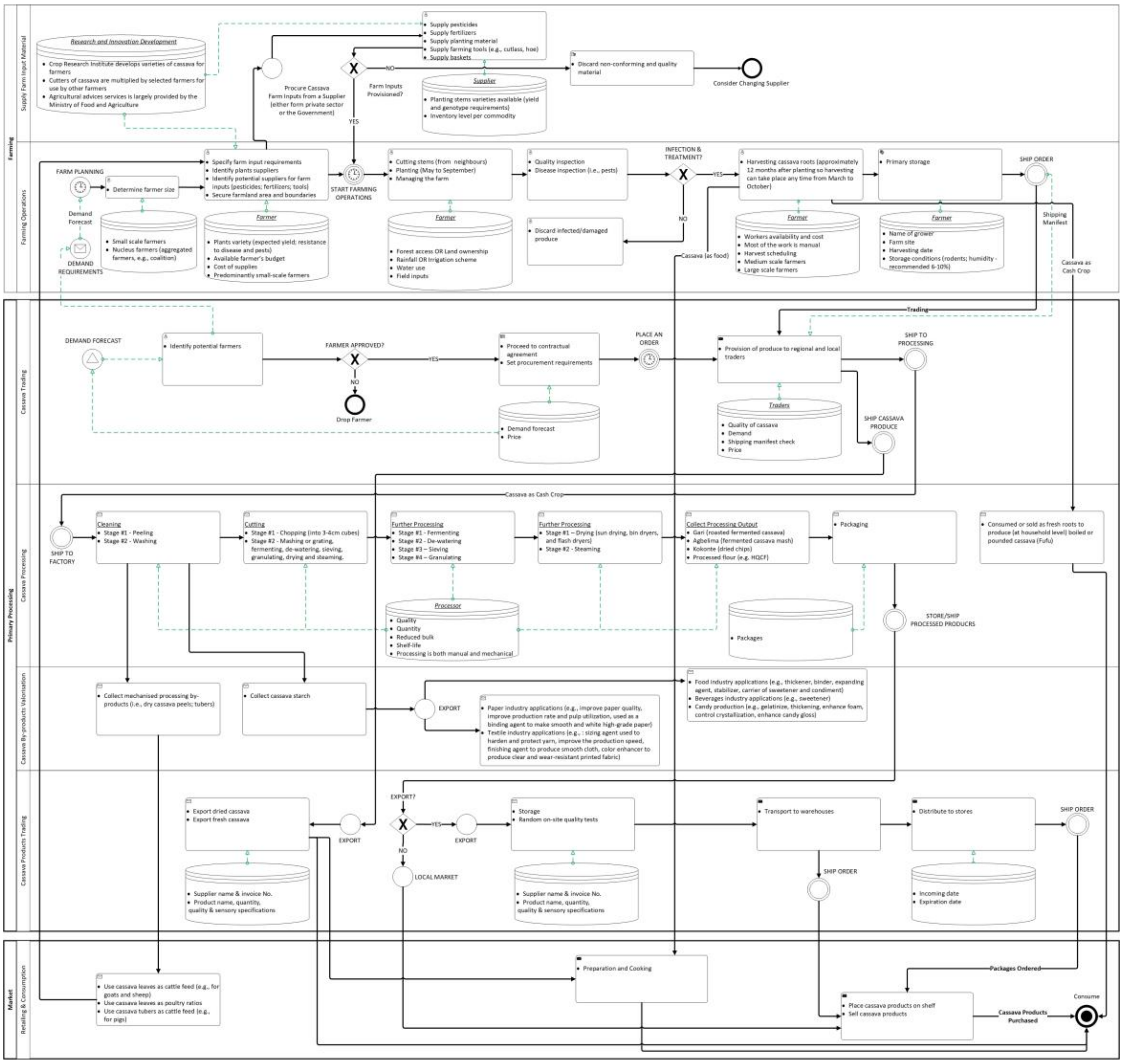
Cassava is one of the most significant staple foods in Ghana. Most cassava is produced by small-scale farmers with small landholdings and therefore all processes (i.e., cultivation, harvesting, and post-harvest) are performed with limited chemical and technical inputs. At the farming echelon, the Crop Research Institute develops varieties for cassava which are then multiplied by selected growers for enabling cassava farming at scale. Thereafter, harvesting occurs, typically 12 months after planting, depending on the variety, and the produce is either used directly for meal preparation at a household level (as fresh roots that are boiled or pounded – Fufu) or is being forwarded to local/regional traders for processing at scale. The most important processing issue is drying cassava, usually either by sun or bin dryers, and flash dryers. For most small-scale processors the only practical option is sun-drying, resulting in limited volumes of processing. Traders either forward cassava produce for domestic consumption, following a series of processing stages such as chopping and cutting, or export it (dried or fresh). Following the processing stages, main edible products that derive include Gari (i.e., roasted fermented cassava), Agbelima (i.e., fermented cassava mash), Kokonte (i.e., dried chips), and processed flour. Figure 3 captures the detailed supply network system map for cassava in Ghana (see tutorial on BPMN flowchart/symbols in section 3.1 and Appendix I).

The map consists of three swimming pools: the *farming*, the *primary processing*, and the *market*. The *farming* has two swim lenes, the *supply farm input material* and the *farming operations*. The production begins with the procurement of cassava farm inputs and the farming operations. After the harvesting, the product either goes for *processing* (second pool) or directly to the *market* (third pool) as food. In the *processing* swimming pool, there are four lanes: the *cassava trading*, the *cassava processing*, the *cassava by-product valorization*, and the *cassava product trading*. The *trading* is an intermediate provision of produce to regional and local traders. The *processing* results in different packed products ready for market and by-products that are mainly exported. Finally, the *trading* either exports packed products or feeds the local market.

The main conclusions of the map concern the valorisation opportunities. Cassava-based renewable feedstock derives either directly from the farm or via the intermediary mechanised processing stages. Based on literature evidence validated through interview results, higher-value applications of cassava by-products include:

- Use of cassava leaves as cattle feed (e.g., for poultry, goats, sheep).
- Use of cassava processing by-products (e.g., dry peels, tubers) as cattle feed (e.g., for pigs).
- Fresh leaves as human feed (sauce)
- Export of cassava starch emanating from the mechanised processing stages for industrial manufacturing purposes. Cassava starch can be used in paper industry applications as a binding agent in pulp production to create higher-value paper.
- Export of cassava starch emanating from the mechanised processing stages for industrial manufacturing purposes. Cassava starch is used as an agent in the textile industry for producing better quality and resistant printed fabric.
- Export of cassava starch emanating from the mechanised processing stages for food manufacturing purposes. Cassava starch is used in food industry applications, e.g., thickener, binder, expanding agent, stabilizer, carrier of sweetener and condiment.
- Export of cassava starch emanating from the mechanised processing stages for beverages industry applications, e.g., sweetener.
- Export of cassava starch emanating from the mechanised processing stages for candy production purposes, e.g., gelatinize, thickening, enhance foam, control crystallization, and enhance candy gloss.

Figure 3: Cassava supply network system map – Ghana.



4.1.2 *Plant Residues*

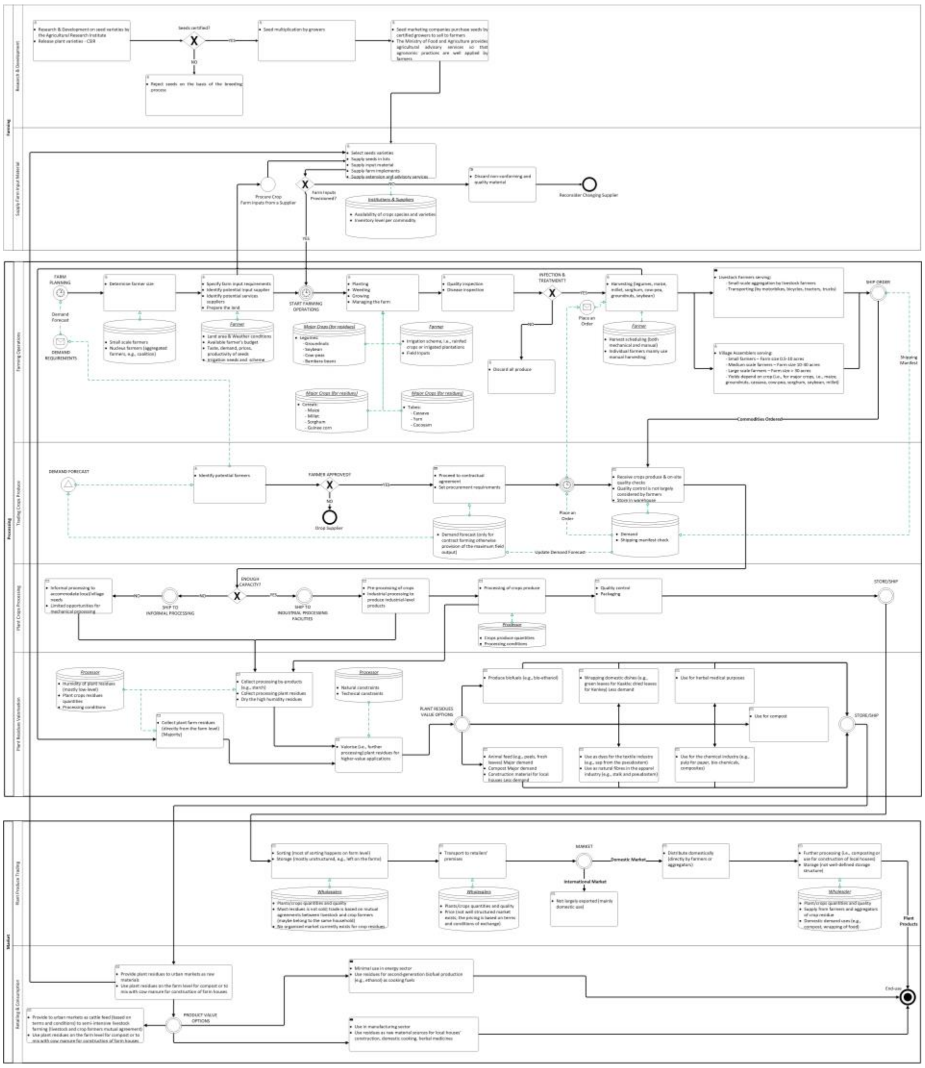
At the farming echelon, the Agricultural Research Institute supports research on seed varieties that are then forwarded to seed growers for ensuring the availability of selected seeds to farmers, at scale. Farmers are classified based on the farmland, i.e., small scale farmers – 0.5-20 acres, medium scale farmers – 10-30 acres, and large scale farmers – >30 acres. The main crops that can be exploited in terms of their residues include: legumes i.e., (i) groundnuts, (ii) soybean, (iii) cow-peas, and (iv) bambara beans; cereals i.e. (i) maze, (ii) millet, (iii) sorghum, and (iv) Guinee corn; tubes i.e., (i) cassava, (ii) yarn, and (iii) cocoyam. Following the harvesting operations (mainly manual), the residues are sorted and storage in an unstructured manner at a farm level. Quality specifications of plant residues (e.g., humidity) are not considered by farmers. Depending on the available volumes, plant residues are typically collected either by livestock farmers or village assemblers. Livestock farmers proceed to small-scale aggregation via using motorbikes, bicycles, tractors or trucks as transport means. Notably, most of the residues are not traded based on commercial rules as an organised market does not exist. Rather, the trade follows informal/mutual agreements between crop and livestock farmers who may even belong to the same family. Figure 4 captures the detailed supply network system map for plant residues in Ghana (see tutorial on BPMN flowchart/symbols in section 3.1 and Appendix I). Concerning processing, small capacity usually shipped to informal processing to accommodate local/village needs (with limited opportunities for mechanical processing), while larger capacity shipped to industrial processing towards industrial-level products.

The map consists of three swimming pools: the *farming*, the *processing*, and the *market*. The *farming* has two lanes, the *research & development* and the *supply farm input material*. The first certifies the seed that reach the growers and the second provides the necessary input to support the production. The next pool (*processing*) begins with the lane of the *farming operation* that feeds the *plant crops processing* lane. Afterwards, if the capacity is enough, it is shipped to industrial processing facilities, if not is shipped to informal processing. Next stage is the *plant residue valorisation lane* with various value options: biofuels, herbal medicine, animal feed, dyers for textile industry, chemical industry and so on. Finally, in the market pool there are two lanes: the *plant produce trading* and the *retailing & consumption* in which the output from the valorisation stage reaches mainly the domestic market.

The key output of the map is about the valorisation options. The majority of crop residues derive directly from the farm level while fewer volumes of by-products are available through an intermediary processing stage (e.g., starch). Based on literature evidence validated through interview results, higher-value applications of plant residues include:

- Use of plant residues for the production of biofuels (e.g., bioethanol).
- Use of plant residues as wrapping medium for domestic dishes such as green leaves for Kaake and dried leaves for Kenkey. The demand for such applications is low.
- Use of plant residues for the production of herbals dedicated to medical purposes.
- Use of plant residues for compost. Composting comprises the major application for plant residues.
- Use of plant residues (e.g., peels, fresh leaves) as animal feed. This is a major applications of plant residues for farmers in Ghana.
- Use of plant residues as dyes for the textile industry (e.g., sap from the pseudostem) and as natural fibres in the apparel industry (e.g., stalk and pseudostem).
- Use of plant residues for the chemical industry (e.g., pulp for paper, bio-chemicals, composites).

Figure 4: Plant residues supply network system map – Ghana.



4.2 Cote d'Ivoire

In the case of Cote d'Ivoire, the two agri-food forage systems that were mapped include: (i) cassava; and (ii) cashew nuts. The theoretical drafts are presented in the Appendix III and were based on scientific publications and reports (CBI, 2019; Kone, 2010; Coulibaly et al., 2014; Loukos, 2017; Ton et al., 2018; Tessemann, 2018). The subsections that follow present the outputs of the mapping process.

4.2.1 Cassava

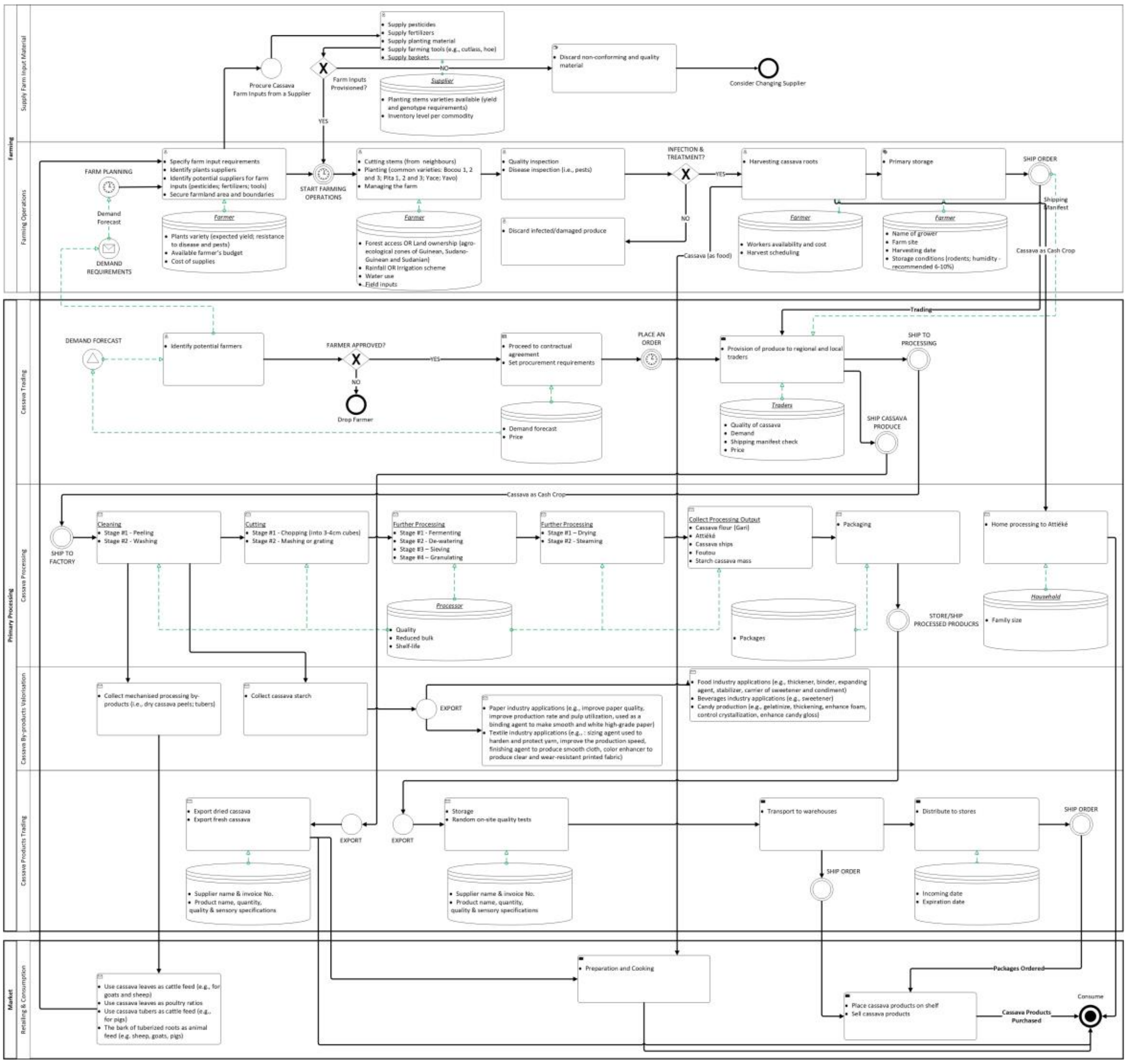
Cassava production system in Côte d'Ivoire is broad with extensive use of traditional/low-yield varieties and minimal use of fertilizers. At the farming echelon, farmers either cut stems from neighbours or plant common cassava varieties such as Bocou 1, Bocou 2, Bocou 3, Pita 1, Pita 2, Pita 3, Yace, and Yavo. Following the harvesting, cassava root supplies are either used at household level for processing to Attièkè and covering dietary needs or supplied directly to the food market. Processing is an essential element of the Cassava value chains in Cote d'Ivoire, resulting to products like Attiékè, a popular food in the region. The demand for these products is significant, yet most of the processors use basic equipment and fail to secure contracts with suppliers/consumers. When traders are involved, cassava supplies undergo a series of processing stages for the export food market. Figure 5 illustrates the detailed supply network system map for cassava in Cote d'Ivoire (see tutorial on BPMN flowchart/symbols in section 3.1 and Appendix I). The country has self-sufficiency in cassava availability for human consumption, with extremely limited imports. Also, the exports are very few. Cassava marketing and trade take place in the local, national, and regional markets. The key restrictions the traders usually face are the low prices, the lack of trucks, and the bad roads.

The map consists of three swimming pools: the *farming*, the *primary processing*, and the *market*. The *farming* has two swim lenes, the *supply farm input material* and the *farming operations*. The production begins with the procurement of cassava farm inputs and the farming operations. After the harvesting, the product either goes for *processing* (second pool) or directly to the *market* (third pool) as food. In the *processing* swimming pool, there are four lanes: the *cassava trading*, the *cassava processing*, the *cassava by-product valorization*, and the *cassava product trading*. The *trading* is an intermediate provision of produce to regional and local traders. The *processing* results in different packed products ready for market and by-products that are mainly exported. Finally, the *trading* either exports packed products or feeds the local market.

In case of Cote d'Ivoire, similarly to the case of cassava in Ghana, the main conclusions are about the applications of cassava-based renewable feedstock that include:

- Use of cassava leaves as cattle feed (e.g., for poultry, goats, sheep).
- Use of cassava processing by-products (e.g., dry peels, tubers) as cattle feed (e.g., for pigs).
- Export of cassava starch in the paper industry as a binding agent in pulp production to create higher-value paper.
- Export of cassava starch as an agent in the textile industry for producing better quality and resistant printed fabric.
- Export of cassava starch for food industry applications, e.g., thickener, binder, expanding agent, stabilizer, carrier of sweetener and condiment.
- Export of cassava starch for application sin the beverages industry, e.g., sweetener.
- Export of cassava starch for candy production purposes, e.g., gelatinize, thickening, enhance foam, control crystallization, and enhance candy gloss.

Figure 5: Cassava supply network system map – Cote d'Ivoire.



4.2.2 *Cashew Nuts*

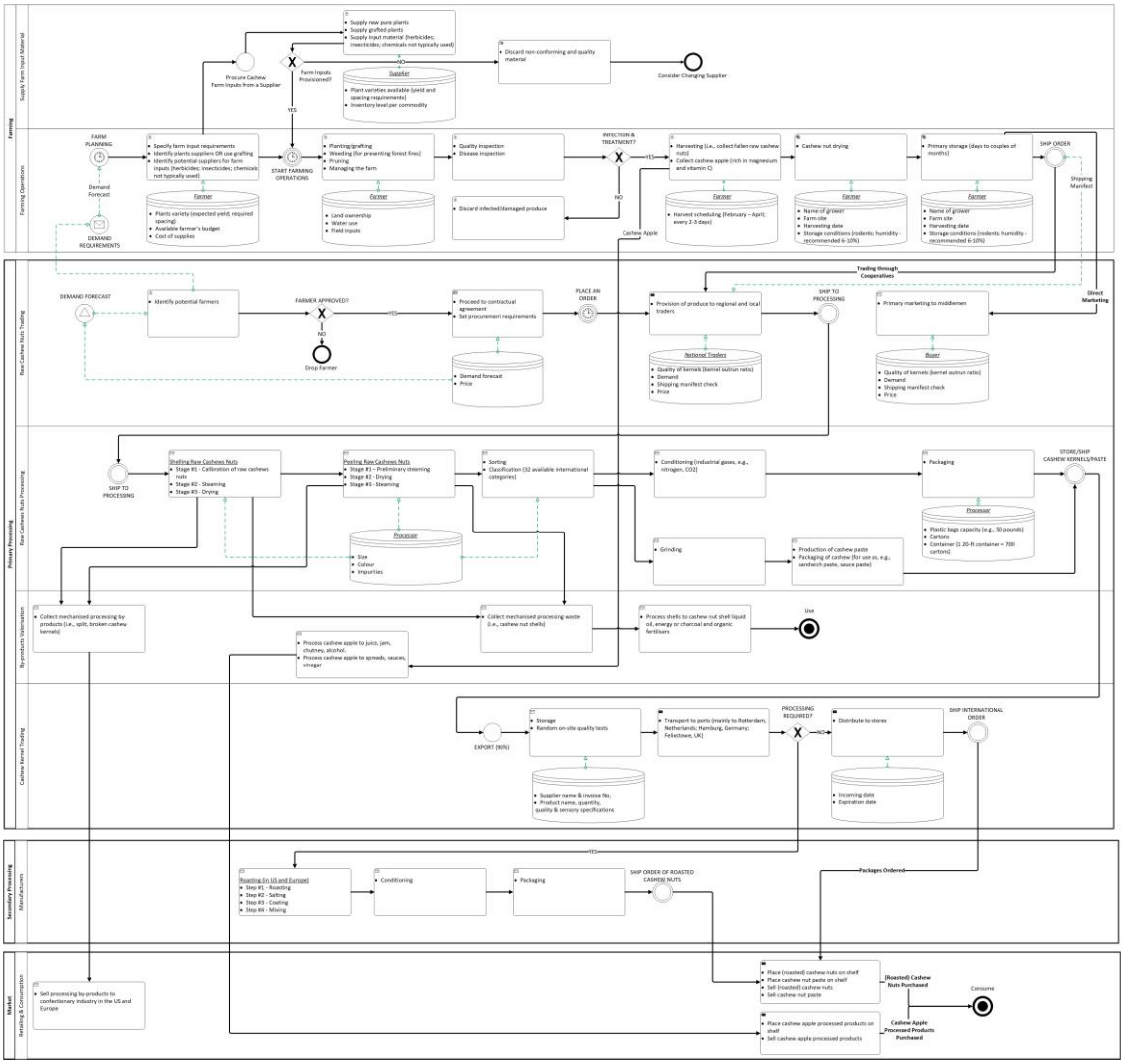
Cashew nuts are grown primarily by small-scale farmers, using limited inputs and fertilizers/pesticides. Moreover, growers do not make satisfactory efforts to appropriately maintain the trees, cautiously harvest the fruit or carry out decent post-harvest treatment thus, their average income is significantly low. At the farming echelon, farmers either select a supplier of farming inputs or use grafting. Following the harvesting (i.e., collects fallen raw cashew nuts), trading occurs either directly between/amongst) individual farmers and middlemen or between cooperatives and local/regional traders based on quality criteria (e.g., kernel output ratio). Most farmers sell to local traders, who usually are community members. Then, the local traders sell to independent buyers or to big trading companies. Only a small percentage of the production is processed locally. Through traders, cashew nuts supplies undergo a series of processing stages that ultimately lead to: (i) conditioning via industrial gases (e.g., nitrogen, CO_2) for providing the nuts in commercial packages or containers; or (ii) grinding for producing cashew paste that is used as sandwich or sauce paste. Cashew nuts can then go through a roasting process and sold in the food retail market. Another primary commodity that derives from the farming stage and is often being overlooked due to its fragility refers to cashew apple. Cashew apple can be processed towards higher value commercial food products such as juice, jam, chutney, alcohol. Figure 6 captures the detailed supply network system map for cashew nuts in Cote d'Ivoire (see tutorial on BPMN flowchart/symbols in section 3.1 and Appendix I).

The map consists of four swimming pools: the *farming*, the *primary processing*, the *secondary processing*, and the *market*. The *farming* has two swim lenes, the *supply farm input material* and the *farming operations*. The production begins with the procurement of farm inputs and the farming operations. After the harvesting, the product either goes for *primary processing* (second pool) or *secondary processing* (third pool). In the *primary processing* swimming pool, there are four lanes: the *raw cashew nuts trading*, the *raw cashew nuts processing*, the *by-product valorization*, and the *cashew kernel trading*. The main product of this stage is cashew kernel for export (over 90%). The *secondary processing* involves roasting and packing, mainly abroad. Finally, the *market pool* involves retailing and consumption of roasted cashew nuts, cashew apples (processed) and by-products.

The primary conclusion of this map is about the valorisation opportunities. The cashew nuts-based by-products that typically derive from intermediary mechanised processing stages and provide high-value commercial opportunities include:

- Collect and export mechanised processing by-products of cashew nuts (e.g., split, broken cashew kernels) that are used to the confectionary industry, particularly in the U.S. and Europe.
- Process cashew nuts processing by-products (e.g., shells) for the production of cashew nut shell liquid oil, energy or charcoal and organic fertilisers.

Figure 6: Cashew nuts supply network system map – Cote d'Ivoire.



4.3 Senegal

In the case of Senegal, the two agri-food forage systems that were mapped include: (i) cashew nuts; and (ii) rice. The theoretical drafts are presented in the Appendix III and were based on scientific publications and reports (Gilleo et al., 2011; Peters et al., 2011; Mbade, 2019; Arnoldus et al., 2020; Randriamamonjy et al., 2020; Scholz et al., 2014; ITC, 2013). The subsections that follow present the outputs of the mapping process.

4.3.1 Cashew Nuts

The cashew value chain in Senegal is quite simple and direct. The production is going through the farmers to traders who operate for bigger collectors and eventually it is exported (mainly in the form of raw cashew nut). At the farming echelon, farmers, after the seeding, cultivation and harvesting, collect the cashew nuts in nylon bags. Thereafter, cashew nuts are processed and traded to the domestic and international markets.

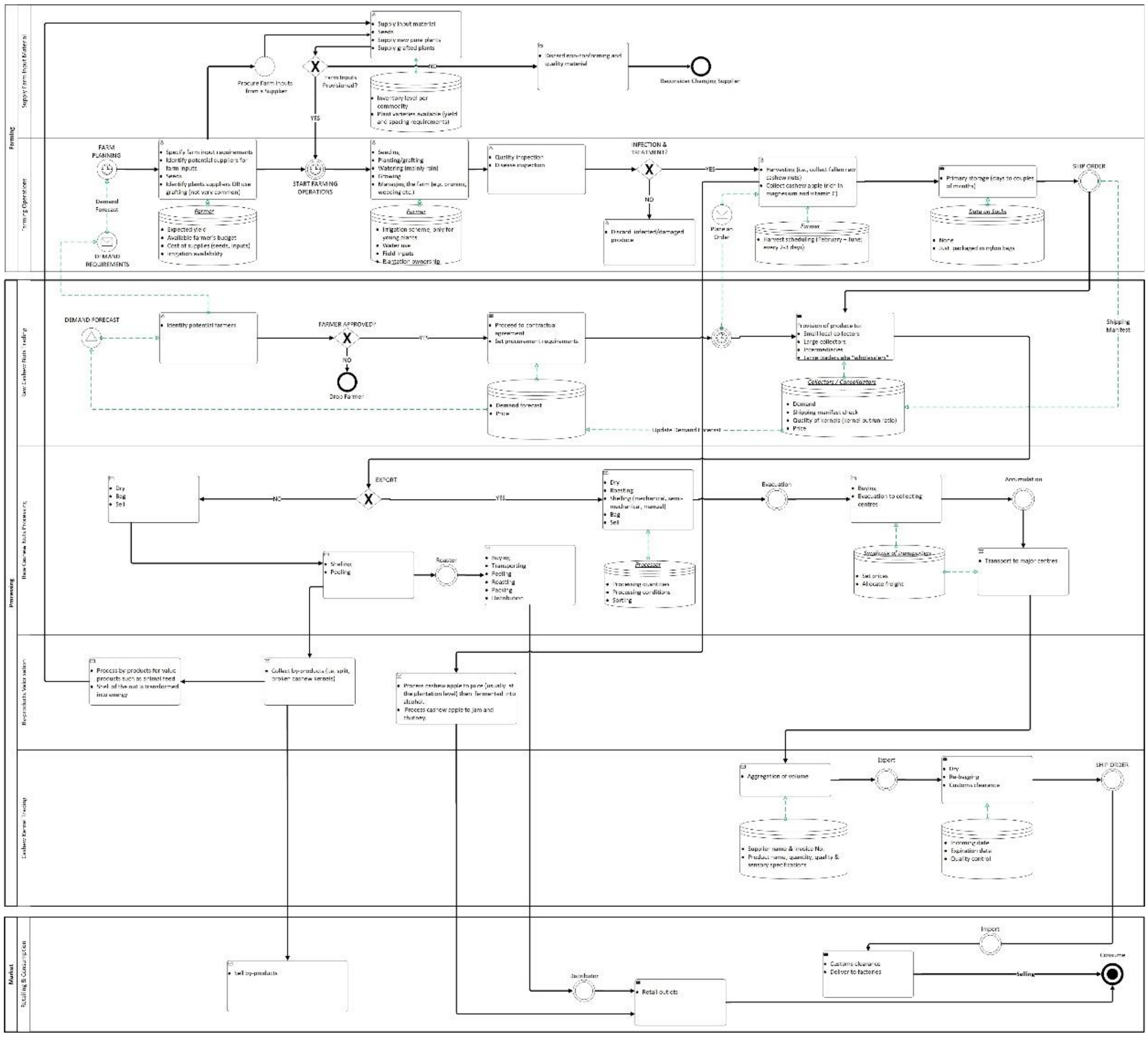
In addition, cashew apple is also collected at a farming echelon. The vast majority of production is not processed locally. Figure 7 depicts the detailed supply network system map for cashew nuts in Senegal (see tutorial on BPMN flowchart/symbols in section 3.1 and Appendix I).

The map consists of three swimming pools: the *farming*, the *processing*, and the *market*. The *farming* has two swim lenes, the *supply farm input material* and the *farming operations*. The production begins with the procurement of cashew nuts inputs and the farming operations. After the harvesting, the product either goes for *raw cashew nut processing* (second pool) or directly to the *market* (third pool) as ready to consume supplies. In the *processing* swimming pool, there are four lanes: the *raw cashew nuts trading*, the *raw cashew nuts processing*, the *by-products valorisation*, and the *cashew kernel trading*. The *processing* results in different products ready for market and by-products that are mainly exported.

The key conclusion is about valorisation options. The main value-added commercial opportunities include:

- Collect and process cashew apple to juice (usually at the plantation level), then fermented to alcohol.
- Collect and process cashew apple to jam and chutney.
- Processing of cashew nuts by-products (e.g., split, broken cashew kernels) that is directly provided to commercial markets, without prior processing.
- Use by-products of cashew nuts as animal feed.
- Use of cashew nut shells for energy generation.

Figure 7: Cashew nuts supply network system map – Senegal.



4.3.2 Rice

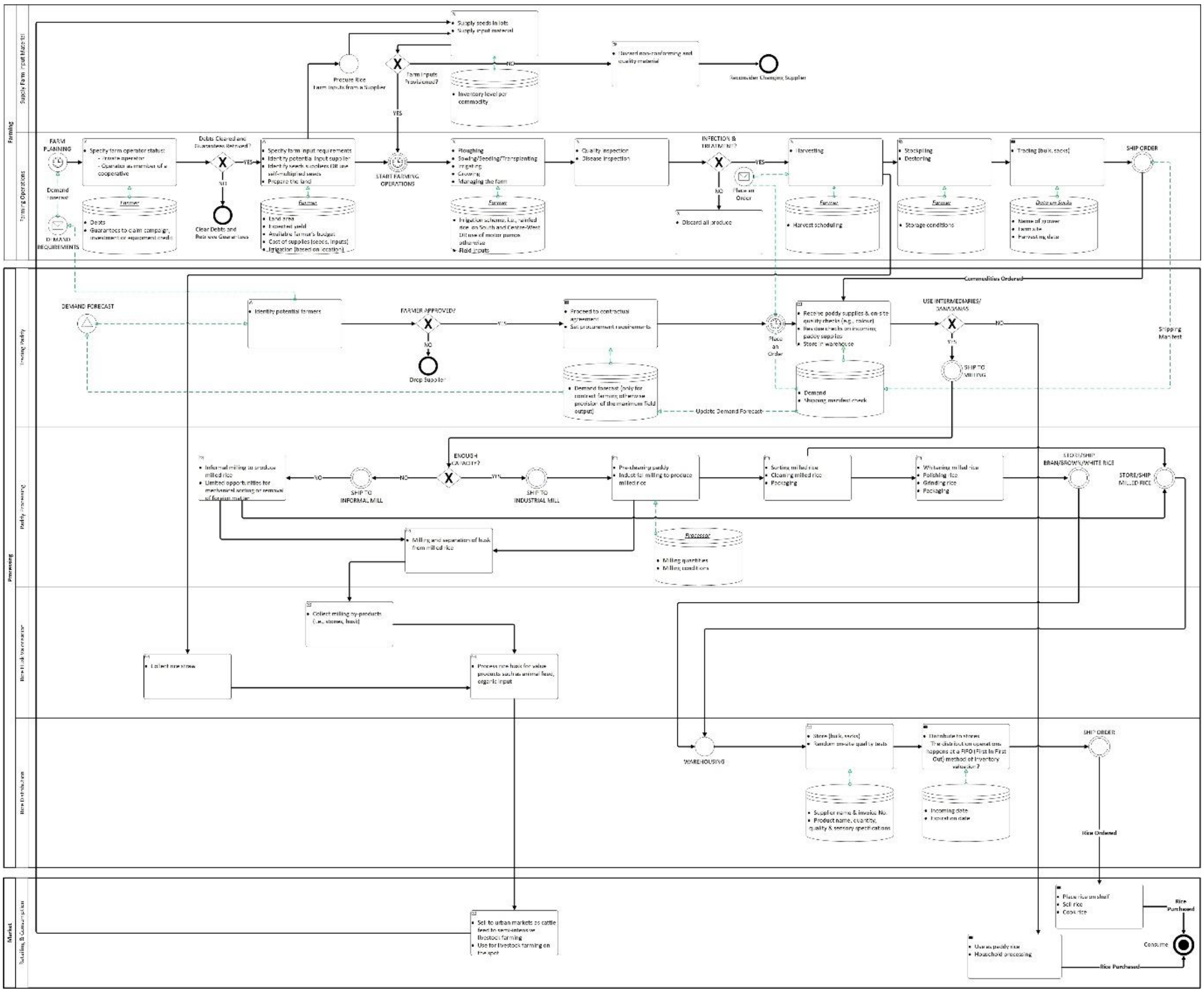
At the farming echelon, farmers act either individually or as members of a cooperative. Following the specification and supply of farming inputs, farming operations begin. Considering the nature of rice crop, irrigation concerns either rainfed rice on South and Centre-West of the country, or the use of motor pumps. Figure 8 depicts the detailed supply network system map for rice in Senegal. Following harvesting, visual quality inspections (e.g., colour) are performed and the rice is stored in sacks or as bulk. Depending on the production capacity, rice is either consumed at a household level or is being traded. At scale, rice undergoes processing involving milling, sorting to remove foreign matter, cleaning and whitening. Following packaging and storing, the distribution of rice occurs at a FIFO method (i.e., First-In First-Out). Processing transforms paddy into rice. Usually, informal small village level mills process removes the husk of the grain. Nonetheless, due to better prices and demand there are also some larger semi-industrial mills. The majority of the farmers sell through informal intermediary traders (called banabanas). Figure 8 demonstrates the detailed supply network system map for rice in Senegal (see tutorial on BPMN flowchart/symbols in section 3.1 and Appendix I).

The map consists of three swimming pools: the *farming*, the *processing*, and the *market*. The *farming* has two swim lenes, the *supply farm input material* and the *farming operations*. The production begins with the procurement of rice farm inputs and the farming operations. After the harvesting, the paddy either goes for *processing* (second pool) or directly to the *market* (third pool) as food. In the *processing* swimming pool, there are four lanes: the *trading paddy*, the *paddy processing*, the *rice husk valorization*, and the *rice distribution*. The *trading* is an intermediate provision of produce to regional and local traders through the banabanas. The *processing* results in different packed products ready for market and by-products.

Main conclusions are about valorisation options. The major value-added commercial opportunities for rice by-products include:

- Collect and use rice straw as animal feed on the spot or to semi-intensive livestock farms.
- Collect and use rice straw as organic input on farms.
- Collect and use rice milling by-products (e.g., husk) as organic input on farms.
- Husks for piggery and poultry houses

Figure 8: Rice supply network system map – Senegal.



4.4 Uganda

In the case of Uganda, the two agri-food forage systems that were mapped include: (i) legumes; and (ii) cassava. The theoretical drafts are presented in the Appendix III and were based on scientific publications and reports (Adekunle et al., 2016; Asante-Pok, 2013; Depetris-Chauvin et al., 2017; Iragaba et al., 2021; Odongo and Etany, 2018; Wesana et al., 2019). The subsections that follow present the outputs of the mapping process.

4.4.1 Legumes

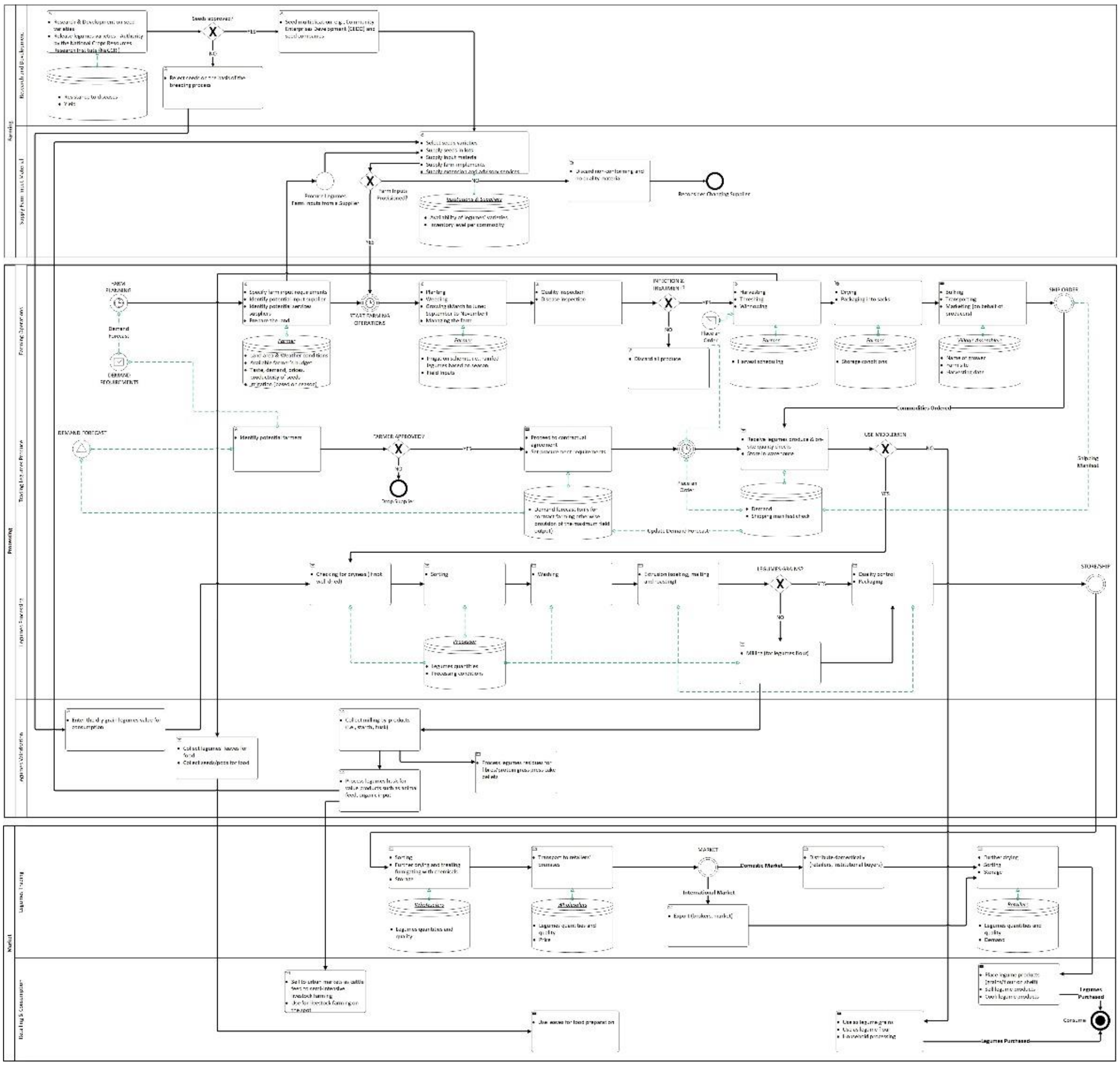
At the farming echelon, farmers procure seed varieties that have been approved by the National Crops resources Research Institute (NaCCRI) and which have been multiplied by Community Enterprises Development (CEDO) and seed companies. Following land preparation and seeds procurement, the farming operations begin. There are two growing seasons, March-June and September-November with slight variations based on the agro-ecological regions, where based on the season rainfed legumes are cultivated. Quality control of the produce regards the level of dryness. The harvested legumes are primarily used at a household level as either grains or flour. A limited number of households deliver the legumes' production to middlemen, while a lack of direct linkages to processing units exist, hence denoting the low position of households within the value chain of legumes. Figure 9 demonstrates the detailed supply network system map for legumes in Uganda (see tutorial on BPMN flowchart/symbols in section 3.1 and Appendix I).

The map consists of three swimming pools: the *farming*, the *processing*, and the *market*. The *farming* has three swim lenes, the *research and development*, the *supply farm input material* and the *farming operations*. The production begins with the research over legume seeds and the procurement of legume inputs and the farming operations. After the harvesting, the product either goes for *processing* or directly to the *market* as food. In the *processing* swimming pool, there are three lanes: the *trading legumes produce*, the *legumes processing*, and the *legumes valorization.* The *processing* results in different products ready for market and by-products that are mainly used at a domestic level.

The main output concerns valorisation options. Legume-based renewable feedstocks and by-products that can be exploited to create value-added commercial opportunities include:

- Use legume leaves for food preparation.
- Use legume husks as animal feed to semi-intensive livestock farming or on the spot.
- Process legume residues for fibres/protein grass press cake pellets.
- Collect and use legume milling by-products (e.g., husk) as organic input on farms.

Figure 9: Legumes supply network system map – Uganda.



4.4.2 Cassava

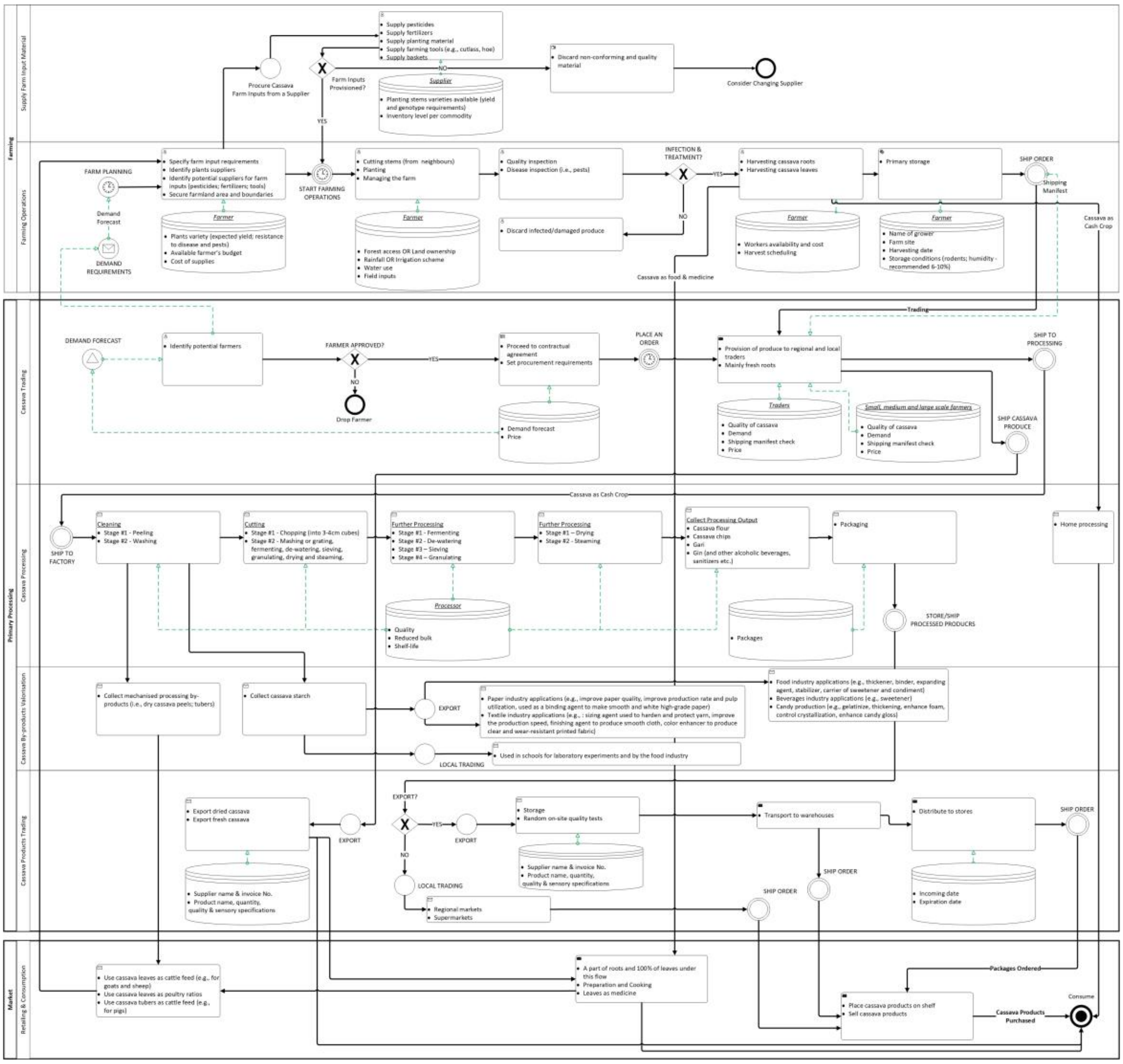
In the same vein to the cassava systems in other participating countries, at the farming echelon farmers either cut stems from neighbours or plant common cassava varieties, while some farmers purchase improved varieties from research sites or from multiplication sites. Following the harvesting, cassava root supplies are either used at household level for covering dietary needs or supplied directly to the food market. Otherwise, when traders are involved, cassava supplies undergo a series of processing stages for the export food market. The main output of the cassava production is fresh cassava root and very small percentage (around 5%) is fresh leaves. The latter are exclusively consumed at household level and occasionally in traditional restaurants, so only the fresh roots are commercialised. From that, half is consumed fresh (roasted, steamed or mashed) and half processes into chips, gin, floor, starch and gari. Figure 10 shows the detailed supply network system map for cassava in Uganda (see tutorial on BPMN flowchart/symbols in section 3.1 and Appendix I).

The map consists of three swimming pools: the *farming*, the *primary processing*, and the *market*. The *farming* has two swim lenes, the *supply farm input material* and the *farming operations*. The production begins with the procurement of cassava farm inputs and the farming operations. After the harvesting, the product either goes for *processing* (second pool) or directly to the *market* (third pool) as food. In the *processing* swimming pool, there are four lanes: the *cassava trading*, the *cassava processing*, the *cassava by-product valorization*, and the *cassava product trading*. The *trading* is an intermediate provision of produce to regional and local traders. The *processing* results in different packed products ready for market and by-products that are mainly exported. Finally, the *trading* either exports packed products or feeds the local market.

The major conclusions are about the applications of cassava-based renewable feedstock and processing by-products, as presented below:

- Use of cassava leaves as animal feed (e.g., for cattle, poultry, goats, sheep).
- Use of cassava processing by-products (e.g., dry peels, tubers) as animal feed (e.g., for pigs).
- Export of cassava starch in the paper industry as a binding agent in pulp production to create higher-value paper.
- Export of cassava starch as an agent in the textile industry for producing better quality and resistant printed fabric.
- Export of cassava starch for food industry applications, e.g., thickener, binder, expanding agent, stabilizer, carrier of sweetener and condiment.
- Export of cassava starch for application in the beverages industry, e.g., sweetener.
- Export of cassava starch for candy production purposes, e.g., gelatinize, thickening, enhance foam, control crystallization, and enhance candy gloss.

Figure 10: Cassava supply network system map – Uganda.



5. Conclusions

Deliverable 1.2 investigated and systematically mapped eight (8) agri-food supply network case studies across four (4) West and East African countries, namely: (i) cassava – Ghana; (ii) plant residues – Ghana; (iii) cassava – Cote d' Ivoire; (iv) cashew nuts – Cote d' Ivoire; (v) cashew nuts – Senegal; (vi) rice – Senegal; (vii) legumes – Uganda; and (viii) cassava – Uganda. Following the scope of the BIO4AFRICA project, the deliverable identifies cropping systems' residues and by-products, and added-value applications thereof, and lays the foundations for quantitative environmental, economic and social modelling and pilot implementations of corresponding renewable feedstock-based networks. Table 3 summarises potential commercial applications of the investigated feedstocks, under scale and quality considerations.

Table 3: Key markets for crop-based intermediates or end-products in West and East Africa.

	Crop-based Added-value Applications				
Crop (by-products)	Cattle Feed	Bio-chemicals	Textiles	Food/Beverages/ Confectionery	Energy/ Biofuels
▪ Cashew Nuts	X			X	X
▪ Cassava	X	X	X	X	
▪ Legumes	X	X		X	
▪ Plant Residues	X		X	X	X
▪ Rice	X	X			

The commercial interest in exploring crop-based residues and by-products to use as raw materials for added-value applications is imminent in West and East Africa. Interview findings indicate the need to explore any material flows for improving the welfare and livelihood of rural populations, as for example in the case of cashew nuts apple in Cote d' Ivoire that could be exported thus ensuring elevated cash flows, or cassava by-products that can be used in a multitude of industrial applications. However, the exploration of such alternative feedstocks necessitates network structural considerations from a raw material perspective. Thereafter, alternative processing options require structured mapping of the emerging supply chains considering the variety of possible commercial products downstream the supply networks. Indeed, the identified material-processing-supply networks are then determined based on business value and viability targets.

Prior secondary evidence suggests that utilising crop residues and by-products may be considered a strategic advantage for initiating a range of entrepreneurial initiatives and fostering industrial growth (Okoro et al., 2017), particularly in developing countries. At a greater extent, leveraging extant agri-food systems provides an opportunity to propel the transition to a circular economy landscape (Tsolakis et al., 2019). However, from the empirical evidence that was gathered it is apparent that to support the design of such networks encounters several uncertainties, including:

i. feedstock availability – to enable scale production, a constant and significant (in volume) availability of feedstock is required that currently seems to reside at a village/community-level;
ii. feedstock quality – to allow for the downstream added-value applications, upstream gathering, pre-processing and storage conditions shall be appropriate to ensure quality aspects of feedstock supplies, e.g., humidity level;
iii. processing pathways and technologies – to select appropriate and feasible processing options, the consideration of the available feedstock is required in terms of availability/supply, quality and downstream market demand; and
iv. complex set of intermediate or end-use markets – the circular network design shall consider the dynamics among local/regional stakeholders to enable certainty regarding the viability of respective supply chain operations.

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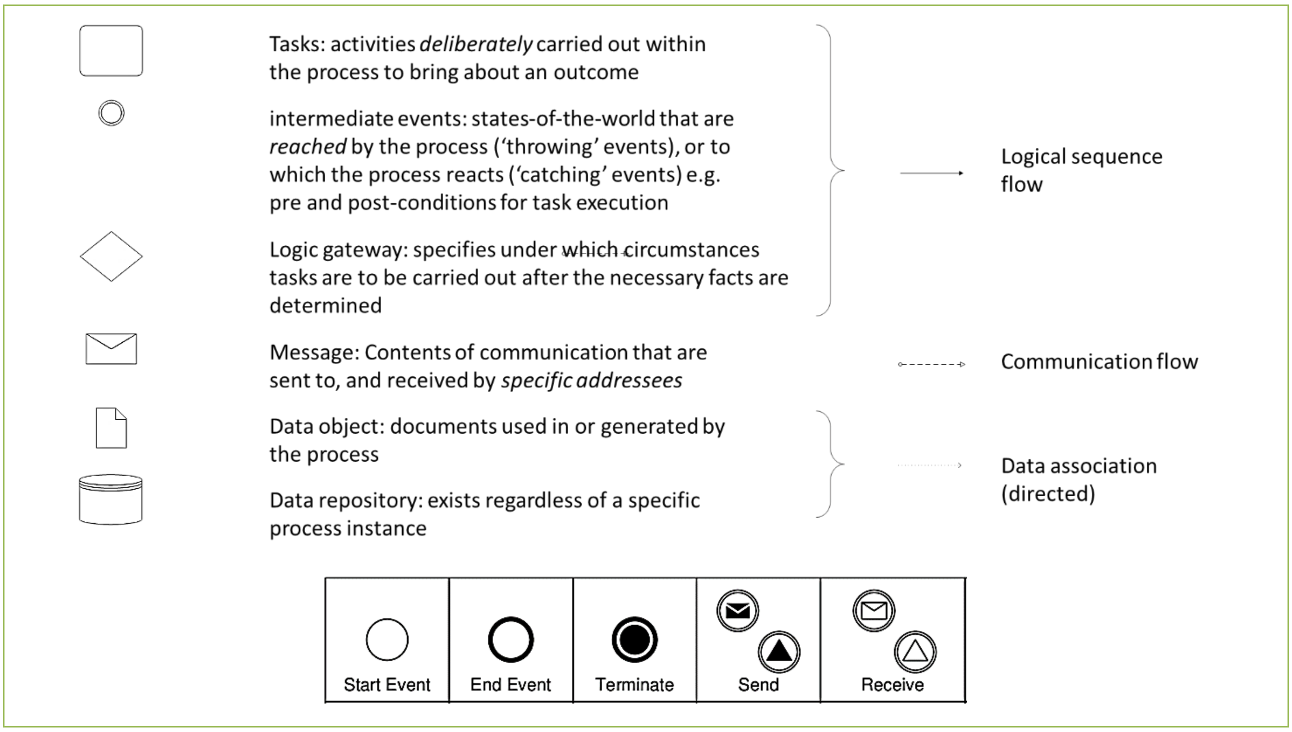
Appendix

Appendix I: BPMN Constructs & Symbols



Appendix II: Main Mapping Sources

Legumes

id	Article Title	Country	Type	Source
1	Value chain analysis of beans in eastern and southern Africa: Building partnerships for impact through research on sustainable intensification of farming systems	Malawi, Zambia, Tanzania	Report	Source Link
2	Value Chain Analysis of the Bean Sub-sector in Uganda	Uganda	Report	Source Link
3	Value chain analysis and mapping for groundnuts in Uganda	Uganda	Report	Source Link
4	Value Chain Analysis of cow pea, groundnut & soy bean in Sierra Leone	Siera Leone	Thesis	Source Link
5	Value Chain Assessment: Maize, Beans, and Groundnuts	Uganda	Report	Source Link

Cassava

id	Article Title	Country	Type	Source
1	Mapping cassava food value chains in Tanzania's smallholder farming sector: The implications of intra-household gender dynamics	Tanzania	Article	Source Link
2	The role of institutions as actors influencing Uganda's cassava sector	Uganda	Article	Source Link
3	Is Africa ready to develop a competitive bioeconomy? The case of the cassava value web in Ghana	Ghana	Article	Source Link
4	Regional cassava value chains analysis in West Africa	Cote d' Ivoire	Report	Source Link

Manure

id	Article Title	Country	Type	Source
1	Climate-smart dairy livestock value chains in Uganda	Uganda	Report	Source Link
2	Dynamics of the Fertilizer Value Chain in Mozambique	Mozambique	Article	Source Link

Cattle Feed

id	Article Title	Country	Type	Source
1	Dairy Compound feed and fodder value chain analysis	Kenya	Report	Source Link

Biochar

id	Article Title	Country	Type	Source
1	A Supply Chain Approach to Biochar Systems	N/A	Report	Source Link
2	Biochar Potential in Improving Agricultural Production in East Africa	Kenya, Tanzania, Uganda, Rwanda, Burundi, South Sudan	Report	Source Link

Pastoral Waste

id	Article Title	Country	Type	Source
1	Developing sustainable value chains for small-scale livestock producers	N/A	Report	Source Link

Wood Residues

id	Article Title	Country	Type	Source
1	An Approach to Promote REDD+ Compatible Wood-fuel Value Chains	N/A	Report	Source Link

Rice Husk

id	Article Title	Country	Type	Source
1	Biochar Systems for Smallholders in Developing Countries	Senegal	Report	Source Link
2	A holistic lens on rice value chain pathways in Senegal	Senegal	Report	Source Link

Crop Residues

id	Article Title	Country	Type	Source
1	Technical analysis of crop residue biomass energy in an agricultural region of Ghana	Ghana	Article	Source Link
2	The potential of plantain residues for the Ghanaian bioeconomy—Assessing the current fiber value web	Ghana	Article	Source Link

Cashew Nuts

id	Article Title	Country	Type	Source
1	Analysis of the cashew sector value chain in Côte d'Ivoire	Cote d' Ivoire	Report	Source Link
2	Cashew nut processing in West Africa - Value chain analysis - Benin and Côte d'Ivoire	Cote d' Ivoire	Report	Source Link
3	Agro-Business of Cashew Nuts in Casamance (Senegal): Strengths, Constraints and Industrialisation Prospects	Senegal	Article	Source Link
4	Analysis of the cashew value chain in Senegal	Senegal	Report	Source Link

Appendix III: Initial Draft Maps

Figure 11: Initial Draft Map – Cassava supply network system map – Ghana.

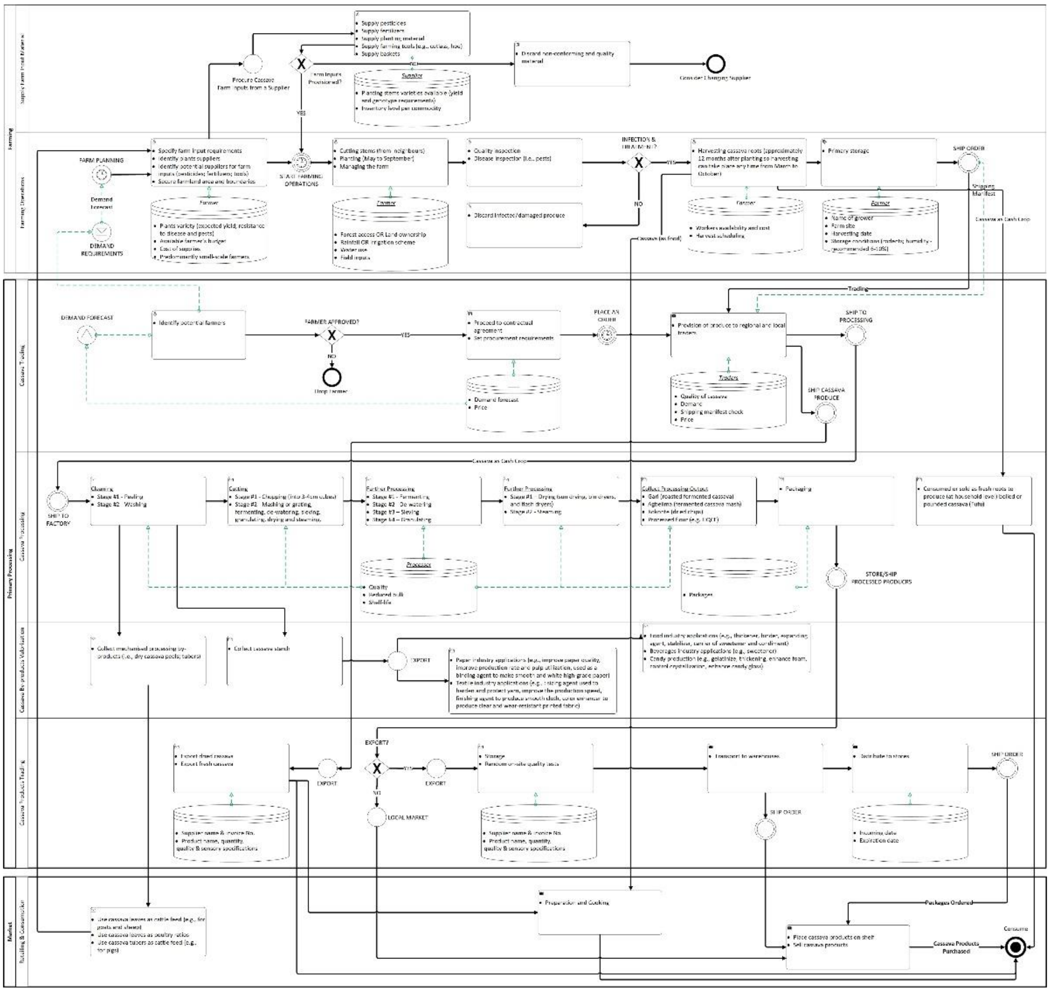


Figure 12: Initial Draft Map – Plant residues supply network system map – Ghana.

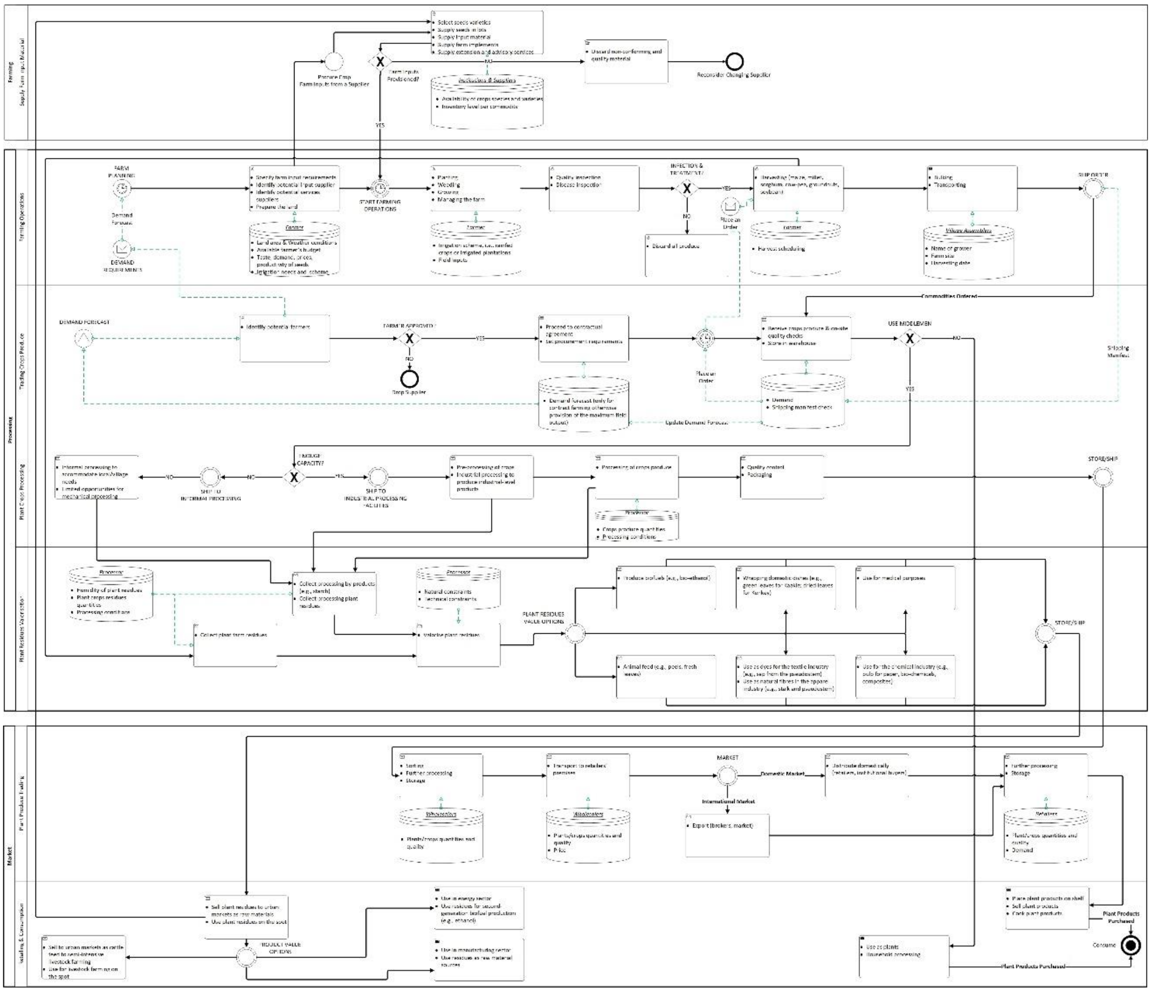


Figure 13: Initial draft map – Cassava supply network system map – Cote d' Ivoire.

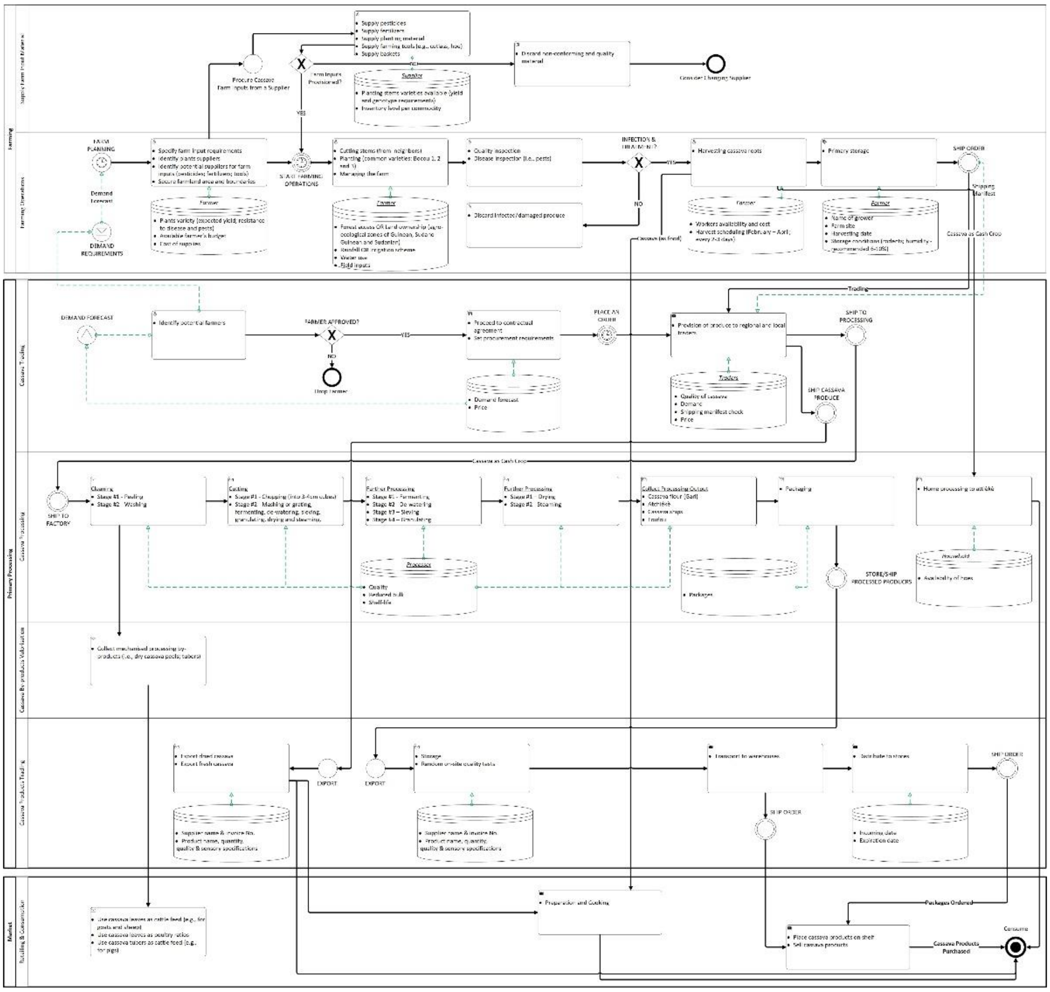


Figure 14: Initial draft map – Cashew nuts supply network system map – Cote d' Ivoire.

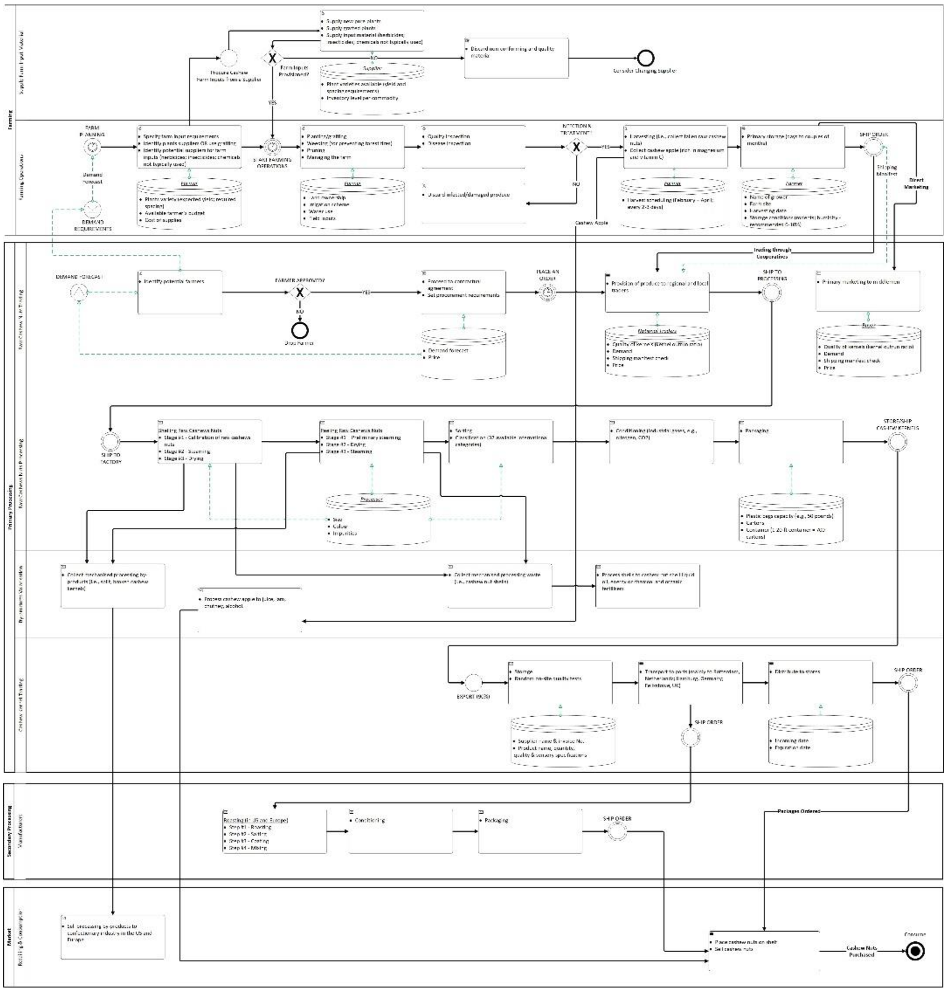


Figure 15: Initial draft map – Cashew nuts supply network system map – Senegal.

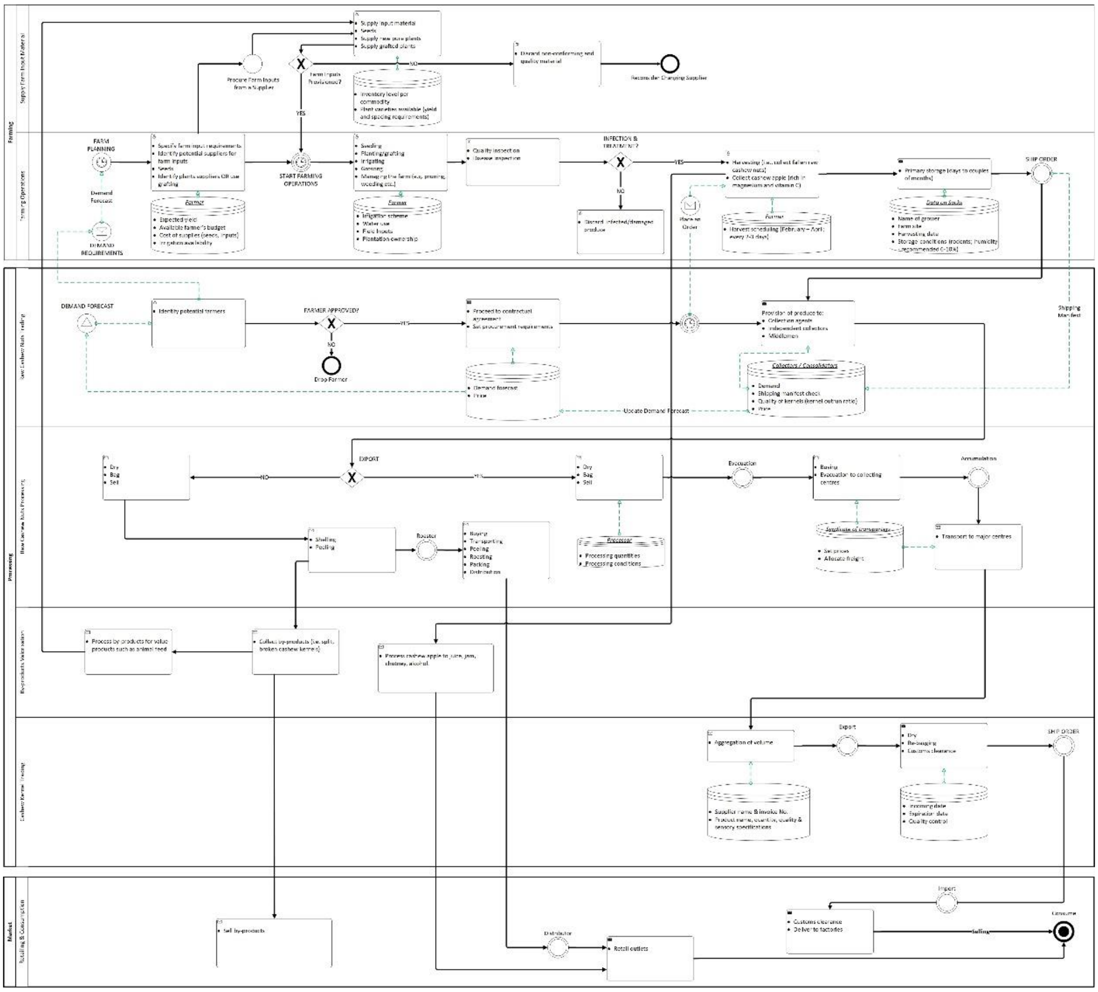


Figure 16: Initial draft map – Rice supply network system map – Senegal.

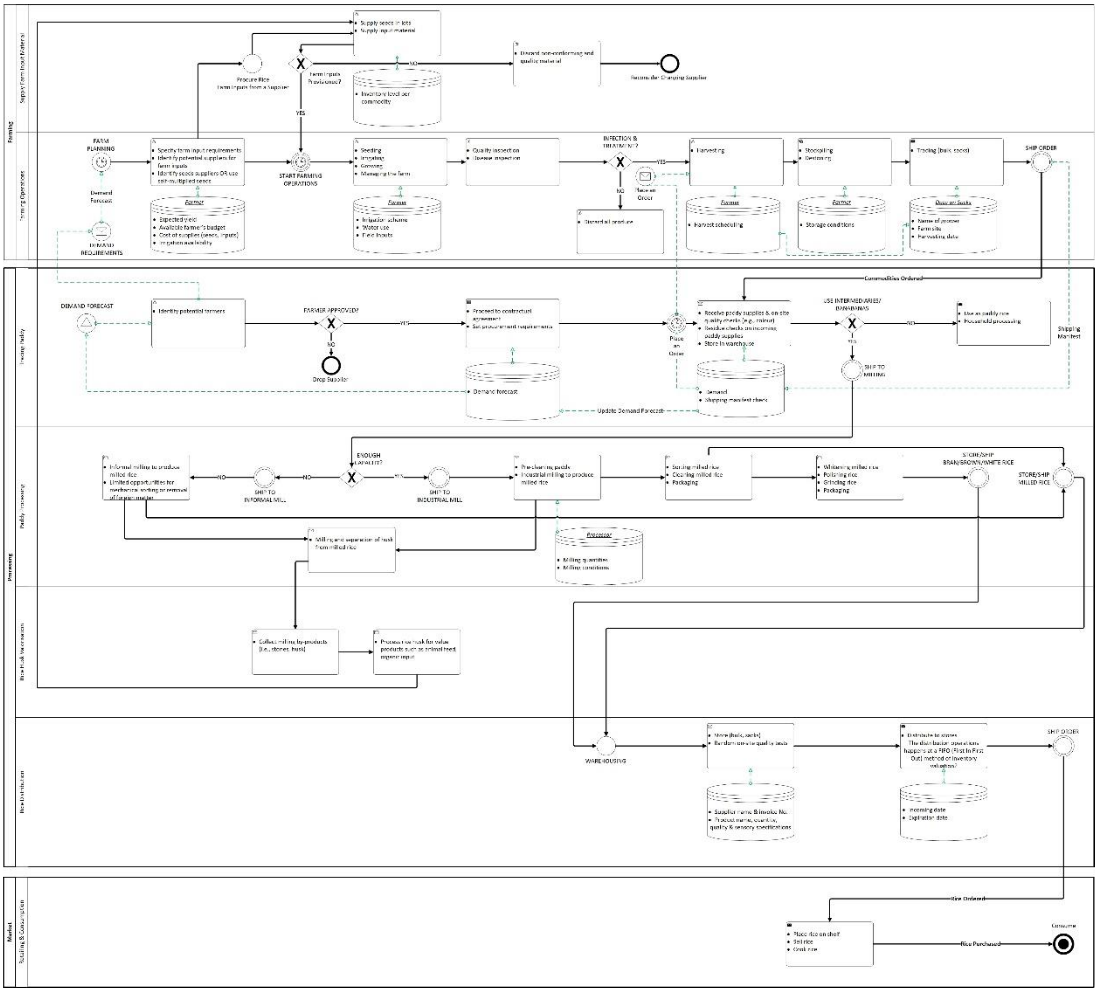


Figure 17: Initial draft map – Legumes supply network system map – Uganda.

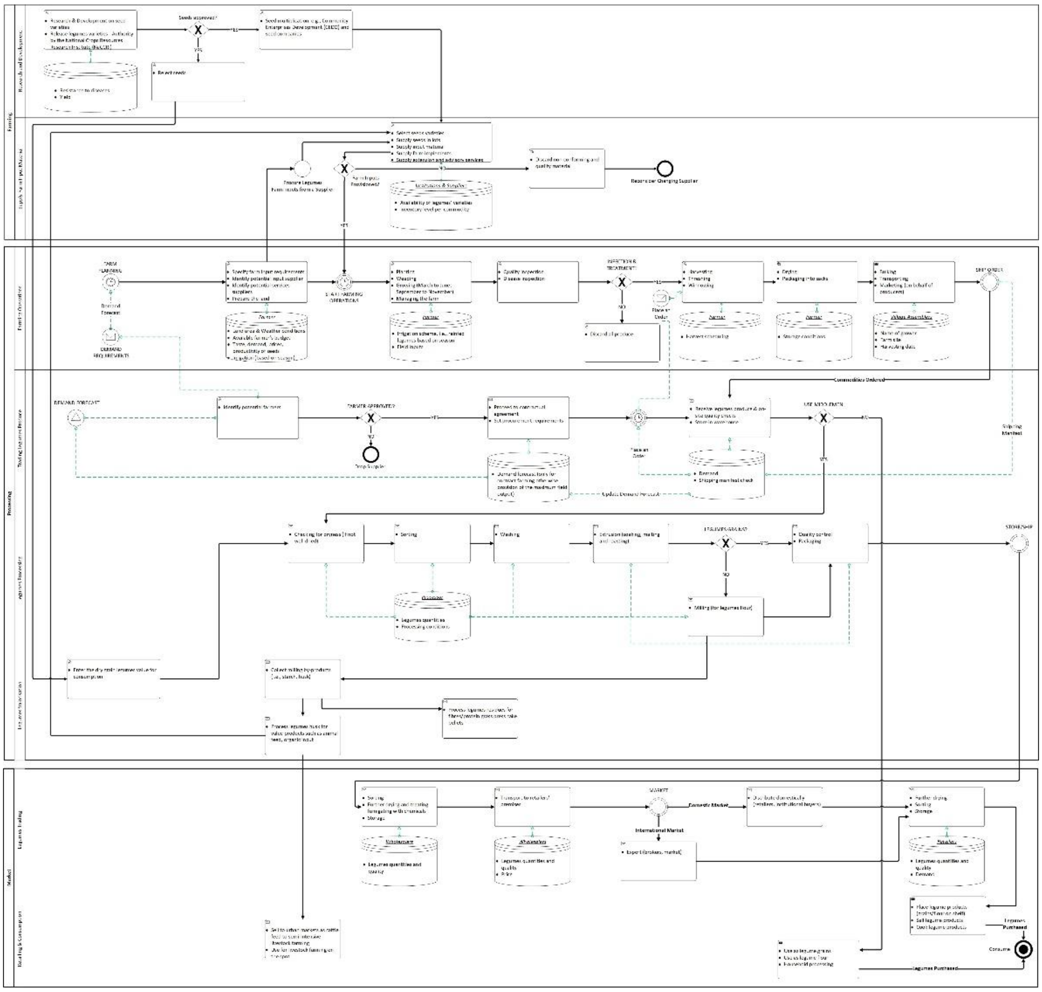


Figure 18: Initial draft map – Cassava supply network system map – Uganda.