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Liquid-gas biofuel supply chain development as a substitute fuel for transportation, electricity and clean cooking in Guinea

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Dedication

I dedicate this thesis to my family, particularly my father Dr Cécé KPOHOMOU, for his constant encouragement throughout my studies.

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Firstly, I would like to express my sincere gratitude to WASCAL and BMFTR for awarding me this scholarship and for all the knowledge and experience I have gained throughout my studies.

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Declaration

I declare that this research was undertaken by me and was conducted accurately, ethically and the conclusions arrived at are a true reflection of my findings and all data generated by me have been appropriately cited.

Abstract

This thesis evaluates the feasibility of integrating sustainable alternative bioenergy into Guinea's energy system to support both short and long-term development goals. The study examined crop residues and municipal solid waste to assess the potential for producing biohydrogen from rice, cassava, millet, and municipal solid waste, as well as bioethanol from sugarcane, pineapple, banana, and maize. This study also included biodiesel production from palm oil fruit and groundnut. Data from the Food and Agriculture Organization, covering the period from 2015 to 2023, were used to estimate the theoretical potential from municipal solid waste and crop residues. These estimates helped determine the potential yields of biomethane and electricity, using Buswell's equation for biogas production, and then evaluating the potential for biohydrogen via Steam Methane Reforming, bioethanol through fermentation, and biodiesel via transesterification. The technical potential for electricity generation from these biofuels was calculated based on their conversion efficiencies. Guinea could potentially generate 7.14 TWh of bioelectricity, supply 10,276,322 GJ of heat to cement and steel factories, provide 42,818 tons of biohydrogen for powering cars and buses, and produce an additional 2,086,282 barrels of bioethanol, 50% of which would be used for transportation and 20% for electricity generation, alongside producing 12,765,905 barrels of biodiesel mainly for transportation and electricity needs. Three scenarios were developed, each focusing on biohydrogen, bioethanol, and biodiesel, to explore production, distribution, feedstock collection, and challenges. This study provides a detailed assessment of the technical potential for bioenergy production from crop residues and municipal solid waste in Guinea. This study has identified challenges and proposed scenarios for establishing a sustainable and efficient biofuel supply chain to improve Guinea's energy security.

Keywords:

- Supply chain development.
- Biofuel, biohydrogen, bioethanol, biodiesel, bioelectricity.
- substitute fuel.

Résumé

Cette thèse évalue la faisabilité d'intégrer une bioénergie alternative durable dans le système énergétique de la Guinée afin de soutenir les objectifs de développement à court et à long terme. L'étude a examiné les résidus de cultures et les déchets solides municipaux afin d'évaluer le potentiel de production de biohydrogène à partir du riz, du manioc, du millet et des déchets solides municipaux, ainsi que de bioéthanol à partir de la canne à sucre, de l'ananas, de la banane et du maïs. Cette étude a également porté sur la production de biodiesel à partir de fruits de palmier à huile et d'arachides. Les données de l'Organisation des Nations unies pour l'alimentation et l'agriculture couvrant la période 2015-2023 ont été utilisées pour estimer le potentiel théorique des déchets solides municipaux et des résidus de cultures. Ces estimations ont permis de déterminer les rendements potentiels de biométhane et d'électricité, en utilisant l'équation de Buswell pour la production de biogaz, puis en évaluant le potentiel de biohydrogène par reformage du méthane à la vapeur, de bioéthanol par fermentation et de biodiesel par transestérification. Le potentiel technique de production d'électricité à partir de ces biocarburants a été calculé sur la base de leurs rendements de conversion. La Guinée pourrait potentiellement produire 7,14 TWh de bioélectricité, fournir 10 276 322 GJ de chaleur aux cimenteries et aciéries, fournir 42 818 tonnes de biohydrogène pour alimenter les voitures et les bus, et produire 2 086 282 barils supplémentaires de bioéthanol, dont 50 % seraient utilisés pour le transport et 20 % pour la production d'électricité, tout en produisant 12 765 905 barils de biodiesel destinés principalement aux besoins en transport et en électricité. Trois scénarios ont été élaborés, chacun axé sur le biohydrogène, le bioéthanol et le biodiesel, afin d'étudier la production, la distribution, la collecte des matières premières et les défis à relever. Cette étude fournit une évaluation détaillée du potentiel technique de production de bioénergie à partir des résidus de cultures et des déchets solides municipaux en Guinée. Elle a identifié les défis à relever et proposé des scénarios pour mettre en place une chaîne d'approvisionnement en biocarburants durable et efficace afin d'améliorer la sécurité énergétique de la Guinée.

Mots-clés : Développement de la chaîne d’approvisionnement, biocarburant, biohydrogène, bioéthanol et biodiesel, carburant de substitution.

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List of abbreviations

greenhouse gas	GHG
European commission	EU
United State of America	USA
National Institute of Statistics	INS
Nationally Determined Contribution	NDC
Liquefied Petroleum Gas	LPG
Food and Agriculture Organization	FAO
Millijoule per kilogram	MJ/kg
Methane	CH_4
Carbon dioxide	CO_2
Water	H_2O
The Guinea National Bioenergy Action Plan	PANBE
Economic Community of West African States	ECOWAS
biological biogas upgrading	BBU
steam methane reforming	SMR
The Minimum Support Price	MSP
Bureau of Indian Standards	BIS
joint ventures	JVs
Oil Marketing Companies	OMCs
Ministry of Petroleum and Natural Gas	MoPNG
The American Society for Testing and Materials	ASTM
Kelvin	K
Mercure	mm Hg,
microbial fuel cells	MFCs
International Renewable Energy Agency	IRENA
foreign direct investment	FDI
a National Biofuel Steering Committee	NBSC

National Bio-fuel Coordination Committee	NBCC
Kilo watt / hours	kWh
Mega watt	MW
volatile solids	VS
chemical oxygen demand	COD
Hydrogen Potential	pH
biochemical oxygen demand	BOD
Cellulose content	(C)
Glucose hydrolysis efficiency	(Hc)
Fermentation efficiency	(Fc)
Hemicellulose content	(H)
Xylose hydrolysis efficiency	(Hh)
Residue-to-Product Ratio	RPR
Total Theoretical Crop Residue Potential	TTCRP
Total Theoretical Municipal Solid Waste Potential	TTMSWP
Annual Crop Production	ACP
Fermentation efficiency	(Fh)
Theoretical Crop Residue Potential	TCRP
Municipal Solid Waste	MSW
Theoretical Municipal Solid Waste Potential	TMSWP
Organic Fraction of Municipal Solid Waste	OFMWS
Annual Municipal Solid Waste	AMSW
Sustainability Factor	SF
standard temperature and pressure	STP
Starch content	(S)
Starch hydrolysis	(Hs)
Fermentation efficiency	(Fs)
The confirmed number of residues	(Ub)
Ethanol conversion factor	Econversion
Ethanol yield from cellulose	E Cellulose
Ethanol yield from hemicellulose	E Hemicellulose
Ethanol yield from Starch:	E Starch
Feedstock	F
Customers	C
Feedstock logistics	FL
Others (expositions)	O
Biofuel production	BP
Station	S
Industries	I
Cars	C
Buses	B
Anaerobic digestion	AD
Calculated value	**Aaa**
No calculated value	**Aaa**
Total	**Aaa**

Introduction

Background

The decline in fossil energy poses a significant challenge to the ecosystem [1]. The global energy demand continues to grow across all sectors, including transport, fueled by technological advances and ongoing population growth. However, fossil fuels, which remain the primary source of non-renewable energy in this sector, significantly contribute to global warming through the release of large amounts of CO_2.[2] More than 25% of greenhouse gas (GHG) emissions in the EU and 28% in the USA come from the transport sector[3 - 4]. In 2020, 20% of global CO_2 emissions came from the transport sector [5]. In this context, biofuels appear to be a promising alternative that can reduce these emissions and mitigate the effects of climate change. Produced through various conversion processes, whether biochemical or thermochemical, they are gradually establishing themselves in the energy market alongside fossil fuels, nuclear energy, and other renewable sources[6].

Guinea, a country with an area of 245,857 km^2, is located on the west coast of Africa. It borders Senegal and Mali to the north, Sierra Leone and Liberia to the south, Côte d'Ivoire and Mali to the east, and the Atlantic Ocean and Guinea-Bissau to the west [7]. The current population of Guinea is 15,029,439 as of Monday, April 21, 2025, based on Worldometer's elaboration of the latest United Nations data, equivalent to 0.18% of the total world population. The median age in Guinea is 18.3 years [8]. According to the National Institute of Statistics (INS), 34.9% of the population lives in urban areas and 65.1% lives in rural areas. [9]. Significant commitments have been made to its updated Nationally Determined Contribution (NDC), aiming to modernize the wood energy sector and shift towards renewable energy solutions for heating needs. Currently, about 75% of the country's energy consumption is derived from forest resources, and the government aims to reduce average per capita fuelwood consumption by 50% by 2030, while keeping total consumption stable despite population growth. Strategies to reach this goal include improving energy efficiency, reducing carbonization losses, and replacing biomass with butane gas. The government also plans to encourage local biofuel production, which could reduce CO_2 emissions by approximately 257 kt annually by 2030. However, the implementation of these bioenergy solutions is estimated to require a significant investment of around USD 1 billion by 2030, reflecting the financial commitment necessary to address Guinea's energy challenges and improve the sector's sustainability while mitigating the impacts of climate change [10].

The Guinea National Bioenergy Action Plan (PANBE) aims to enhance access to sustainable cooking energy and biomass electricity and address socio-economic challenges while minimizing health risks and improving agricultural productivity and the environment[7]. Following the adoption of the ECOWAS bioenergy policy in 2017, Guinea is developing its national strategy with stakeholder involvement under the Ministry of Energy. The plan outlines objectives for bioenergy, including the promotion of improved cooking stoves, biogas adoption, and alternative fuels like LPG By 2030, specific targets have been set for the population's use of biofuels, biomass energy production, and overall energy efficiency improvements, addressing the need to reduce traditional wood fuel consumption and enhance energy sustainability in rural areas. The plan emphasizes a multi-sectoral approach and the importance of effective regulatory frameworks and assessments to ensure the successful implementation and sustainability of bioenergy projects in the country[7].

Problem statement

Despite some successes, such as the Ministry of Environment's biogas project, which reached 80% of its target and installed a 30 m3 semi-industrial biodigester in Boffa to generate Electricity with a 10.5 KVA generator highlights that Guinea's biomass potential remains largely untapped. Currently, biomass makes up 77% of the national energy mix, followed by imported hydrocarbons (20.98%) and hydropower (2%)[7]. The main challenges facing the development of bioenergy in Guinea include the absence of a national strategy and policy to optimize biomass collection and use, as well as the lack of legal frameworks and regulations to guide interventions in the sector. The absence of attractive taxation and support measures for industry players and the lack of incentives for private operators also hinder the growth of the sector [7]. However, the gap between potential and actual use highlights significant challenges in the bioenergy sector. The key barriers include the lack of bio-carbon production projects, insufficient microfinance support for bioenergy initiatives, and the absence of a comprehensive national bioenergy policy[7].

Research hypotheses

- Exploiting Guinea's biomass potential can help reduce energy dependency and improve national energy security through sustainable bioenergy production.

Objectives

- To assess the potential of crop residues and municipal solid waste for Guinea.
- To determine the biohydrogen, bioethanol, biodiesel and biogas generation capacity of the selected feedstock.
- Design a biohydrogen, bioethanol, biodiesel and biogas distribution and consumption chain in Guinea.
- To identify the challenges and potential solutions for establishing biohydrogen and biomethane supply chains in Guinea.

Specific objectives

- What is the potential of various crop residues and municipal solid waste in Guinea?
- What is the availability, potential, and logistical feasibility of different feedstocks in Guinea?
- Is the production of biohydrogen and biomethane feasible in Guinea?

Structure of the Thesis

This thesis is structured in three main parts to address the research objectives: first, to assess the biomass potential in each region of Guinea by determining the availability, potential, and logistical feasibility of various feedstocks, including agricultural residues and municipal solid waste, through the collection and analysis of secondary data from relevant government entities, agricultural sectors, and FAO data.

second, to determine the production capacity of biohydrogen Bioethanol biodiesel and biomethane from the selected feedstocks by assessing whether their production is technically and economically viable in the Guinean context; and finally, to design a comprehensive biohydrogen and biomethane distribution and consumption chain that identifies key challenges and proposes strategic solutions to establish sustainable supply chains, thus offering concrete recommendations to integrate these biofuels into Guinea's national energy strategy and support the country's overall energy transition.

Chapter 1: Literature review

Supply chain development

‘’ A supply chain is a network of facilities and distribution options that performs the functions of procurement of materials, transformation of these materials into intermediate and finished products, and the distribution of these finished products to customers. Supply chain exists in both service and manufacturing organizations, although the complexity of the chain may greatly vary from industry to industry and firm to firm’’ [11].

According to [12]Converting waste into biohydrogen involves a complex supply chain that requires careful planning. For this chain to function effectively, it is crucial to select the appropriate methods for collecting the waste, converting it into biohydrogen, and delivering the hydrogen energy where it is needed. These decisions depend on factors such as resource availability, technological capability, and market demand. By considering these aspects, the design of the supply chain from waste to biohydrogen is illustrated in Figure 9. The supply chain for converting waste to biohydrogen includes five key steps. Initially, waste is collected from sources like farms and food processing facilities before being stored and transported to the hydrogen production plant. Waste located nearby can be delivered directly, while waste that is farther away is first stored and transported in bulk later. In the third step, the waste undergoes processing through methods such as dark or light fermentation to produce biohydrogen. Once generated, hydrogen is securely stored and transported in solid, liquid, or gaseous states, ensuring both efficiency and cost-effectiveness. Finally, hydrogen reaches the market, where it can be utilized for fueling hydrogen vehicles, generating electricity, or supporting fuel cell production [12]. Figure 9 presents the typical graphical representation of a waste biomass supply chain.

Biofuel

Biofuels are energy vectors made from biomass. These fuels which can be liquid, solid or gaseous, such as wood pellets, biogas, bioethanol and biodiesel, are used to deliver renewable energy services. Various feedstocks can be used through multiple conversion processes to produce biofuels, like sugary and starchy crops, lignocellulosic biomass, oil from crops, organic waste and algal biomass [13].

Overview of Biohydrogen and Biomethane

Hydrogen is a valuable alternative to fossil fuels because it offers a higher energy output 142 MJ/kg, and does not release harmful emissions when it burns [14]. Biomethane comes from the purification of biogas, a type of renewable gas produced by anaerobic digestion. This microbial fermentation process uses bacteria in an oxygen-free environment to break down complex molecules of organic matter into simpler molecules [15]. The anaerobic digestion of biomass typically produces biogas with a CH_4 making up 50 – 70%, and carbon dioxide, which can be between 30-50% [12-14];[17];[19] while CO_2 (35–40%) and CH_4 (55–60%), according to [16]. It can be improved to consist of over 90% methane [18], which offers a higher energy content and can be utilized as a fuel for vehicles or fed into natural gas networks [17]. Microbial communities in anaerobic digesters include hydrogenotrophic methanogens, which utilize H_2 as a reducing element to transform CO_2 into CH_4 [19]. Introducing H_2 into these digesters has been demonstrated to enhance the overall CH_4 production and achieve CH_4 concentrations exceeding 90%[13],[15] [20] Losses of CO_2 to the environment through commercial upgrading technologies (such as scrubbing, pressure swing adsorption, and membrane separation) can be reduced through biological biogas upgrading (BBU), by converting CO_2 into CH_4 [21]

According to [22]'' To produce hydrogen and biomethane, substantial amounts of energy are required, but renewable energy sources can supply these needs, depending on the technology used and the efficiency of the process. Hydrogen can be produced primarily through steam methane reforming (SMR) and electrolysis. Steam methane reforming (SMR) is the predominant technique; still, it is energy-intensive and dependent on fossil fuels, specifically natural gas. It generally necessitates 4–6 MJ of energy to produce 1 kg of hydrogen [22]. The electrolysis technique uses electricity to dissociate water into hydrogen and oxygen. The energy consumption for electrolysis fluctuates based on the electrolyzer's performance, often necessitating approximately 50–55 kWh of electricity to generate 1 kg of hydrogen. This process can be decarbonized using various sources, such as wind or solar energy, making it an appealing choice for sustainable hydrogen production. The feasibility of renewable energy suggests that utilizing renewable electricity, such as wind or solar, for electrolysis can significantly mitigate environmental impacts. Solar and wind energy generation possess energy densities compatible with hydrogen production. A 1 MW solar farm can generate around 30–35 kg of hydrogen daily, based on a 50 kWh/kg consumption [22]. Biomethane is produced predominantly via anaerobic digestion of organic substances, such as agricultural byproducts, food refuse, or sewage sludge. The procedure entails decomposing organic material to generate biogas, which is further refined to biomethane by eliminating contaminants. The energy necessary for biomethane synthesis fluctuates based on the feedstock and the upgrading procedure. Anaerobic digestion typically requires approximately 1.5–3 kWh per cubic meter of biogas, with biomethane upgrading necessitating an extra 0.2–0.5 kWh per cubic meter of biogas. Both hydrogen and biomethane generate substantial energy, but renewable energy sources such as sun, wind, and biomass can provide the requisite inputs. Hydrogen production through electrolysis can be entirely fueled by renewable sources, rendering it an environmentally friendly option. However, biomethane production is intrinsically more sustainable as it depends on organic waste and can utilize biogas for energy needs '' [22] .

Biohydrogen can be obtained through microbial fermentation of organic materials, bio-photolysis of water by microalgae, or microbial electrolysis [23]. Biohydrogen production through biological techniques can be either light-dependent or light-independent [24].

The selection of organic solid waste suitable for biohydrogen production depends on biodegradability, cost, availability, volatile solids (VS), biochemical oxygen demand (BOD), chemical oxygen demand (COD), the presence of inhibitors, and nutrient content [23]. Various factors, such as the pretreatment technique, pH level, temperature, pressure, substrate concentration, bioconversion technology, and microbial strain, influence biohydrogen production [25].

Production processes

The process of biohydrogen through fermentation is categorized into two methods depending on the bacteria's requirement for light: (a) dark fermentation and (b) photofermentation [26]. Dark fermentation is a process that occurs without light and generates hydrogen, organic acids, and alcohols biologically from organic waste materials rich in carbohydrates, utilizing microbes that thrive in anaerobic or optionally anaerobic conditions [26]. While photofermentation depends on light for photo-heterotrophic bacteria to transform organic acids (like lactic, butyric, and acetic acids) into carbon dioxide and hydrogen under anaerobic circumstances [27]. The result of anaerobic digestion is a broken-down organic matter called digestate, which can potentially be used as an organic fertilizer,

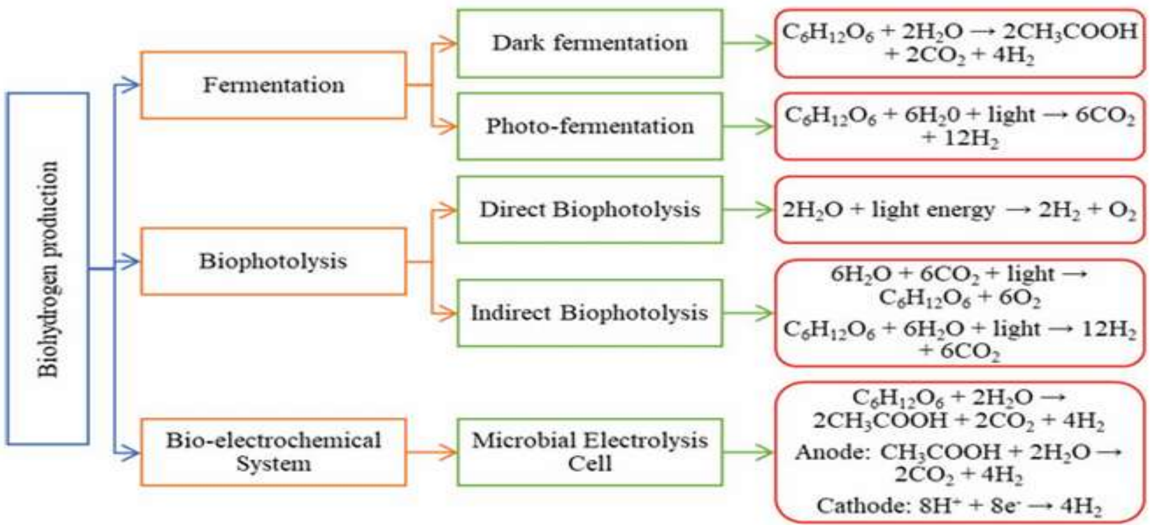

Figure 1: Overview of the routes of biohydrogen production processes [30].

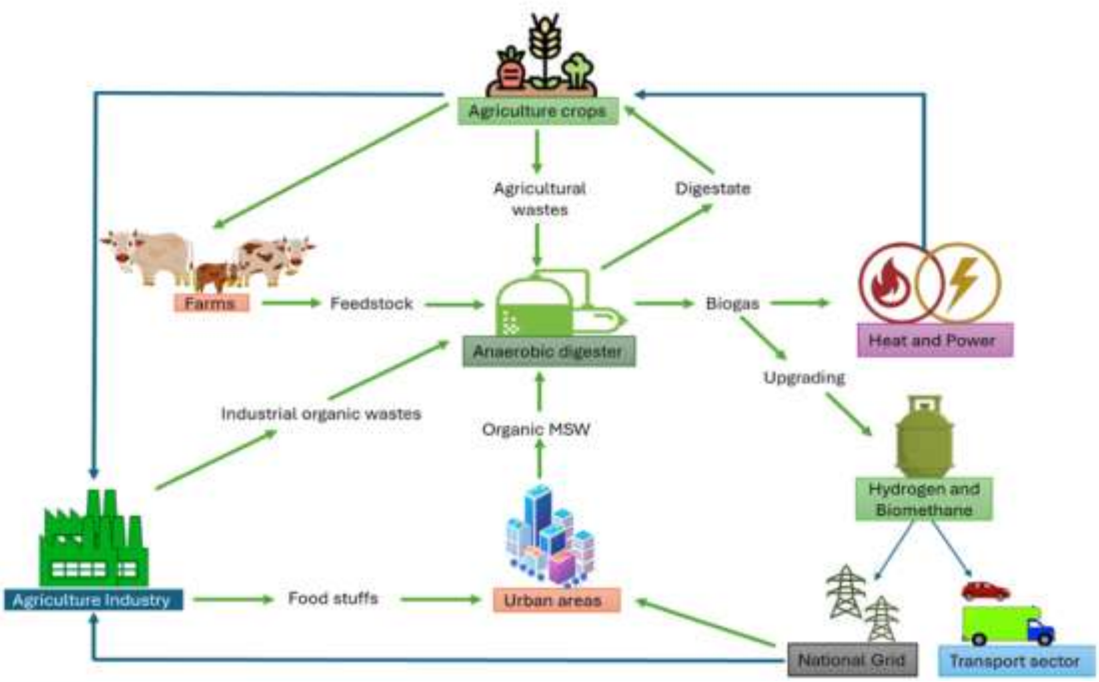

Figure 2: Hydrogen and biomethane chain with various organic waste processes [22].

Biodiesel

The American Society for Testing and Materials (ASTM) defined biodiesel as a monoalkyl ester of fatty acids or fatty acid (m)ethyl ester [29], a clear, golden-yellow liquid with a viscosity similar to petrodiesel. Unlike petrodiesel, it is non-flammable and non-explosive with a flash point of 423 K versus 337 K. Biodiesel is also biodegradable, non-toxic, and significantly reduces toxic emissions when burned as a fuel [29].

Derived from renewable feedstocks, such as vegetable oils. The term ''bio'' indicates the biological source of biodiesel, in contrast with conventional diesel [30].

Table 1: Technical properties of biodiesel [29]

Common name	Biodiesel(bio-diesel)
Common chemical name	Fatty acid (m)ethyl ester
Chemical formula range	C14-C24 methyl ester or C15-25H28-48O2
Kinematic viscosity range (mm2/s at 313 k)	3.3 – 5.2
Density range (kg/m3, at 288 k)	860 – 894
Boiling point range (k)	>475
Flash point range (k)	420 – 450
Distillation range(k)	470-600
Vapor pressure (mm Hg, at 295 k)	<5
Solubility in water	Insoluble in water
Physical appearance	Light to dark yellow, clear liquid
Odor	Light musty/soapy odor

Triacylglycerols, which are found in vegetable oils and fats, are esters of long-chain carboxylic acids and glycerol. These acids can be converted into methyl esters through transesterification. Parameters influencing methyl ester formation include reaction temperature, pressure, molar ratio, water content, and free fatty acid content. Increasing the reaction temperature was found to favorably influence the ester conversion yield. The alkyl ester yield increases as the oil-to-alcohol molar ratio increases [31], [32].

The most practical and common way of producing biodiesel is by transesterification (also called methanolysis)[33], Which is a catalyzed reaction of vegetable oil in the presence of alcohol to yield biodiesel and glycerol[32].

Transesterification (Equation 1) consists of several consecutive, reversible reactions. It proceeds with or without a catalyst by using primary or secondary monohydric aliphatic alcohols having 1–8 carbon atoms. Among the alcohols, methanol and ethanol are used most frequently. Ethanol is a preferred alcohol in the transesterification process compared to methanol because it is derived from agricultural products and is renewable and biologically less objectionable in the environment [34]

Equation 1 : Transesterification

$$\begin{array}{l} CH_2\text{-}OOC\text{-}R_1 \\ | \\ CH\text{-}OOC\text{-}R_2 \\ | \\ CH_2\text{-}OOC\text{-}R_3 \end{array} \quad + \quad 3ROH \quad \underset{}{\overset{\text{Catalyst}}{\rightleftharpoons}} \quad \begin{array}{l} R_1\text{-}COO\text{-}R \\ \\ R_2\text{-}COO\text{-}R \\ \\ R_3\text{-}COO\text{-}R \end{array} \quad + \quad \begin{array}{l} CH_2\text{-}OH \\ | \\ CH\text{-}OH \\ | \\ CH_2\text{-}OH \end{array}$$

Triglyceride Alcohol Esters Glycerol

Bioethanol

Bioethanol is a renewable biofuel liquid produced through the microbial fermentation of sugars, starches, or lignocellulosic biomass(Lignocellulosic biomass consists of fiber strands of cellulose connected by hydrogen bonds [36-37] derived from agricultural or food waste materials[37]. It is used as an alternative fuel and as an additive in various products, including disinfectants, personal care products, pharmaceuticals, and chemicals[37].

It can be found in corn, sorghum, barley, and grain peels; sugarcane bagasse; brewer's residues; grasses; stems; husks; shells; sawdust; and straw. It is practically present in all plants [38]. Compared to petroleum, the energy produced from bioethanol is lower, at about 68% [39]. Burning ethanol releases fewer hazardous substances and can reduce carbon emissions, which will be higher than 80% [35].

The process of producing bioethanol from cellulosic feedstock involves three main steps: pretreatment, hydrolysis, and fermentation(Figure 3). Pretreatment is crucial before hydrolysis and fermentation because it breaks down polysaccharides into soluble sugars, enhancing the accessibility of chemicals, enzymes, and microorganisms. This enables the subsequent steps to work effectively [40].

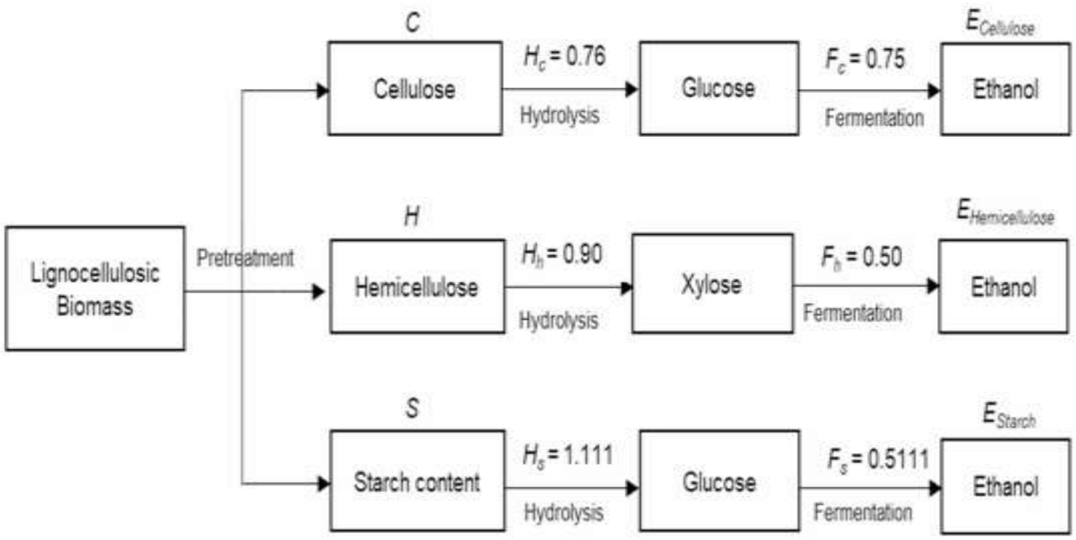

Figure 3: Bioethanol conversion pathway from lignocellulosic biomass and the conversion factors used in the stoichiometric calculation [41]

Bioelectricity

It is a form of bioenergy obtained from renewable feedstocks, such as agricultural and forestry residues, food waste, and municipal waste via methods including direct combustion, thermochemical conversion, gasification and microbial fuel cells(MFCs)[42]

Waste

Waste refers to useless materials or byproducts discharged from biodegradable processes, plants, or animals [43].They can be grouped into different categories, such as: solid, liquid, organic, recyclable, and hazardous [44]. Nutritive components such as lipids, proteins, carbohydrates, and minerals are found in organic solid waste, making them reusable as feedstock for the production of biobased products [45].

Type of solid waste

According to [46]Solid waste is categorized into various groups based on its source and properties. Because of its characteristics, solid waste can be classified as organic, inorganic, biodegradable, non-biodegradable, hazardous, or non-hazardous [47]. There are several main types of solid waste.

- ***Agricultural waste***

Rice straw and husks, cassava peels, millet stalk, sugar cane bagasse and leaves, banana peels and leaves, pineapple peels, maize stalk, husk and cob, palm fruit fibers and shell and groundnut shell and straw. These crop residues are considered waste, including both vegetable and fruit waste [48]. According to [49]Agricultural waste consists of materials generated from farm fields. It primarily consists of 35–50% cellulose, 25–30% hemicellulose, and 25–30% lignin.

- ***Municipal waste***

Municipal waste refers to the waste materials collected from households, institutions, and commercial activities. The waste composition is affected by seasonal variation, economic status, and the social activities of people [50]. The calorific value of municipal waste is an important indicator that determines its suitability for bioenergy production. A higher calorie content in solid waste is advantageous for bioenergy generation [51].

- ***Industrial waste***

Industrial waste is material produced before, during, or after production processes [46]. These wastes have great potential as raw materials for producing valuable products, such as biofuels, organic acids, and enzymes [43].

Guinea's energy landscape

Guinea’s energy consumption comes from two sources, namely renewable and non-renewable energy. According to IRENA in 2021, the total energy supply reached 185,967TJ, with 67% from renewable sources, while oil at 33% of non-renewable. Once break down that 67%, the traditional bioenergy dominated the 92% and hydro/marine 8% [52]

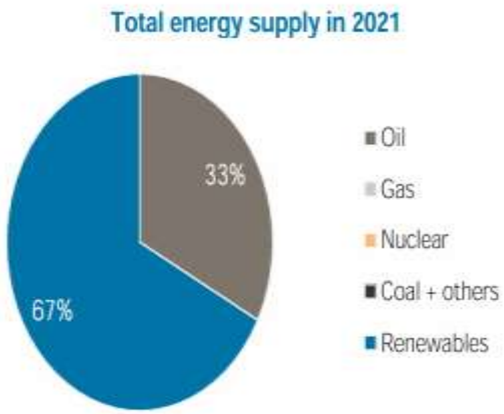

Figure 4: Total energy supply 2021[52]

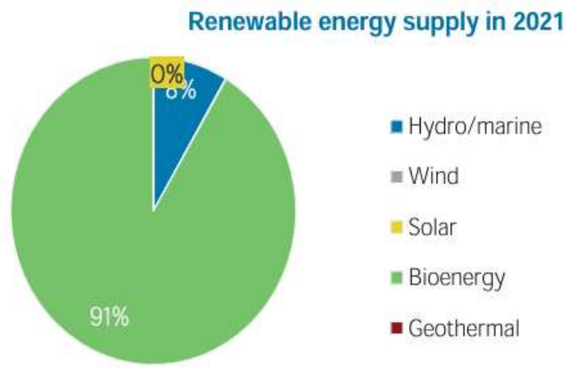

Figure 5: Renewable energy supply in 2021[52]

Concerning the renewable energy consumption, 79% of the total energy use was based on the household sector, the industry sector with 4% while the other 17% [52].

Table 2: renewable energy consumption [51]

Consumption by sector (TJ)	*2016*	*2021*
Industry	2663	5295
Transport	0	0
Household	103 349	106 537
other	14 912	22 872

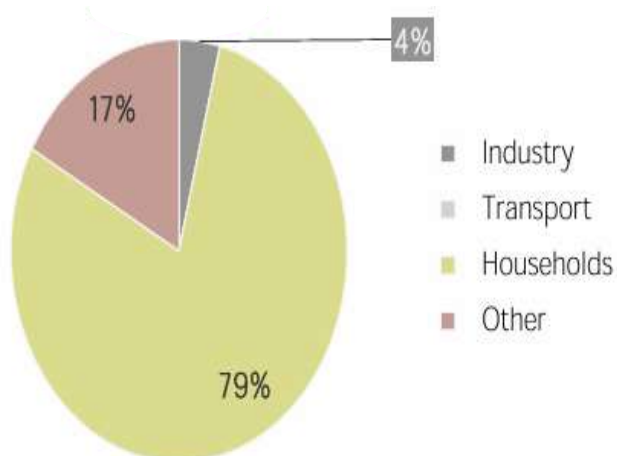

Figure 6: Renewable energy consumption in 2021[52]

Between 2015 and 2022, Guinea gradually increased its electricity production, as shown in Figure 7 with renewable energy, particularly hydropower, playing an essential role in this improvement even though the fossil fuels has also increased slightly

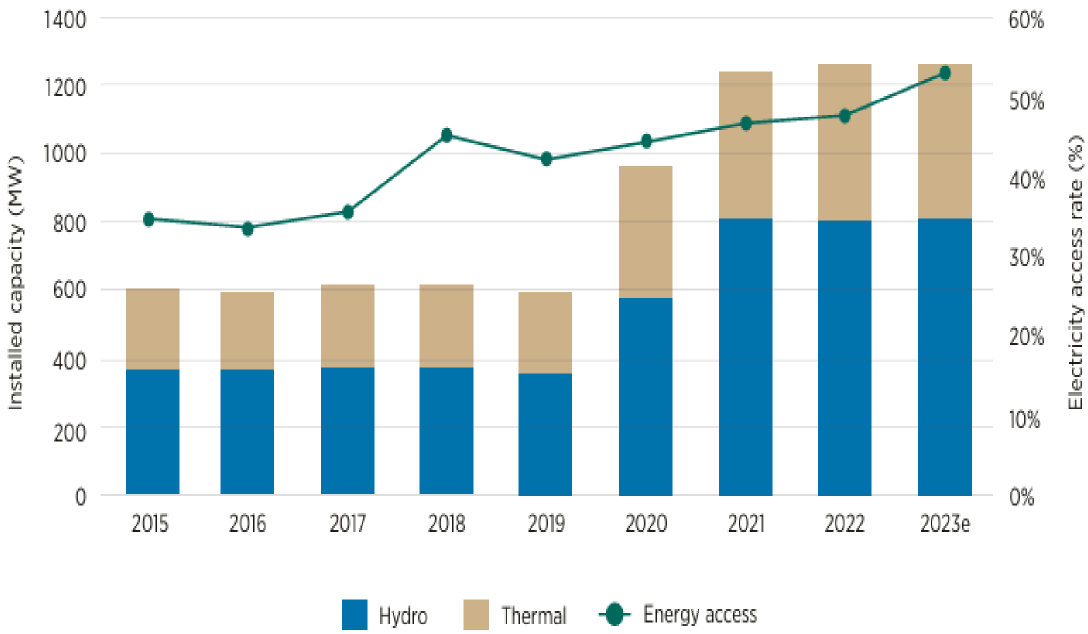

Figure 7: Installed capacity and electricity access rate in Guinea[53]

Concerning the delivery of hydrocarbons by product, here are the statistics from 2015 to 2022 in volume at 15°c

Table 3: Delivery of hydrocarbons by product (in volume at 15°C) in thousands of liters[9]

Energy products	*2015*	*2016*	*2017*	*2018*	*2019*	*2020*	*2021*	*2022*
Gasoline	398 761	Nd	570926	577013	599270	636560	670736	673537
diesel	488 736	Nd	1141650	681302	781617	820671	817334	805132
Petroleum	2 388	Nd	1939	994	1383	352	Nd	Nd
HFO	75 071	nd	340586	220764	241078	219809	168616	169988
jet	11085	nd	22917	20945	35709	21027	38296	41354

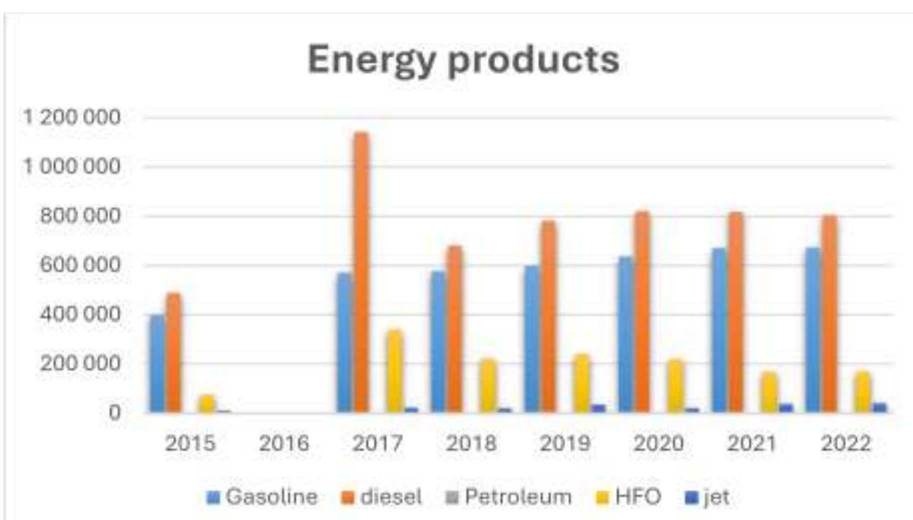

Figure 8: Energy products

India’s Biofuel policy

According to [54] ‘’India's Biofuel Policy aims to strengthen the country’s energy security by promoting the use of renewable energy resources to supplement motor transport fuels. A 20% target for blending biofuel, including biodiesel and bioethanol, is proposed by the end of the 12th Five-Year Plan (fiscal 2012/13 through fiscal 2016/17). The Minimum Support Price (MSP) mechanism for inedible oilseeds aims to ensure a fair price for oilseed growers but is subject to periodic revisions. Cabinet decisions state that ethanol produced from non-food feedstocks such as cellulosic and ligno-cellulosic materials, including through petrochemical routes may be procured, provided it meets the relevant Bureau of Indian Standards (BIS) standards. On January 16, 2015, the Indian Union Cabinet decided to amend the national bio-fuel policy to facilitate consumers of diesel in purchasing biodiesel directly from private manufacturers, their authorized dealers, and joint ventures (JVs) with Oil Marketing Companies (OMCs) authorized by the Ministry of Petroleum and Natural Gas (MoPNG). The price of biodiesel will now be determined by the market. If needed, the government proposes to establish a National Bio-fuel Fund to offer financial incentives, including subsidies and grants, for developing new and second-generation feedstocks, advancing technologies and conversion processes, and establishing production units based on these feedstocks [54].

Thrust for innovation, multi-institutional, indigenous, and time-bound research and development on bio-fuel feedstock, including the utilization of indigenous biomass feedstock, and production of second-generation biofuels. Bring biofuels under the ambit of “Declared Goods” by the GoI to ensure their unrestricted interstate and intrastate movement. Except for a concessional excise duty of 16 percent on bioethanol, no other central taxes or duties are proposed to be levied on biodiesel and bioethanol. Bio-fuel technologies and projects will be allowed 100 percent foreign equity through automatic approval to attract foreign direct investment (FDI), provided the biofuel is for domestic use only and not for export. Plantations of inedible oil-bearing plants will not be open for FDI participation. The establishment of a National Biofuel Steering Committee (NBSC) under the Prime Minister will provide policy guidelines. The National Bio-fuel Policy proposes establishing a National Bio-fuel Coordination Committee (NBCC) led by the Prime Minister.

Various state governments will work closely with respective research institutions, forestry departments, universities, and other partners to develop and promote biofuel programs within their states. Several states have drafted policies and established institutions to facilitate the use of biofuels'' [54].

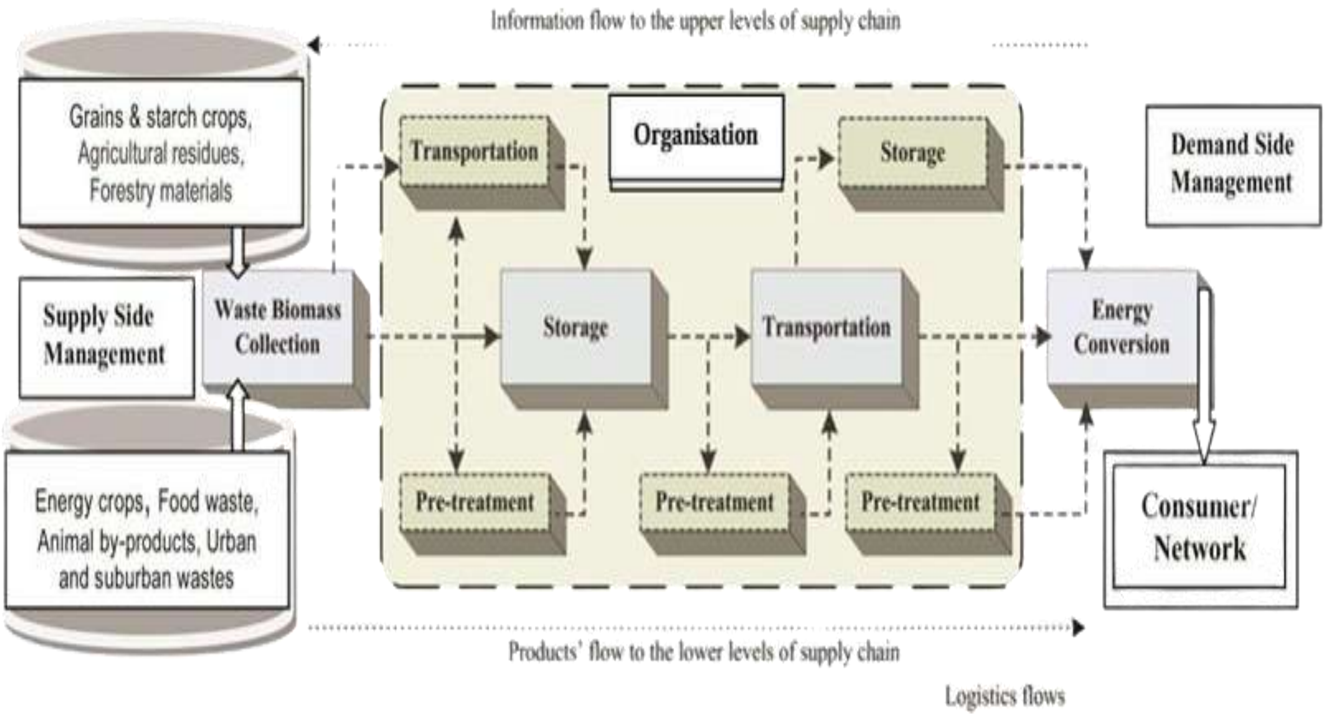

Figure 9: Typical graph of a waste biomass supply chain [54]

Chapter 2: Materials and Methods

Study site and feedstock

The Republic of Guinea, with an area of 245,857 km^2, has a population of about fifteen million [8]. It is characterized by four main ecoclimatic zones: Lower Guinea, Middle Guinea, Upper Guinea and Forest Guinea. The hydrographic network is very dense, with 1166 rivers divided into 23 basins, 14 of which are international. Administratively, the country is divided into 7 regions (Boké, Kindia, Mamou, Faranah, Kankan, Labé, Nzérékoré) and one governorate (Conakry), 33 urban communes and 304 rural development communes [10]. **Error! Reference source not found.** shows the study site highlighting the seven administrative regions. Agriculture is the country's largest employer, providing income to 57% of rural households and employment to 52% of the labour force, and plays a key role in poverty reduction and rural development [55]. This study focuses on municipal solid waste and the crop residue generated by the whole country,

Figure 10:Study site with the major crop produced

In this study, crop residues and OFMSW were utilized. The feedstocks listed in Table 4, along with the types of residues considered for the research, were categorized into three groups based on their high oil and fat content; oil palm fruit and groundnut were paired for biodiesel production capacity (Group 1). Cassava, rice, millet, and OFMSW, classified by moisture content (MC) and organic matter, were used to assess biohydrogen potential (Group 2). Meanwhile, sugarcane, banana, pineapple, and maize, characterized by high sugar content and starch, were used for bioethanol production capacity (Group 3). Due to the absence of data on their annual production in each administrative region, the generation capacity was estimated for the entire country.

Table 4: List of feedstocks used for this research

		SELECTED FEEDSTOCK
N°	FEEDSTOCK	SPECIFIED TYPE
1	Rice	Straw
		Husk
2	Maize	Stalks
		Husk
		Cob
3	Cassava	peelings
4	Groundnut	Straw
		Shells
5	Millet	Stalks
6	Oil Palm Fruit	Fibers
		Kernel Shells
7	Banana	peels
		leaves
8	Pineapple	Peels
9	Sugar Cane	Leaves
		Bagasse

Methods

The methodology of this research is divided into three main steps. Firstly, the primary and secondary data are collected and compiled, secondly, the calculations, and thirdly, the results are represented.

Secondary Data Collection

The data collected in *Table 5* is collected from FAO(Food and Agriculture Organization).

Table 5:The crop production t/year (Source : (FAO, 2023)

crops	2017	2018	2019	2020	2021	2022	2023
Bananas	225265,9	229674,5	234028,5	233029,1	235159,2	234072,2	234086,8
Cassava	1751719,0	1895396,0	2145484,0	2523455,0	2743166,0	2978621,4	3217565,3
Maizes	817286,0	818544,0	773452,0	792509,0	798327,0	814706,3	982000,0
Groundnut	695622,0	770105,0	738721,0	801197,0	907137,0	1025144,1	1000000,0
Millet	241714,0	214747,0	210303,0	213420,0	216579,0	219784,0	220000,0
Oil palm fruit	853235,7	860445,7	864000,0	887500,0	883000,0	886000,0	886478,2
Pineaple	110637,3	84690,2	64057,0	66428,0	68887,0	71437,0	74174,7
Plantain	475221,4	473766,0	531122,0	575205,0	619288,0	663371,0	706875,3
Rice	2197907,0	2339747,0	2385929,0	2459015,0	2839900,0	3158100,0	3534800,0
Sugarcane	308555,0	311691,3	314435,6	318939,6	319641,8	321783,9	324026,1

Residue to Product Ratio (RPR)

According to[56] and [57] the Residue-to-Product Ratio (RPR) is the ratio of crop residue generated per unit of primary crop. Mathematically, the ratio of the above-ground harvestable biomass residue [58] It is used to calculate the theoretical potential of crop residues by multiplying it by the annual production potential [57]. The Table 6 presents the RPR values of the selected feedstock research.

Table 6: The residue-to-product ratio of the selected feedstock

CROP RESIDUE		RPR	REFERENCES
Rice	Husks	0.26	[59]
	Straw	1.66	[60]
Maize	Stalks	1.59	[60]
	Husk	0.20	[60]
	Cob	0.29	[60]
Cassava	peelings	0.25	[60]
Sugar Cane	Leaves	0.11	[60] [61]
	Bagasse	0.18	[60][61]
Millet	Stalks	1.83	[60]
Groundnut	Shells	0.37	[60]
	Straw	2.15	[60]
Oil Palm Fruit	Fibers	0.14	[60][61]

	Kernel shell	0.07	[60][61]
Banana	peels	0.25	[62]
	leaves	0.35	[63]
Pineapple	Peels	0.30	[64]

Ultimate and proximate Analysis

Table 7 The ultimate and proximate analysis of the selected feedstock

FEEDSTOCK		**Ultimate Analysis**					***Ref***	**Proximate Analysis**				***REF***
		C	**H**	**O**	**N**	**S**		**MC**	**VM**	**ASH**	**FC**	
Banana	Peels	35.65	6.19	45.94	1.94		[65]	11.56	88.02	9.28	2.7	[65]
	Leaves	38.57	6.44	43.49	2.45		[65]	6.67	83.35	9.05	7.60	[65]
Rice	Straw	39.98	2.45	52.61	4.43	0.53	[66]	10.8	66.89	7.56	14.57	[66]
	Husk	39.32	5.78	31.59	0.43	0.01	[67]	9.5	68.4	16.3	3.11	[68]
Maize	Stalks	49.27	6.55	42.62	1.56		[69]	5.70	76.15	5.70	12.45	[69]
	Husk	43.79	6.00	43.15	0.53		[70]	13.1	77.57	1.7	20.73	[71]
	Cob	44.81	5.93	45.03	0.53		[70]	11.7	69.5	2.9	15.9	[72]
Cassava	Peelings	54.15	8.38	34.56	2.82	0.09	[73]	10.67	79.23	3.55	14.53	[73]
Sugarcane	Bagasse	41.45	5.51	50.37	0.51	0.05	[74]		88.48	2.1	9.41	[74]
	Leaves	44.51	6.14	38.76	0.65		[75]	6.96	74.89	9.78	15.33	[75]
Millet	Straw	46.5	4.9	41.0	0.4	0.0	[76]	8.91	65.55	6.87	18.67	[77]
Groundnut	Shells	43.05	5.48	51.09	0.39		[78]	8.0	64.63	5.91	29.45	[79]
	Stalks	34.52	9.80	51.50	1.16		[80]	3.78	74.83	4.69	16.70	[80]
Oil Palm Fruit	Shell	48.06	6.38	34.10	1.27		[81]	10.23	85.11	3.24	1.42	[82]
	Fibers	39.90	5.40	48.88	2.01		[82]	11.10	80.08	7.90	1.01	[82]
Pineapple	Peels	43.40	5.47	42.03	8.77		[83]	2.51	71.01	8.02	18.47	[83]

OFMSW	47.03	6.75	32.7	2.58	[84]	60.08	20.29	-	-	[84]

Composition of selected feedstock

Table 8 The composition of the selected feedstock

CROP WASTE TYPES		***Cellulose(%)***	***Hemicellulose(%)***	***Lignin(%)***	***References***
Rice	Straw	44.3	33.5	20.4	[85]
	Husks	33.47	21.03	18.80	[86]
Maize	Stalks	34.2	28.1	21.7	[72]
	Husks	28.06	30.89	10.9	[71]
	Cob	28.7	39.3	19.6	[72]
Cassava	Peels	37.9	23.9	7.5	[87]
Groundnut	Shells	40.5	14.7	26.4	[88]
	Stalks	36.28	32.4	20.12	[80]
Millet	Straw	32.88	36.28	14.64	[77]
Oil palm fruit	Shell	33.4	14.4	46.3	[81]
	Fibers	28.3	36.6	35.1	[89]
Banana	Peels	9.9	41.38	8.9	[90]
	Leaves	35.58	23.46	10.58	[90]
Sugar cane	Leaves	32.4	26.1	17.1	[91]
	Bagasse	36.6	28.45	13.81	[92]
Pineapple	Peels	20.9	31.8	10.4	[93]

The crop residue and MSW theoretical potentials

The total theoretical potential of all the feedstocks was calculated annually as shown in Equation 2.

Equation 2: Total Theoretical potential

$$\textbf{Total Theoretical Potential} = \mathrm{TTMSWP} + \mathrm{TTCRP}$$

Theoretical Crop Residue Potential (TCRP)

The theoretical potential of crop residue can be calculated by multiplying the annual crop production time by the residue-to-product ratio, as demonstrated in Equation 3 below

Equation 3 The Theoretical Crop Residue Potential

$$\textbf{Theoretical Crop Residue Potential}(\textbf{TCRP}) = \text{ACP} \times \text{RPR}$$

For this research, the estimation of theoretical crop residue potential is conducted by using the annual crop production of the selected feedstock from the FAO in Table 5 , using Equation 3 with the data in Table 6, the values obtained are then summed to have the theoretical crop residue potential from 2017 to 2023

Theoretical Municipal Solid Waste Potential (TMSWP)

The theoretical potential of municipal solid waste is calculated by multiplying the estimated municipal solid waste generation by the Organic Fraction of the Municipal Solid Waste percentage for each respective year of the study site as demonstrated in Equation 4 below

Equation 4 The Theoretical Municipal Solid Waste Potential

$$\textbf{Theoretical MSW Potential}(\textbf{TMSWP}) = \text{OFMSW} \times \text{AMSW}$$

To calculate the AMSW for each of the specified years, Equation 5 is applied by multiplying the population by the Per capita generation of MSW and the number of days per year. The values are shown below in Table 9.

Equation 5 Annual municipal solid waste production

$$\textbf{Annual MSW} = \text{Population} \times \text{Per capita generation} \times \text{Number of days in the years}$$

Table 9 Guinea's Population and Per Capita Generation of Municipal Solid Waste

Year	*Population*	*Ref*	*PerCapita Generation MSW(Kg/person/day)*	*Ref*	*OFMSW*	*Ref*
2017	11 555 062	[9]	0.2	[94]	0.46	[95]
2018	11 883 516	[9]	0.2	[94]	0.46	[95]
2019	12 218 357	[9]	0.2	[94]	0.46	[95]
2020	12 559 623	[9]	0.2	[94]	0.46	[95]
2021	12 907 396	[9]	0.2	[94]	0.46	[95]
2022	13 261 638	[96]	0.2	[94]	0.46	[95]
2023	13 622 399	[96]	0.2	[94]	0.46	[95]

Sustainability Factor (SF)

According to FAO [97] 25% of the crop residue is considered the default value for the sustainability residues for each of the specified years, which should be left in the field if the country-specific recommendations do not exist

Equation 6 Sustainability Factor (SF)

$$\boldsymbol{Sustainability\ Factor}(\boldsymbol{SF}) = TCRP - (1 - 0{,}25)$$

Technical Potential

The technical potential for energy generation and hydrogen production was calculated to determine the quantity that could be produced. To achieve this, it is necessary to consider the conversion efficiencies for electricity from methane at 85%, for hydrogen through steam methane reforming, ranging from 65% to 75% [98], for bioethanol through the fermentation of dry corn is 80%[99] and for Biodiesel through Transesterification at 81%[100].

Equation 7: Technical potential

$$\boldsymbol{Technical\ Potential} = Theoretical\ Potential \times Conversion\ Efficiency\ Percentage\ )$$

Theoretical Buswell's equation

Introduced in 1952, Buswell's equation [101] helps to predict how much biogas can be produced from a given material using anaerobic digestion. To use the equation, it is necessary to know the amounts of Carbon, Oxygen, Hydrogen, Nitrogen, and sulfur in the material. Combining Buswell's equation with the carbon content of the decomposed material allows to estimate the amount of methane that can be generated[72],[73],[74]

Equation 8: Buswell's equation

$$C_cH_hO_oN_nS_s + \frac{1}{4}(4c - h - 2o + 3n + 2s)H_2O \rightarrow$$

$$\frac{1}{8}(4c - h - 2o + 3n + 2s)CO_2 + nNH_3 + sH_2S + \frac{1}{8}(4c - h - 2o + 3n + 2s)CH_4$$

With the data from Table 7, the methane and energy yield are calculated. First and foremost, to get the theoretical biogas composition, Equation 8 and Equation 9 are used. Technically, to get the coefficients of carbon dioxide and methane, the value from the ultimate analysis of a specific feedstock is divided by its corresponding atomic mass. The value obtained is used in Equation 8 to get the earlier-mentioned coefficients.

The methane percentage of the biogas is determined by dividing its coefficient by the sum of the methane and carbon dioxide coefficients as shown in Equation 9. This value is extracted from one hundred to get the Carbon dioxide percentage

Equation 9: Methane percentage $$\%CH_4 = \frac{CH4}{(CH4+CO2)} \times 100$$

Second and foremost, about the Methane yield, the theoretical potential of each selected feedstock is converted from tons to kilograms. These values are then used to calculate the theoretical potential for dry matter or moisture content by multiplying the specified moisture percentage in Table 7 by its corresponding theoretical potential. The same approach is taken for dry matter content.

The carbon percentage is determined by multiplying the elemental value obtained from the ultimate analysis by its atomic mass. Next, the values for each element are summed together. Finally, the carbon value is divided by this total and multiplied by 100 to calculate the carbon percentage.

The weight of carbon in the feedstock is calculated by multiplying its carbon percentage by its theoretical dry matter potential. Firstly, calculate the weight of carbon converted to biogas, assuming the percentage of biodegraded carbon is 70% Multiply this percentage by the weight of carbon to get the weight of carbon converted to biogas. Then multiply the methane percentage of biogas by the weight of carbon converted to biogas to get the weight of methane in kilograms, before converting to grams.

According to[104], 1 mol of methane is equal to 16g of methane, which is the weight of methane. This weight is then divided by the atomic mass of carbon and multiplied by the weight of methane carbon to get the weight of methane in kilograms before converting to grams and according to [104] 1 mol of gas at standard temperature and pressure (STP) is equivalent to 22.4 liters, and 16g of methane is equivalent to 22.4 liters. the volume of methane in cubic meters and weight of methane in gram are obtained. Earlier, it is divided by 16 to obtain the volume of methane in moles. This value is then multiplied by 22.4 to get the volume of methane in liters, which is then converted to cubic meters. The weight of methane is converted to metric tons. The weight of methane is then converted to metric tons by dividing the value of methane in kilograms by one thousand. Concerning the energy value of methane. According to [104] $1m^3$ of methane is equal to 36MJ(Megajoules) and 1kWh is equivalent to 36MJ and $1m^3$ of methane is equal to 10kWh. The energy value of methane for each of the chosen feedstock is determined by multiplying the volume of methane in cubic meters by ten(10) to get it in kWh then converted to MWh using Equation 8

Equation 10 : kWh to MWh conversion equation

$$\boldsymbol{MWh} = kWh \times 10^{-3}$$

Equation 11: MWh to MW conversion equation

$$\boldsymbol{MW} = \frac{MWh}{h}$$

Hydrogen production potential from steam methane reforming

Steam methane reforming is an endothermic reaction that converts methane into hydrogen with the help of steam. To determine the theoretical hydrogen potential of the selected feedstock, the stoichiometry is used. This branch of chemistry involves using the reactants and products in a chemical reaction to derive the quantity of the element needed, in this case, hydrogen. the Equation 12 obtained from [105] is used to estimate the hydrogen potential of the selected feedstocks for this research

Equation 12: Steam methane reforming

$$CH_{4\,(g)} + H_2O_{(g)} \rightarrow CO_{(g)} + 3H_{2(g)} \quad \Delta H^{\circ} = +206\ kJ/mol$$

According to [106], [107], 1mol of methane will give 3 moles of hydrogen gas stoichiometrically. Equation 13 ; Equation 14 and Equation 15 are used to calculate the theoretical hydrogen potential

Equation 13: Molar mass of methane

$$\boldsymbol{Molar\ mass\ of\ methane} = 12 + 4 = 16\ kg/kmol$$

Equation 14: Amount of methane

$$\boldsymbol{Amount\ of\ methane} = \frac{m}{M} = \frac{y}{16} = x\ kmol$$

Equation 15: Amount of hydrogen

$$\textbf{Amount of hydrogen} = x \times 3 = z\ kmol$$

Bioethanol conversion

The C, H and S values were analyzed based on experimental results as reported as secondary data. For the hydrolysis step, the hydrolysis efficiency values for cellulose and hemicellulose, Hc and Hh, are obtained from [41] as 0.76 and 0.90 from [108]. The saccharification of starch to glucose (Hs) is converted using 1.111 as the theoretical conversion factor [41], the monomeric saccharides glucose and xylose have fermentation efficiencies of 0.75 and 0.50, respectively [108][41].In the starch-to-ethanol pathway, the fermentation efficiency(Fs) is employed, yielding a stoichiometric value of 0.5111 from glucose [108]. According to [109] The stoichiometric yield of ethanol fermentation from glucose is 0.5111kg of ethanol kg/glucose, while the theoretical conversion factor of xylose to ethanol is 0.5175. The total volume of ethanol is determined as described in equations(Equation 16, *Equation 17*, *Equation 18*, *Equation 19* and *Equation 20*) from [41] by applying them to the dry residues and converting using an ethanol density of 0.7893liters/kg[110]. (Data in Table)

Equation 16 $$E_{\textbf{Cellulose}} = 0.5111 \times C \times Hc \times Fc$$

Equation 17 $$E_{\textbf{Hemicellulose}} = 0.5175 \times H \times Hh \times Fh$$

Equation 18 $$E_{\textbf{Starch}} = S \times Hs \times Fs$$

Equation 19 $$E_{\textbf{Conversion}} = \frac{(ECellulose + EHemicellulose + Estarch)}{0.7893}$$

Equation 20 $$V_{\textbf{Ethanol}} = Ub \times E\ Conversion$$

Biodiesel conversion

According to[111] mechanically, the average percentage of oil yield extracted is 45.3% [111], therefore, we determine the mass of oil extracted from the sample based on equation 18 from [111] .

Equation 21 $$\textbf{Percentage of oil Yield} = \frac{masse\ of\ the\ oil\ extract}{masse\ of\ the\ sample} \times \mathbf{100\%}$$

Knowing the mass of oil extracted, the transesterification process yields 86.8% according to [88], we convert first the groundnut and oil palm fruit masses of oil extract to milliliters (1g of groundnut oil = 1.97ml [112][113]; 1g of oil palm=0.924ml [113]) and we determine the volume of biodiesel based on equation 19

Equation 22

$$\boldsymbol{Yield\ of\ ethyl\ ester} = \frac{volum\ of\ ethyl\ esters}{volum\ raw\ oil\ used} \times \mathbf{100\%}$$

Biofuel Supply Chain Development Design in Guinea

Feasibility studies

Guinea's transport sector is a significant energy consumer, relying mainly on imported fossil fuels such as diesel and gasoline to power freight and passenger vehicles. Between 2016 and 2021, Guinea's dependence on diesel and gasoline was consistently high, according to [9] shown in chapter one, Table 3 and *Figure 8*. This presents a clear opportunity to introduce bioethanol and biodiesel as alternative fuels by blending them with existing diesel and gasoline fuels. It could reduce Guinea's dependence on fossil fuel imports and improve energy security like in 2022, biofuels accounted for about 6% of U.S transportation sector energy consumption, ethanol was about 4% and the rest came from biodiesel and other biofuels [114]. Here is an estimation of demand and supply and the world liquid demand.

Table 10: The world liquid demand [115]

	Historical		Stated Policies		Announced Pledges		Sustainable Development	
	2019	2020	2030	2050	2030	2050	2030	2050
Total liquids	98.6	89.7	106.4	108.7	100.8	83.3	93.3	55.1
Biofuels	2.0	1.9	3.5	5.7	4.7	6.6	5.8	8.1
Total oil	96.6	87.9	103.0	103.0	96.1	76.7	87.6	47.0
CTL, GTL and additives	0.8	0.8	1.1	1.3	1.0	0.5	0.9	0.2
Direct use of crude oil	1.0	0.7	0.4	0.2	0.4	0.2	0.2	0.0
Oil products	94.8	86.3	101.5	101.5	94.8	76.1	86.4	46.7
LPG and ethane	12.7	12.5	15.1	15.3	14.3	12.9	13.2	7.6
Naphtha	6.3	6.3	7.6	9.0	7.4	7.6	7.3	7.6
Gasoline	24.6	21.8	24.2	20.5	22.1	14.1	19.9	5.6
Kerosene	7.8	5.6	9.1	11.6	8.4	8.1	7.4	5.6
Diesel	27.3	24.9	29.4	30.0	27.3	20.6	24.3	10.7
Fuel oil	6.2	5.8	5.7	5.7	5.2	4.0	4.6	2.1
Other products	11.7	11.1	11.9	10.8	11.5	9.3	10.8	7.9
Products from NGLs	11.4	11.4	13.1	12.9	12.2	10.2	12.1	7.2
Refinery products	83.4	75.0	88.4	88.6	82.6	65.9	74.4	39.5
Refinery market share	*85%*	*84%*	*83%*	*82%*	*82%*	*79%*	*80%*	*72%*

Table 11: demand and supply estimations

Sector	Fuel type	Estimated use case	Biofuel substitute
Transport	Gasoline, Diesel	Cars, buses, freight trucks	Biodiesel, bioethanol
Electricity	Gasoline, diesel	generators	Biodiesel, biohydrogen
Industry	Ethanol,diesel, gasoline	Machinery, off-grid operation, Industry applications	Biodiesel, bioethanol

Table 12: Fuel comparison overview [115 - 117]

Fuel	Efficiencies	Cost (US$/liter)	Cost (GNF/ liter)	Environment Impacts
Gasoline	25 – 30% Thermal efficiency	1.384	12000	Hight CO_2emissions
Diesel	30 – 45% Thermal efficiency	1.384	12000	Lower CO2 per Km than gasoline
LPG	25-30%	0.75	6500	LowerCO_2 emission
Ethanol	20-25%	1.36	11750	Renewable, LowerCO_2 emission
Biodiesel	30 – 45%	1.22	10539.58	Renewable, LowerCO_2 emission
Biohydrogen	60%High(Fuelcell efficiency)	3.76€/Kg	32500	Zero emission

Supply chain process

Feedstock collection and pre-treatment

The feedstocks are collected directly from farmers and food markets. For some feedstocks such as rice straw and husk, millet stalks, banana leaves, sugarcane leaves, maize stalks and husks, groundnut straw, and palm fruit fibers and kernel shells, the collection is done directly from farmers. For others, such as maize cobs, cassava peels, groundnut shells, pineapple peels, sugarcane bagasse, and palm fruit kernel shells, they are collected from markets, with sellers collecting them back by charging their customers. The policy in place involves establishing central collection parks in different administrative regions to gather all the packages collected from various sources (markets, industrial waste). Once a specific amount is accumulated and pretreated, considering the different conversion methods needed in the various pilot plants, the drying process and grinding is implemented and once done, it is delivered to the pilot plant for conversion processing.

Feedstock transport

Concerning the logistics, some great vehicles adapted are needed to collect the feedstocks from the sellers to the central parks, next to the different central parks stations to the three factories used to produce the biofuels

Biofuels Production

As already explained in chapter one, the feedstocks once received are pretreated, then go through the different production processes such as anaerobic digestion, fermentation, and transesterification. Transformed into the study biofuels target: biohydrogen in gas form, and bioethanol and biodiesel in liquid form.

Biofuel distribution

Logistically, well-adapted vehicles are needed to distribute products from the factory to various central stations in different regions, such as trucks and trains, making it easier for customers to access them for end use. This study does not focus on the release of carbon dioxide during the life cycle of the different biofuels produced. Find below the models: model 1a (Figure 22) and model 1b (Figure 22)

Representing result with QGIS

QGIS is an application used to design geographical maps, this research used it to represent the study site area and prospective potential pilot plants location based on the resources most abundant. Here were the steps when designing the map

- Download the shapefile of the country
- The administrative region were labeled and colored randomly
- The location of the pilot plants was selected and scale, legend and compass were added to the design map

Chapter 3: Results and Discussion

Results

Theoretical potential

Theoretical crop residue potential

After considering the sustainability factor, the total theoretical crop residue potential for the respective years, as shown in Table in the appendix, it is indicated that in Figure 11, 2023 had the highest potential due to its high production yield, compared to 2017, which had a lower potential. The crop residue potential from 2017 to 2023 increases over the years.

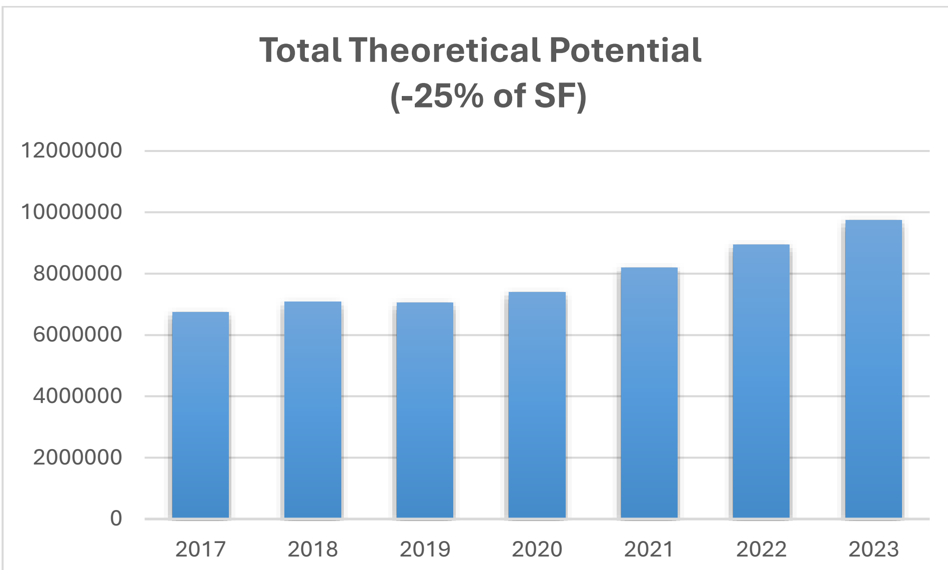

Figure 11: The total theoretical crop residue potential per year

Municipal solid waste theoretical potential

The increase in municipal solid waste theoretical potential is due to the rise in population size and per capita generation in Guinea.

Table 13: Municipal solid waste theoretical potential

Year	Population	Per Capita (Kg)	OFMSW	number of days	Annual MSW	Theoretical MSWP
2017	11,5	0,2	0,46	365	839,5	386,17
2018	11,8	0,2	0,46	365	861,4	396,244
2019	12,2	0,2	0,46	365	890,6	409,676
2020	12,5	0,2	0,46	365	912,5	419,75
2021	12,9	0,2	0,46	365	941,7	433,182
2022	13,2	0,2	0,46	365	963,6	443,256
2023	13,6	0,2	0,46	365	992,8	456,688

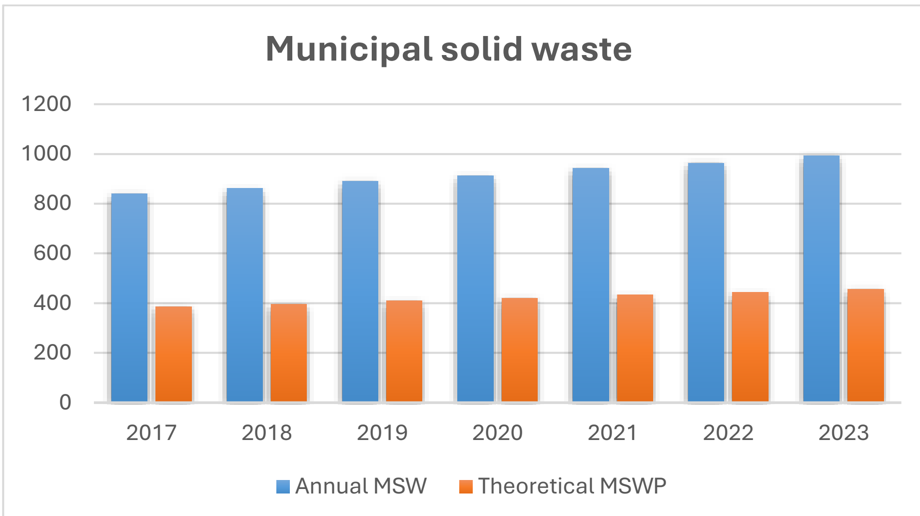

Figure 12: The Annual and Total theoretical MSW potential

Table 14 Resumed the crop residue theoretical potential to the theoretical MSW potential, and the total theoretical potential of Guineas from 2015 to 2023.

Table 14: The total theoretical potential

	Theoretical CRP (-25% of SF)	Theoretical MSWP	Total Theoretical Potential (-25% of SF)
2017	6742635,98	386,17	6743022,15
2018	7077511,67	396,24	7077907,91
2019	7053620,06	409,67	7054029,74
2020	7386584,72	419,75	7387004,47
2021	8190849,13	433,18	8191282,31
2022	8947211,99	443,25	8947655,25
2023	9749399,87	456,68	9749856,56

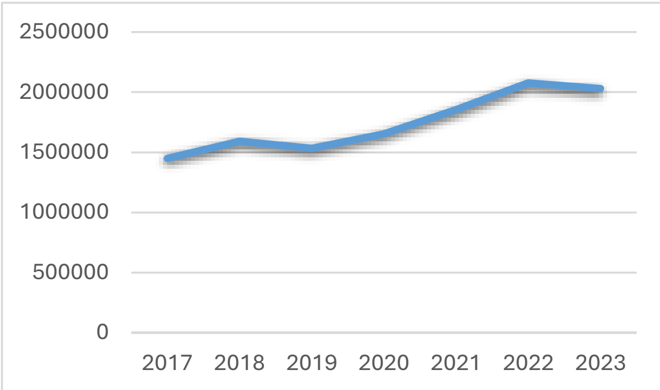

Figure 15: Total Theoretical Potential used for Biodiesel Group 1

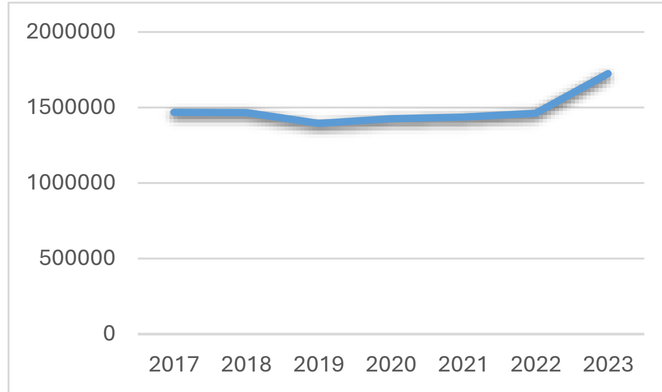

Figure 14: The theoretical potential of crops used for bioethanol (Group 3)

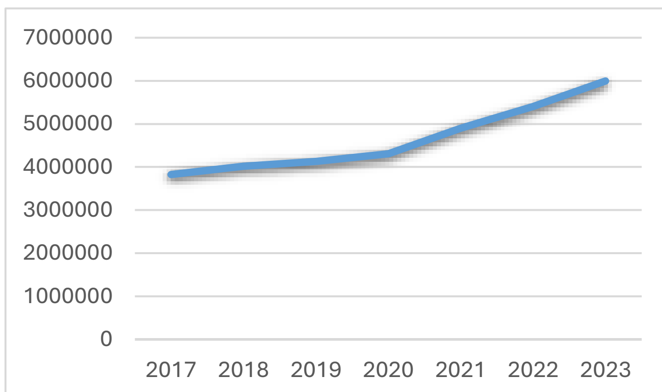

Figure 13: Total Theoretical Potential of crops and MSW used for Biogas. (-25% of SF) Group 2

Theoretical methane potential

The results (Figure 16) show that rice crop residue has a higher methane production potential compared to other crops, with values from 2017 to 2023 of 572770.03 mt/year; 609733.24 mt/year; 621768.18 mt/year; 640814.24 mt/year; 740072.09 mt/year; 822994.35 mt/year; and 921161.59 mt/year. Meanwhile, the consistently lowest theoretical methane production potential is from the organic fraction of municipal solid waste, with values of 39.89 mt/year; 40.93 mt/year; 42.32 mt/year; 43.36 mt/year; 44.75 mt/year; 45 mt/year; and 47.18 mt/year, respectively, from 2017 to 2023.

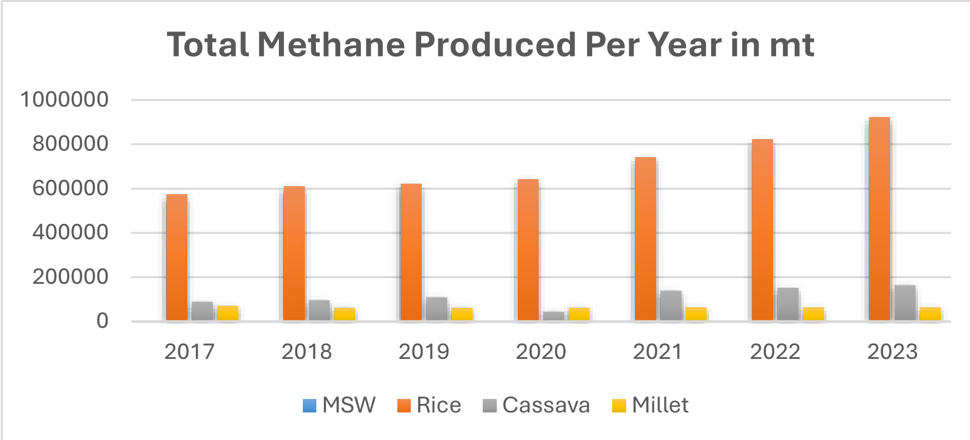

Figure 16: Total Methane Produced Per Year in mt

Theoretical and technical energy potential

Hydrogen

The results (*Figure 17*) show that rice crop residue has a higher potential for methane production compared to other crops, with values from 2017 to 2023 of 8018780.46 MWh; 8536265.43 MWh; 8704754.50 MWh; 8971399.35 MWh; 10361009.20 MWh; 11521920.89 MWh; and 12896262.30 MWh. Meanwhile, the lowest theoretical methane production potential consistently comes from the organic fraction of municipal solid waste, with values of 558.52 MWh; 573.09 MWh; 592.52 MWh; 607.09 MWh; 626.51 MWh; 641.08 MWh; and 660.51 MWh from 2017 to 2023. Combining crop residues with OFMSW results in more favorable output: 10119531.23 MWh in 2017; 10622095.20 MWh in 2018; 10934610.58 MWh in 2019; 10369949.98 MWh in 2020; 13002654.86 MWh in 2021; 14328721.92 MWh in 2022; and 15858522.89 MWh in 2023.

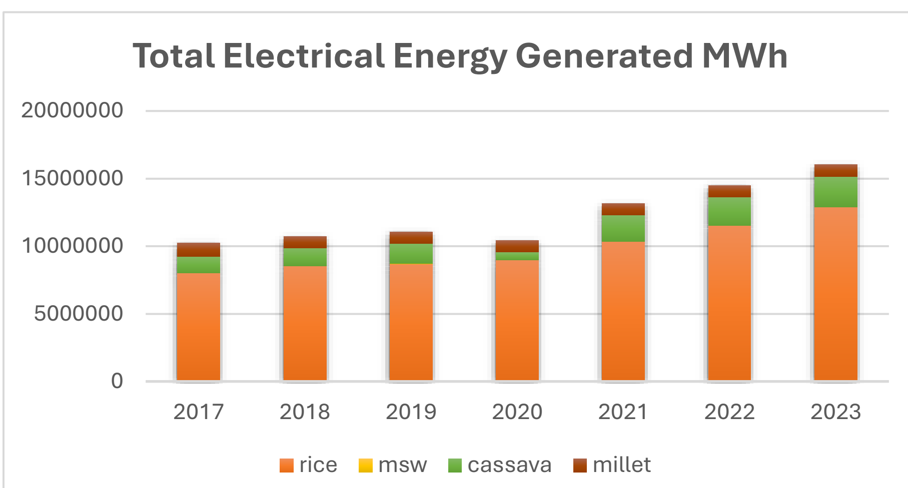

Figure 17: Theoretical Energy potential MWh

The difference is clearly shown in Figure 18, the results show that the theoretical potential for hydrogen is higher than the technical potential from 2017 to 2023. to 2023

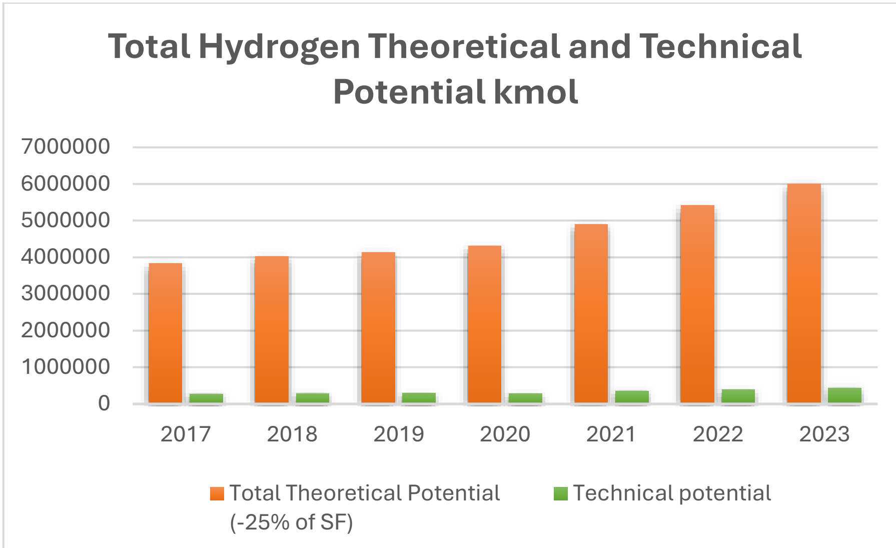

Figure 18: Total Hydrogen Theoretical and Technical Potential kmol

Bioethanol

The results (Figure 19) clearly demonstrate that sugarcane bagasse has a higher potential for bioethanol production compared to other residues, with values from 2017 to 2023 of 184125248 liter; 184408661 liters; 174249946 liters; 178543272 liters; 179854001 liters; 183544060 liters; and 221233441 liters. Meanwhile, the lowest theoretical bioethanol production potential consistently comes from banana peels, with values of 3948786 liters; 3022701 liters; 2286277 liters; 2370901 liters; 2458665 liters; 2549678 liters; and 2647391 liters from 2017 to 2023.

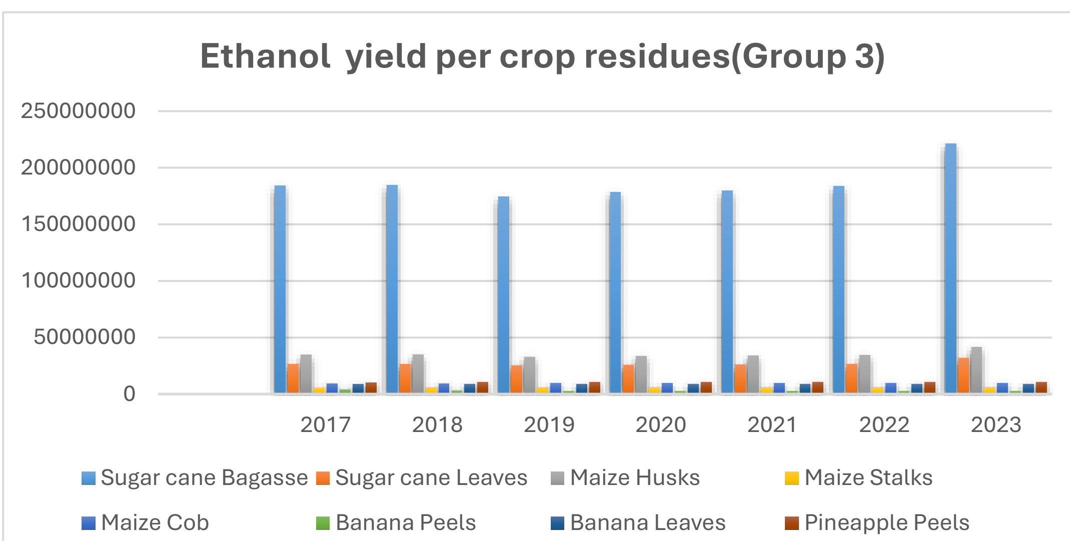

Figure 19: Theoretical bioethanol potential per liter

In Figure 20, the results for the theoretical potential in tons are higher than the technical potential for Bioethanol (tons) from 2017 to 2023.

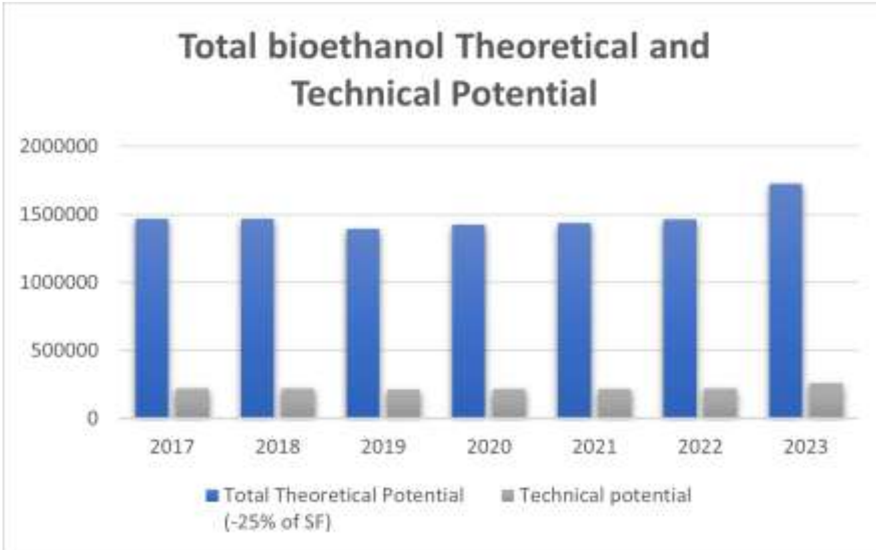

Figure 20: Total Bioethanol Theoretical and Technical Potential in tons

Biodiesel

The results (*Figure 21*) show that oil palm fruit fibers have a higher potential for biodiesel production compared to kernel shell residues, while for groundnut, the straws are more abundant than shells and the theoretical potential in tons exceeds the technical potential for biodiesel (liters) from 2017 to 2023. The difference is due to the application of different efficiencies used throughout the conversion process

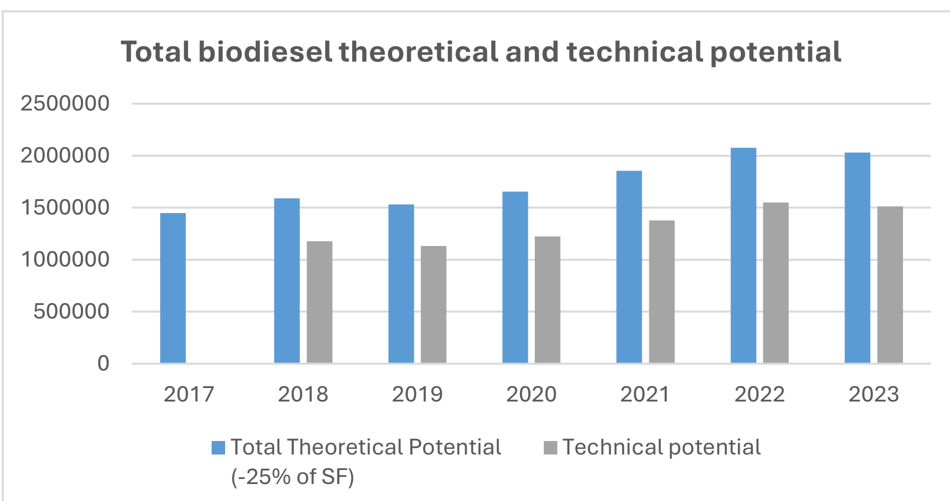

Figure 21: Total Biodiesel Theoretical and Technical Potential

Supply chain process

As clearly explained in Chapter 2, here is the model of the supply chain considering all the scenarios

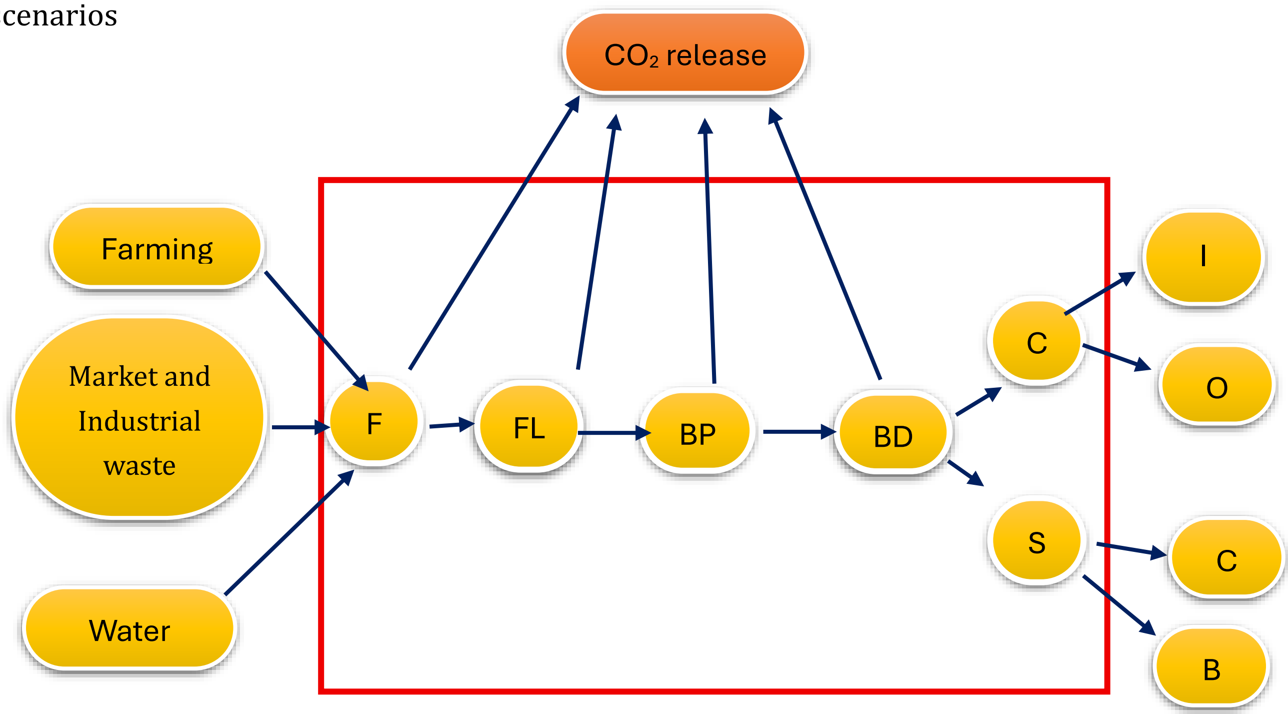

Figure 22: Supply chain model 1b

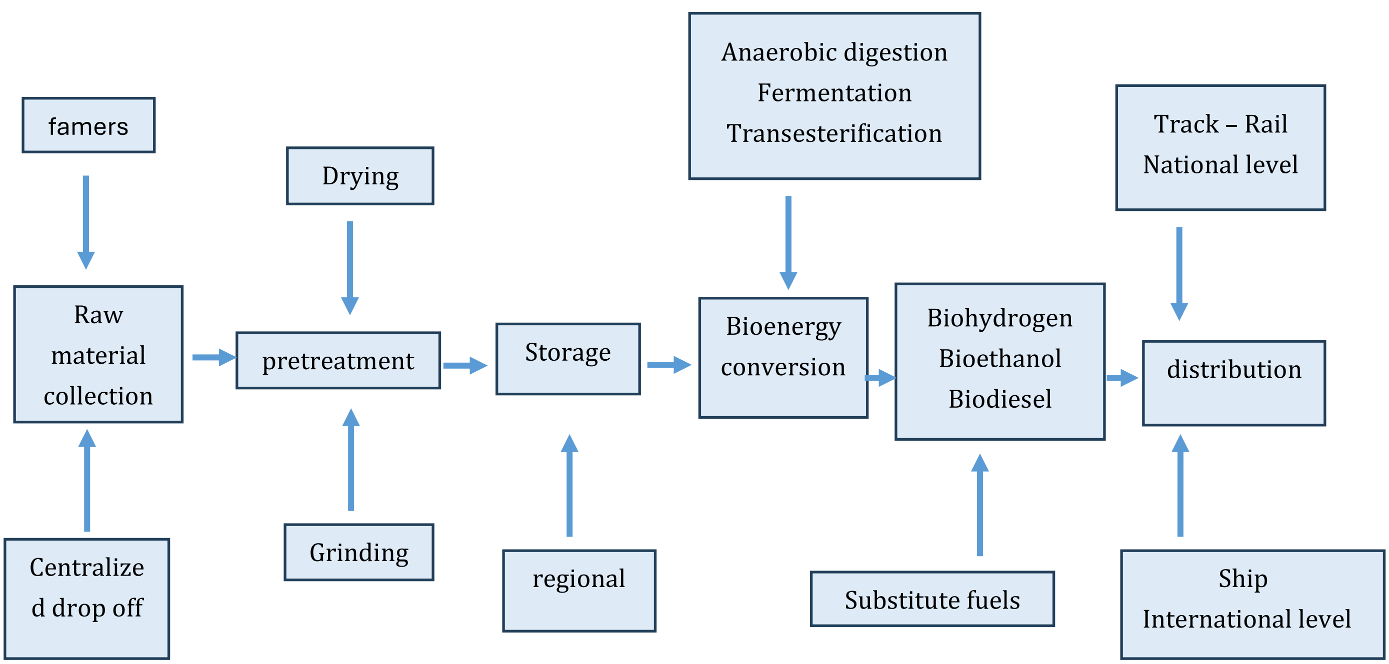

Figure 23: Supply chain model 1a

Challenges

The establishment of a biofuel supply chain as an alternative fuel in Guinea faces several major challenges. First, the high costs of developing infrastructure and transportation, feedstock cultivation, processing technologies, and logistics. Second, another critical barrier is social acceptance. Many Guineans are not familiar with biofuels, and there is a lack of awareness about their benefits and reliability. People may be hesitant to replace diesel and gasoline with substances derived from plants or organic waste; adopting new things requires trust, sensibilization, and visible examples of success. In addition, resistance stems from the fact that using land to grow biofuels could compete with food production.

Recommendations

- A strategic approach is essential for overcoming the financial and logistical hurdles in establishing a biofuel supply chain in Guinea. First, public-private partnerships can be vital by pooling resources, allowing for shared risks and lower costs. A phased rollout, starting with small-scale pilot projects in regions with high feedstock potential, can prove the supply chain's viability and generate momentum. Utilizing existing agricultural and transportation infrastructure can also help reduce initial costs, making the shift to biofuels more feasible and sustainable.
- Building public trust and awareness is key to successfully promoting biofuels in Guinea. Using radio broadcasts, school programs, and respected local leaders can educate citizens about the benefits and dependability of biofuels. Demonstration projects that power clinics or schools with biofuel can serve as proof of concept and boost confidence.

Discussion

Pilots of waste-to-energy plants based on technical energy potential

Scenarios based on biofuels development in Guinea

Scenarios are data-driven cases that help us understand how a strategy is implemented. In this study, three different scenarios are examined, each covering the entire process from biofuel production to its final use in Guinea. These scenarios specifically focus on the feedstock collection, transportation, industrial processes, and electricity generation sectors.

Scenario A: *Hydrogen production from municipal solid waste, Millet, Cassava, and Rice*

Based on 2023 results, 603,293.50 tons of cassava peels; 689286 tons of rice husks and straws; 301950 tons of millet stalks; and 992.8 tons of municipal solid waste are collected from various farms and transported to Dubreka (A town in the Kindia administrative region in western Guinea), where the hydrogen plant is assumed to be located based on the availability of large quantities of certain feedstocks such as millet and rice. Through the anaerobic digestion and steam methane reforming process, municipal solid waste is combined with cassava peels, rice husks and straws, and millet stalks, **428,180.12 tons of hydrogen** is generated.10% of the hydrogen produce is used in the transportation sector, amounting to 42,818.01 tons used in the hydrogen stations to power **3425 cars** (assumed 5kg /car) and **2141 bus** (assumed 12kg/bus). In the electricity sector, 50% (214,090.06 tons) of hydrogen produced- equivalent to 7.14 TWh (1 kg of hydrogen = 33.33 kW according to [117] and [92])- is expected to supply 2,378,541 households with 3,000 kWh annually, leaving no electrified regions in the country without access to electricity. 10276322,4 gigajoules (1kg of hydrogen = 0.12 GJ [118]) of heat are generated from 20% of the total hydrogen produced to power industries such as mining, cement (assuming 4.5 GJ per ton, sufficient to produce a total of 1141814 tons of cement), and 734023 tons of steel (assuming 7 GJ per ton). 35% of the total hydrogen produced(85636,02 tons) is for exportation to some African countries and European nations to ameliorate this energy crisis and contribute to the substantial growth of Guinea's Gross Domestic Product (GDP), the exportation can be executed by ships or track. Find below a visual of this scenario in the Figure 24.

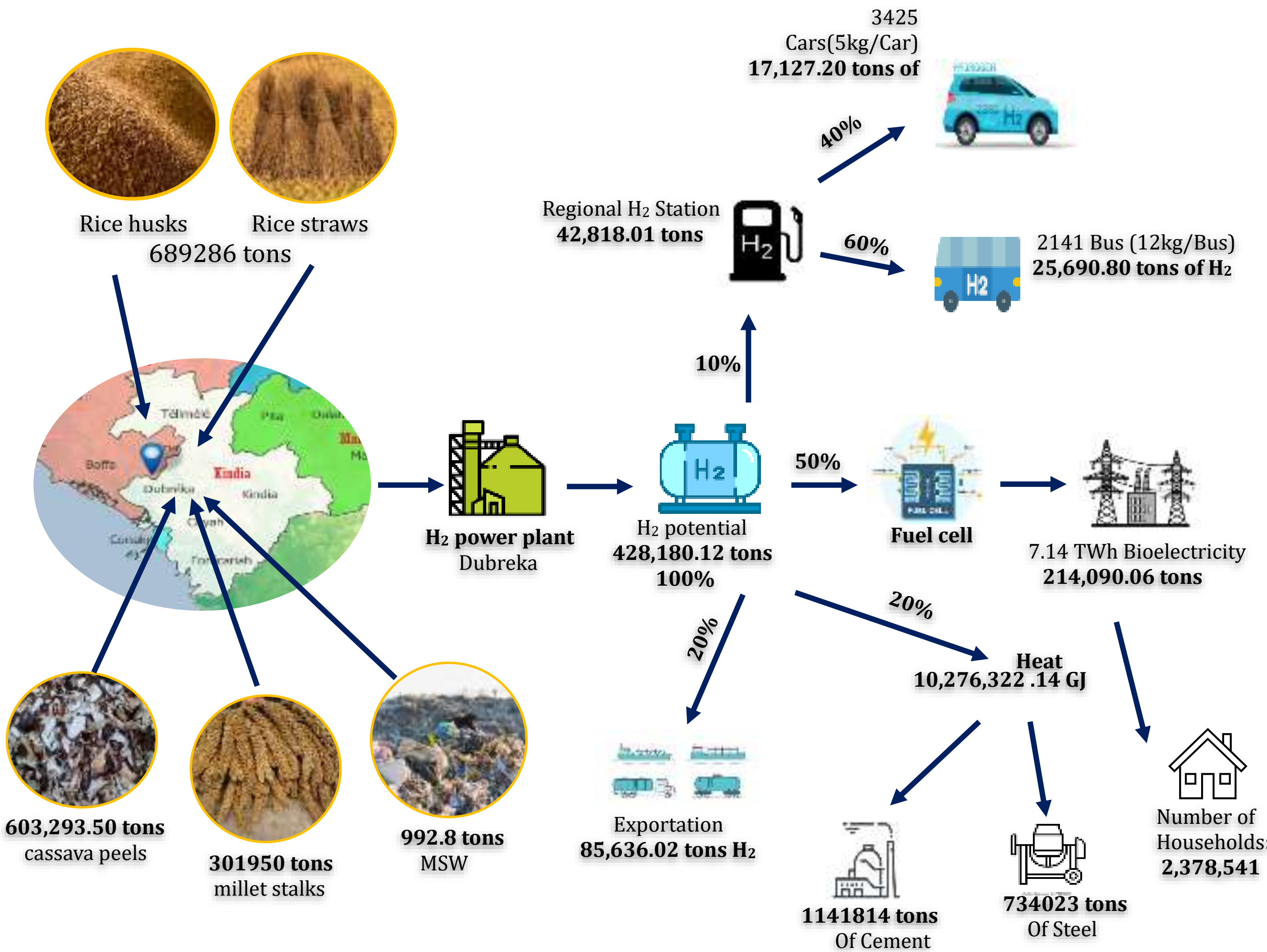

Figure 24: Schematic diagram of the different steps of scenario A

Scenario B: Bioethanol production from Sugar cane; banana, pineapple and maize residues

As showing in Figure 25, based on 2023 results, 1531920 tons of maize residues(Stalks, husks and cob), 16689.31 tons of pineapple, 70475.67 tons of sugar cane and 105339.07 tons of banana, so in total 1724424.05 tons of residues are collected from various farms and transport to Labe, a town located in the administrative region of Labe due to the large number of maize residues quantify. The fermentation process helps generate 331,693.03 m^3(2086282.82 barrels) of bioethanol. 50% (1043141.37 bbl) of total production is focused on the transportation sector.20% (417256.52 bbl) dedicated to exportation representing 40% of Tanzania annual output [119], 20% of the production is used as a fuel to produce electricity and 10% for industrial applications.

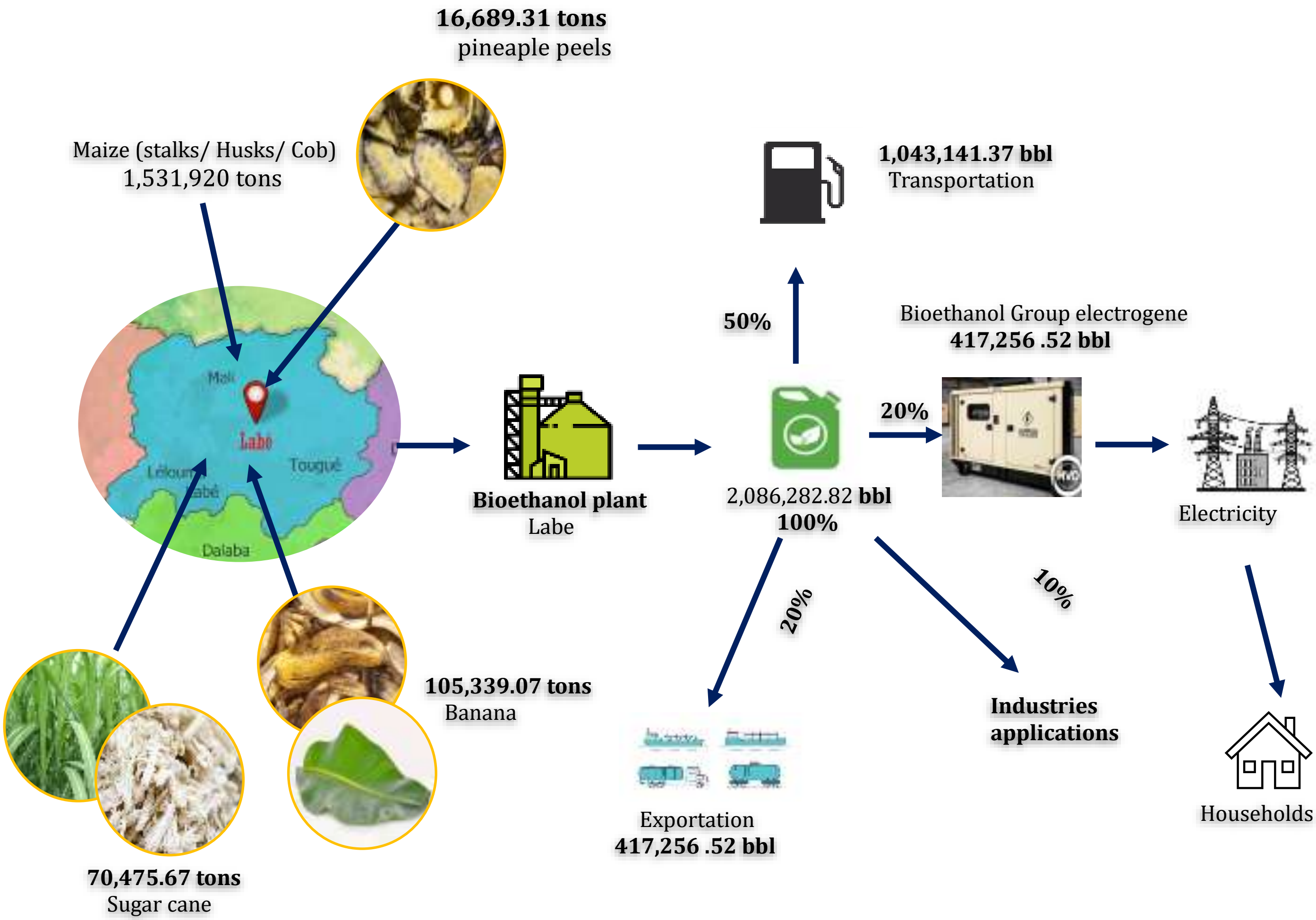

Figure 25: Schematic diagram of the different steps of scenario B

Scenario C: Biodiesel production from oil palm fruit and groundnut oil.

Compare to the two first scenarios, this is more focused on the kind of biomass that have more oil, particularly palm fruit and groundnut. Based on 2023 results, 1890000 tons of groundnut residues (shells and straws), 139620,3 tons of oil palm fruit residues (fibers and kernel shell), , so in total 2029620,32 tons of residues are collected from various farms and transport to N'zerekore, a town located in the administrative region of N'zerekore due to the large number of palm fruit residues quantify. The transesterification process helps to generate 2029620.32 m^3(12765905.89 barrels) of biodiesel. 50% (6382952.94 bbl) of total production is focused on the transportation sector.10% (1276590.58 bbl) for exportation, 20%(2553181.17bbl) is used to produce electricity and 20% for industrial applications.

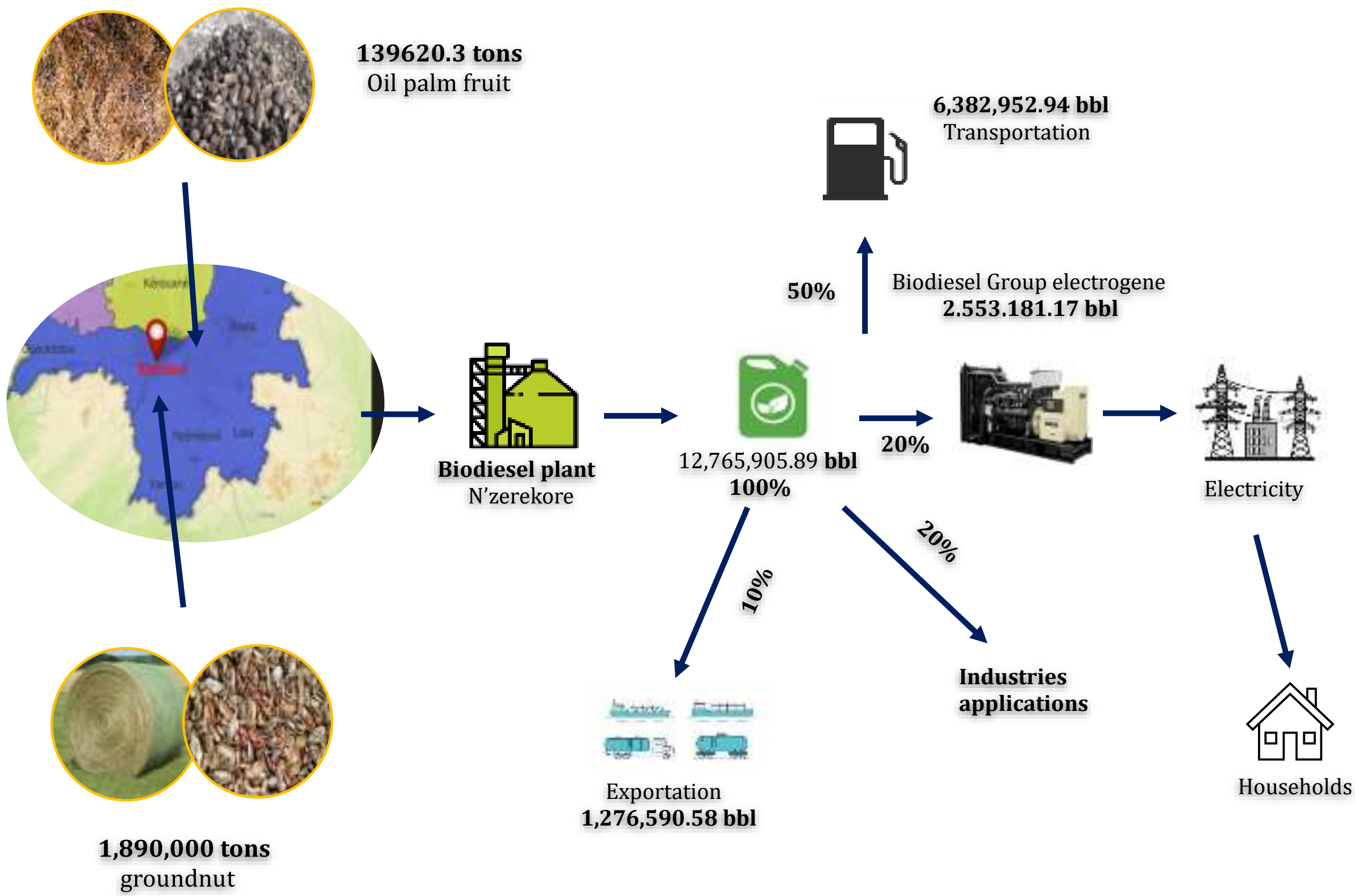

Figure 26: Schematic diagram of the different steps of scenario C

This map (Figure 27) serves as valuable tool for educators, researchers and anyone interested in Guinea's political geography. The inclusion of compass red and blue is to help viewers to understand where the different pilot plant develop through the scenarios for this study is located based on where the feedstock is highly accessible.

Figure 27: prospective potential pilot plants location

The three scenarios have a great positive impact on the environment, the economy and the society of Guinea. Assuming the number of hydrogen produced to be equivalent to gasoline, for small vehicle (1kg of H_2 =2.8kg) and diesel for buses (1kg of H_2 =2.79kg) [120]

Conclusion

This thesis aims to develop Guinea's biofuel supply chain, primarily to assess the potential for producing biohydrogen, bioethanol, and biodiesel from fractionated organic municipal solid waste and residues from major crops. The study uses data from 2017 to 2023 to calculate the theoretical potential of these raw materials, then applies the results to estimate the capacity for biomethane and electricity production using Buswell's equation. Additionally, using stoichiometry to determine the potential for hydrogen production through steam methane reforming, bioethanol via fermentation, and biodiesel through transesterification. The technical potentials are assessed by considering their respective conversion efficiencies.

Thanks to three production scenarios and robust modeling, as illustrated in the Figure 22 to Figure 26, Guinea could potentially generate 7.14 TWh of bioelectricity, supply 10,276,322.14 GJ of heat to cement and steel factories, provide 42,818.01 tons of biohydrogen for powering cars and buses, and produce an additional 2,086,282.82 barrels of bioethanol, 50% of which would be used for transportation and 20% for electricity generation, alongside producing 12,765,905.89 barrels of biodiesel mainly for transportation and electricity needs.

Regarding some limitations of this study, the data used for analysis is secondary. It would be better for future research to gather data directly in Guinea for more precise and tailored results. Moreover, the limited timeframe for this research was a key constraint. Future studies should include a techno-economic analysis and a life cycle assessment to provide a comprehensive understanding.

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Appendix

Table 15 : The crop residues potential

2017 THEORETICAL CROP RESIDUE POTENTIAL

CROP TYPE	Production/ annum in tons		Susta.Factor		Residue / tons
GROUNDNUT	Shells	257380,14	0,25	64345,04	193035,11
	Straw	1495587,30	0,25	373896,83	1121690,48
OIL PALM FRUIT	Fibers	119452,99	0,25	29863,25	89589,75
	Kernel Shell	59726,50	0,25	14931,62	44794,87
CASSAVA	peelings	437929,75	0,25	109482,44	328447,31
RICE	Husks	571455,82	0,25	142863,96	428591,87
	Straw	3648525,62	0,25	912131,41	2736394,22
MILLET	Stalks	442336,62	0,25	110584,16	331752,47
MAIZES	Stalks	1299484,74	0,25	324871,19	974613,56
	Husks	163457,20	0,25	40864,30	122592,90

	Cob	237012,94	0,25	59253,24	177759,71
SUGARCANE	Leaves	33941,05	0,25	8485,26	25455,79
	Bagasse	55539,90	0,25	13884,97	41654,92
PINEAPLE	Peels	33191,18	0,25	8297,80	24893,39
BANANA	peels	56316,48	0,25	14079,12	42237,36
	leaves	78843,08	0,25	19710,77	59132,31
TOTAL					6742635.98

2018 THEORETICAL CROP RESIDUE POTENTIAL

CROP TYPE	Production/ annum in tons			Susta.Factor	Residue / tons
GROUNDNUT	Shells	284938,85	0,25	71234,71	213704,14
	Straw	1655725,75	0,25	413931,44	1241794,31
OIL PALM FRUIT	Fibers	120462,40	0,25	30115,60	90346,80
	Kernel Shell	60231,20	0,25	15057,80	45173,40
CASSAVA	peelings	473849	0,25	118462,25	355386,75
RICE	Husks	608334,22	0,25	152083,56	456250,67
	Straw	3883980,02	0,25	970995,01	2912985,02
MILLET	Stalks	392987,01	0,25	98246,75	294740,26
MAIZES	Stalks	1301484,96	0,25	325371,24	976113,72
	Husks	163708,80	0,25	40927,20	122781,60
	Cob	237377,76	0,25	59344,44	178033,32
SUGARCANE	Leaves	34286,05	0,25	8571,51	25714,54
	Bagasse	56104,44	0,25	14026,11	42078,33
PINEAPLE	Peels	25407,05	0,25	6351,76	19055,29
BANANA	peels	57418,63	0,25	14354,66	43063,97
	leaves	80386,09	0,25	20096,52	60289,56
TOTAL					7077511.67

2019 THEORETICAL CROP RESIDUE POTENTIAL

CROP TYPE		Production/ annum in tons	Susta.Factor		Residue / tons
GROUNDNUT	Shells	273326,77	0,25	68331,69	204995,08
	Straw	1588250,15	0,25	397062,54	1191187,61
OIL PALM FRUIT	Fibers	120960,00	0,25	30240,00	90720,00

	Kernel Shell	60480,00	0,25	15120,00	45360,00
CASSAVA	peelings	536371,00	0,25	134092,75	402278,25
RICE	Husks	620341,54	0,25	155085,39	465256,16
	Straw	3960642,14	0,25	990160,54	2970481,61
MILLET	Stalks	384854,49	0,25	96213,62	288640,87
MAIZES	Stalks	1229788,68	0,25	307447,17	922341,51
	Husks	154690,40	0,25	38672,60	116017,80
	Cob	224301,08	0,25	56075,27	168225,81
SUGARCANE	Leaves	34587,92	0,25	8646,98	25940,94
	Bagasse	56598,42	0,25	14149,60	42448,81
PINEAPLE	Peels	19217,10	0,25	4804,28	14412,83
BANANA	peels	58507,11	0,25	14626,78	43880,33
	leaves	81909,96	0,25	20477,49	61432,47
TOTAL					7053620.06

2020 THEORETICAL CROP RESIDUE POTENTIAL

CROP TYPE		Production/ annum in tons	Susta.Factor		Residue / tons
GROUNDNUT	Shells	296442,89	0,25	74110,72	222332,17
	Straw	1722573,55	0,25	430643,39	1291930,16
OIL PALM FRUIT	Fibers	124250,00	0,25	31062,50	93187,50
	Kernel Shell	62125,00	0,25	15531,25	46593,75
CASSAVA	peelings	630863,75	0,25	157715,94	473147,81
RICE	Husks	639343,9	0,25	159835,98	479507,93
	Straw	4081964,9	0,25	1020491,23	3061473,68
MILLET	Stalks	390558,6	0,25	97639,65	292918,95
MAIZES	Stalks	1260089,31	0,25	315022,33	945066,98
	Husks	158501,80	0,25	39625,45	118876,35
	Cob	229827,61	0,25	57456,90	172370,71
SUGARCANE	Leaves	35083,35	0,25	8770,84	26312,51
	Bagasse	57409,12	0,25	14352,28	43056,84
PINEAPLE	Peels	19928,40	0,25	4982,10	14946,30
BANANA	peels	58257,27	0,25	14564,32	43692,95
	leaves	81560,18	0,25	20390,04	61170,13

TOTAL	***7386584.72***

2021 THEORETICAL CROP RESIDUE POTENTIAL

CROP TYPE		Production/ annum in tons	Susta.Factor		Residue / tons
GROUNDNUT	Shells	335640,69	0,25	83910,17	251730,52
	Straw	1950344,55	0,25	487586,14	1462758,41
OIL PALM FRUIT	Fibers	123620,00	0,25	30905,00	92715,00
	Kernel Shell	61810,00	0,25	15452,50	46357,50
CASSAVA	peelings	685791,50	0,25	171447,88	514343,63
RICE	Husks	738374,00	0,25	184593,50	553780,50
	Straw	4714234,00	0,25	1178558,50	3535675,50
MILLET	Stalks	396339,57	0,25	99084,89	297254,68
MAIZES	Stalks	1269339,93	0,25	317334,98	952004,95
	Husks	159665,40	0,25	39916,35	119749,05
	Cob	231514,83	0,25	57878,71	173636,12
SUGARCANE	Leaves	35160,60	0,25	8790,15	26370,45
	Bagasse	57535,52	0,25	14383,88	43151,64
PINEAPLE	Peels	20666,10	0,25	5166,53	15499,58
BANANA	peels	58789,79	0,25	14697,45	44092,34
	leaves	82305,71	0,25	20576,43	61729,28
TOTAL					8190849.13

2022 THEORETICAL CROP RESIDUE POTENTIAL

CROP TYPE		Production/ annum in tons	Susta.Factor		Residue / tons
GROUNDNUT	Shells	379303,32	0,25	94825,83	284477,49
	Straw	2204059,86	0,25	551014,96	1653044,89
OIL PALM FRUIT	Fibers	124040,00	0,25	31010,00	93030,00
	Kernel Shell	62020,00	0,25	15505,00	46515,00
CASSAVA	peelings	744655,36	0,25	186163,84	558491,52
RICE	Husks	821106,00	0,25	205276,50	615829,50
	Straw	5242446,00	0,25	1310611,50	3931834,50

MILLET	Stalks	402204,68	0,25	100551,17	301653,51
MAIZES	Stalks	1295382,94	0,25	323845,73	971537,20
	Husks	162941,25	0,25	40735,31	122205,94
	Cob	236264,81	0,25	59066,20	177198,61
SUGARCANE	Leaves	35396,23	0,25	8849,06	26547,17
	Bagasse	57921,10	0,25	14480,28	43440,83
PINEAPLE	Peels	21431,10	0,25	5357,78	16073,33
BANANA	peels	58518,06	0,25	14629,51	43888,54
	leaves	81925,28	0,25	20481,32	61443,96
TOTAL					8947211.99

2023 THEORETICAL CROP RESIDUE POTENTIAL

CROP TYPE		Production/ annum in tons	Susta.Factor		Residue / tons
GROUNDNUT	Shells	370000,00	0,25	92500,00	277500,00
	Straw	2150000,00	0,25	537500,00	1612500,00
OIL PALM FRUIT	Fibers	124106,95	0,25	31026,74	93080,22
	Kernel Shell	62053,48	0,25	15513,37	46540,11
CASSAVA	peelings	804391,34	0,25	201097,83	603293,50
RICE	Husks	919048,00	0,25	229762,00	689286,00
	Straw	5867768,00	0,25	1466942,00	4400826,00
MILLET	Stalks	402600,00	0,25	100650,00	301950,00
MAIZES	Stalks	1561380,00	0,25	390345,00	1171035,00
	Husks	196400,00	0,25	49100,00	147300,00
	Cob	284780,00	0,25	71195,00	213585,00
SUGARCANE	Leaves	35642,87	0,25	8910,72	26732,15
	Bagasse	58324,69	0,25	14581,17	43743,52
PINEAPLE	Peels	22252,42	0,25	5563,10	16689,31
BANANA	peels	58521,71	0,25	14630,43	43891,28
	leaves	81930,39	0,25	20482,60	61447,79
TOTAL					9749399.87

Table 16 : Technical potential of bioethanol

		Volume ethanol						
		2017	2018	2019	2020	2021	2022	2023
Sugar cane	**Bagasse**	184125248,58	184408661,69	174249946,49	178543272,04	179854001,32	183544060,22	221233441,06
	Leaves	26317998,68	26358508,42	24906469,36	25520137,16	25707486,65	26234926,34	31622069,51
Maize	**Husks**	34610880,65	34664155,13	32754574,11	33561610,52	33807994,41	34501631,97	41586280,44
	Stalks	5323742,82	5377856,75	5425206,32	5502916,01	5515031,96	5551991,65	5590677,23
	Cob	9242438,79	9336384,84	9418587,45	9553497,61	9574531,87	9638696,82	9705858,05
Banana	**Peels**	3948786,97	3022701,13	2286277,01	2370901,06	2458665,95	2549678,74	2647391,86
	Leaves	8470301,93	8636071,22	8799784,47	8762206,81	8842300,69	8801430,66	8801979,26
Pineapple	**Peels**	10109473,78	10307322,72	10502717,74	10457868,06	10553461,69	10504682,49	10505337,26
	Total (l)	282148872,21	282111661,89	268343562,95	274272409,27	276313474,54	281327098,89	331693034,68
	Total (hl)	2821488,72	2821116,62	2683435,63	2742724,09	2763134,75	2813270,99	3316930,35
	Total (m3)	282148,87	282111,66	268343,56	274272,41	276313,47	281327,10	331693,03

Total (tons)	222615,46	222586,10	211723,07	216400,93	218011,33	221967,08	261705,80

Table 17: Technical potential of biodiesel

crops	*years*		*Mass of sample*	*Mass of oil*	*Oil yield*	*volum of oil*	*trans yield*	*volum ethyl ester*
groundnut	2017	Shells	193035,1	87444,90	45,3	172266,454	0,868	149527,2817
		Straw	1121690,47	508125,78		1001007,79	0,868	868874,7637
	2018	Shells	213704,13	96807,97	45,3	190711,703	0,868	165537,7579
		Straw	1241794,31	562532,82		1108189,66	0,868	961908,625
	2019	Shells	204995,07	92862,77	45,3	182939,65	0,868	158791,6166
		Straw	1191187,61	539607,99		1063027,74	0,868	922708,074
	2020	Shells	222332,16	100716,47	45,3	198411,443	0,868	172221,1324
		Straw	1291930,16	585244,36		1152931,39	0,868	1000744,45
	2021	Shells	251730,51	114033,92	45,3	224646,824	0,868	194993,4436
		Straw	1462758,41	662629,56		1305380,23	0,868	1133070,042
	2022	Shells	284477,49	128868,30	45,3	253870,557	0,868	220359,6433
		Straw	1653044,89	748829,34		1475193,79	0,868	1280468,21
	2023	Shells	277500	125707,50	45,3	247643,775	0,868	214954,7967
		Straw	1612500	730462,50		1439011,13	0,868	1249061,657
							Total (t1)	8693221,494

crops	*years*		*Mass of sample*	*Mass of oil*	*Oil yield*	*volum of oil*	*trans yield*	*volum ethyl ester*
oil palm fruit	2017	Shells	44794,87268	20292,08	45,3	18749,879	0,868	16274,89536
		fibers	89589,74535	40584,15		37499,759	0,868	32549,79072
	2018	Shells	45173,40135	20463,55	45,3	18908,321	0,868	16412,42258

	fibers	90346,8027	40927,10		37816,642	0,868	32824,84517
2019	Shells	45360	20548,08	45,3	18986,426	0,868	16480,2177
	fibers	90720	41096,16		37972,852	0,868	32960,4354
2020	Shells	46593,75	21106,97	45,3	19502,839	0,868	16928,46436
	fibers	93187,5	42213,94		39005,678	0,868	33856,92872
2021	Shells	46357,5	20999,95	45,3	19403,951	0,868	16842,62989
	fibers	92715	41999,90		38807,903	0,868	33685,25979
2022	Shells	46515	21071,30	45,3	19469,877	0,868	16899,85287
	fibers	93030	42142,59		38939,753	0,868	33799,70574
2023	Shells	46540,1076	21082,67	45,3	19480,386	0,868	16908,97498
	fibers	93080,2152	42165,34		38960,772	0,868	33817,94995
						Total (t2)	8693221,494

T= t1+t2

	residues	
2017	165802,2	1067226,7
	901424,6	
2018	181950,2	1176683,7
	994733,5	
2019	175271,8	1130940,3
	955668,5	
2020	189149,6	1223751
	1034601	

2021	211836,1 1166755	1378591,4
2022	237259,5 1314268	1551527,4
2023	231863,8 1282880	1514743,4
total		9043464

Table 18: Conversion factors [41]

Conversion factors	Sugar Cane		Maize			Banana		Pineapple
	Leaves	*bagasse*	*Husks*	*Stalks*	*Cobs*	*Peels*	*Leaves*	*Peels*
Cellulose content (C)	32.4	37.3	28.06	34.2	28.7	9.9	35.58	20.9
Glucose hydrolysis efficiency (Hc)	76.0	76.0	76.0	76.0	76.0	76.0	76.0	76.0
Glucose to ethanol conversion	0.5111	0.5111	0.5111	0.5111	0.5111	0.5111	0.5111	0.5111
Fermentation efficiency (Fc)	75.0	75.0	75.0	75.0	75.0	75.0	75.0	75.0
Hemicellulose content (H)	23.5	26.1	30.89	28.1	39.3	41.38	23.46	31.8
Xylose hydrolysis efficiency (Hh)	90.0	90.0	90.0	90.0	90.0	90.0	90.0	90.0
Fermentation efficiency (Fh)	50.0	50.0	50.0	50.0	50.0	50.0	50.0	50.0
Ethanol yield from cellulose (Ecellulose)	0.108							
Stoichiometric conversion(xylose to ethanol)	0.5175	0,5175	0,5175	0,5175	0,5175	0,5175	0,5175	0,5175
Ethanol conversion factor (Econversion) : [liters kg−1]	0.21	0.21	0.21	0.21	0.21	0.21	0.21	0.21

Figure 29 : The theoretical potential of crops used for biogas (Group 2)

Cassava **Rice** **Millet**

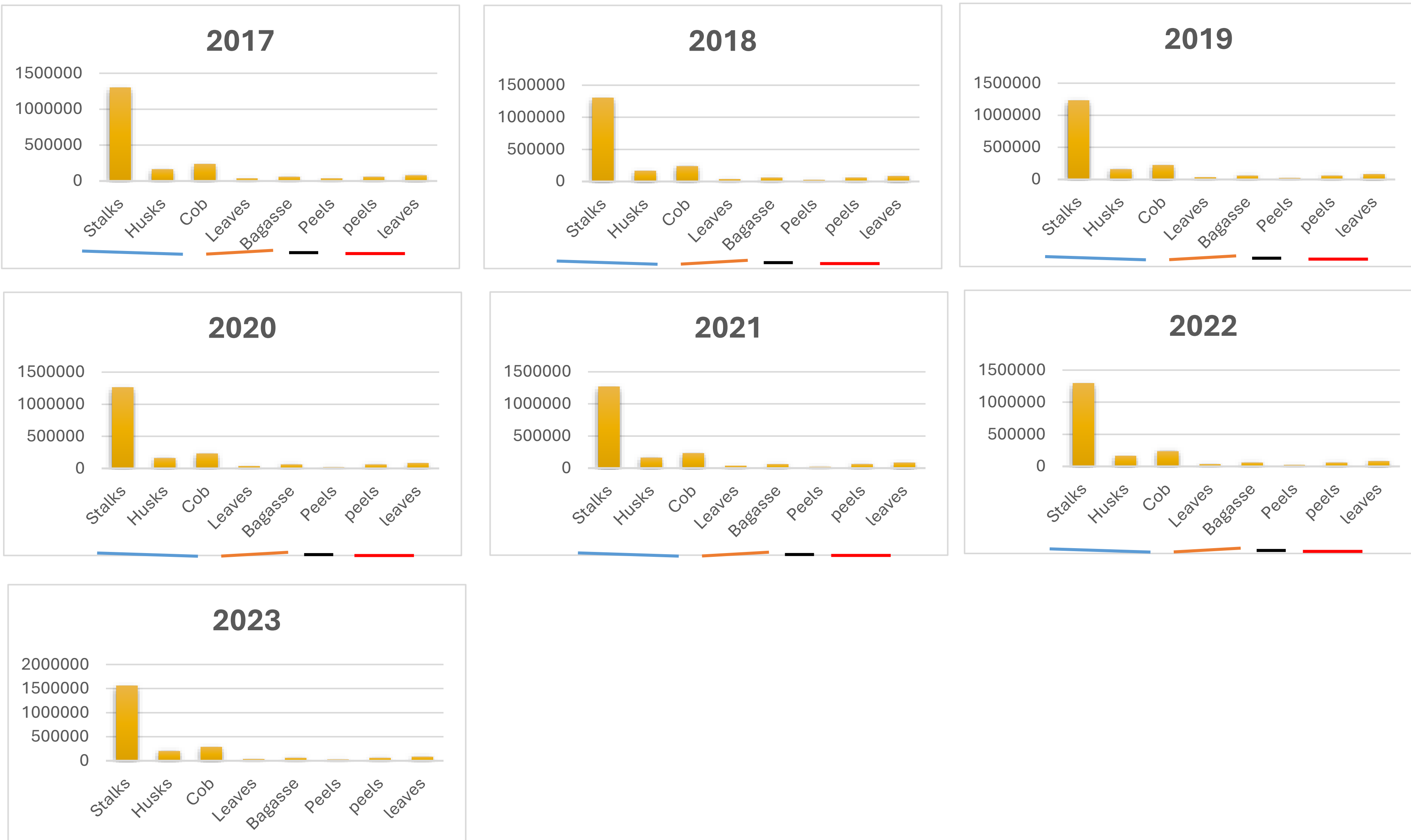

Figure 30 : The theoretical potential of crops used for bioethanol (Group 3)

Figure 31: The theoretical potential of crops used for biodiesel (Group 1)