energies

Article

E-Technology Enabled Sourcing of Alternative Fuels to Create a Fair-Trade Circular Economy for Sustainable Energy in Togo

Essossinam Beguedou [1,*], Satyanarayana Narra [1,2], Ekua Afrakoma Armoo [1], Komi Agboka [3] and Mani Kongnine Damgou [4]

1 Department of Waste and Resource Management, University of Rostock, 18059 Rostock, Germany
2 German Biomass Research Centre gGmbH, 04347 Leipzig, Germany
3 West African Service Center for Climate Change and Adaptive Land Use (WASCAL), University of Lomé, Lomé P.O. Box 1515, Togo
4 Department of Physique, University of Lomé, Lomé P.O. Box 1515, Togo
* Correspondence: essossinam.beguedou@uni-rostock.de

Abstract: Sustainable energy projects in Africa are particularly vulnerable in terms of sourcing vital alternative fuels due to the complexity of sourcing processes, contract agreements and relationships between society managers or directors and supplier chain entities. These challenges can affect any phase of a sustainable project, and the losses can be as high as 3.2 EURO/GJ. In addition, there is reduced competition and fair trade, low profits and poor quality of the fuel purchased. Technology (mobile application) is one powerful tool that can solve the above challenges by controlling or managing the supply and demand of biomass-based fuels, agriculture residue, industrial waste and many more. Thus, the main objective of this study is to evaluate the feasibility of a developed digital platform to remove barriers in the trade of alternative fuels. Data collection began with the identification of the key production areas (sources) and quantities of three selected AFs. Secondly, data on the seasonal variations in alternative fuel (AF) quantities were obtained from the identified locations. Thirdly, the acquisition costs were calculated based on the quality and characteristics of the AFs. Results were then transferred into a mobile application where industries could assess, compare, and bargain for AF based on quality and price. Due to the introduction of competitive pricing, overall, the mobile application improved the savings on sourcing for AFs by industries by 2.89 EURO/GJ. In terms of profit optimization, the farmers have value for money and fair bargaining for their products, thus increasing their revenues for the planting season. It was also observed that the cost of the fuel was based on the proximity of the source to the demand industry. In conclusion, the mobile application facilitates a circular economy between the farmers, suppliers and industries where industries receive fair and competitive prices for their fuel whiles farmers receive extra income for farming businesses and agricultural waste is sustainably managed through a circular economy.

Keywords: circular economy; Africa; Togo; bioenergy; mobile application; supply chain; alternative fuel (AF); risk husk; palm kernel shells; cashew nutshell; cost optimization; profit optimization; e-commerce

check for updates

Citation: Beguedou, E.; Narra, S.; Afrakoma Armoo, E.; Agboka, K.; Kongnine Damgou, M. E-Technology Enabled Sourcing of Alternative Fuels to Create a Fair-Trade Circular Economy for Sustainable Energy in Togo. *Energies* **2023**, *16*, 3679. https://doi.org/10.3390/en16093679

Academic Editor: Seung-Hoon Yoo

Received: 9 March 2023
Revised: 17 April 2023
Accepted: 21 April 2023
Published: 25 April 2023

1. Introduction

Industrial energy in Africa is mainly sourced from fossil fuels, especially in the production of building materials such as concrete and cement [1]. Due to the high reliance on fossil fuels, the conflict between Russia and Ukraine has caused a significant decrease in the share of sustainable energy in the primary energy supply [2]. In addition, the fluctuating energy prices and environmental and energy security concerns have also become major drivers for the adoption of alternative energy [3].

Africa's vast land and agricultural resources provide an opportunity for biomass-based renewable energy production, including waste which has the potential to replace and reduce the dependence on fossil-based energy [4]. Since biomass combustion can potentially be CO_2 neutral, using it to partially replace fossil fuels is crucial from an environmental standpoint to combat global warming [5]. Agricultural leftovers, which are periodically planted and collected, are a good example. However, it is critical to stress that agricultural leftovers differ from other wastes and coals in having greater volatile matter levels [6,7].

Due to the impact of the new international energy and environmental regulations over the past ten years, the evolution of bioenergy demonstrates a departure from the initial approach [8]. Undoubtedly, the role of agriculture and particularly the policies and strategies on the circular economy and bioeconomy have changed because of the worldwide regulatory framework on sustainable development. Based on industrial innovation and cutting-edge technology, new and improved methods for recovering agricultural waste have been created, helping to ensure resource efficiency, sustainable production and consumption, and the mitigation of adverse environmental effects [9].

Renewable energy is a critical component to fulfilling rising energy needs and combating climate change, yet its potential bottlenecks are frequently ignored. Given the close relationship between ecology and climate, it is essential to consider the complete range of global environmental problems when evaluating the consequences of energy technologies [10]. Without mitigation policies and actions, global GHG emissions are predicted to rise by 42% to 30 million tons in 2030. While SLCPs (Social & Labor Convergence Program) and air pollutants were projected to decrease more, with a more than 75% reduction in black carbon emissions in 2030, the adoption of the ten prioritized mitigation measures might reduce GHG emissions by around 20% in 2030 compared to the baseline [11].

Meanwhile, over the past ten years, several African countries such as Ghana and Togo have experienced a gradual transition away from hydroelectric energy dependence toward thermal energy, which is powered by light crude oil, unprocessed coal, and occasionally natural gas. As a result, Togo's carbon footprint has plummeted, sending troubling indications of non-abatement. Togo's Greenhouse gas (GHG) emissions for 2018 came primarily from the energy and agriculture, forestry, and other land use sectors [12].

Promoting AFs can create new market opportunities and reduce the carbon footprint. The promotion of AF uses in industrial applications have the potential to create new market opportunities for rural and peri-urban communities while also providing Togolese industries the opportunity to reduce the carbon footprint of their products, thus moving closer to goals in sustainability and carbon neutrality. Expanding economic opportunities also has a potential developmental impact on communities, such as improved infrastructure, education, water supply, sanitation etc. [13]. In countries like Togo, research on the valorization of agricultural waste has focused on conversion to biogas and compost. For instance, elephant grass adapts to varied environments and can be used as an alternative fuel in cement factories [6]. However, very little has been done on the conversion to energy at an industrial scale.

It has been demonstrated that in 2022, co-processing could integrate 25.5% of the agricultural waste produced in Togo into the sustainable waste management paradigm. Moreover, by 2023, clean energy produced from renewable sources has the potential to replace 27.0% of the cement energy used in Togo. Therefore, selling agricultural waste to cement plants for co-processing would be one way to integrate the agricultural waste part into the circular macro-economy. Consequently, the amount of money earned can range from EURO 25.5 per day in 2022 to EURO 45.5 per day in 2027 [14].

Togo can potentially develop a specific program of zero agricultural waste on farms, eliminating uncontrolled landfills, using circular macroeconomic indicators. In Togo, waste products from agricultural processes are discarded or burned in the open, leading to no value of waste. This calls for increasing environmental consciousness among Togo's urban society and agricultural communities [13]. In this regard, more efforts are needed in business research and market studies for the proper implementation of a circular macro-economy-based agricultural waste management plan. Further research lines could be created as a result to consider the needs of the market, logistics, and other business-related factors.

As part of its Health and Safety Environment policy, the Togolese clinker industries have committed to complying with national and international environmental, climate and social responsibility standards. Some Togolese clinker plants have made some efforts in this direction by obtaining an ISO 14001 certification (2015) and BS OHSHAS 18001 "Occupational Health and Safety Assessment Series" (2007) [6]. In addition, as part of its 2030 Sustainability Strategy, Togolese clinker industries have been targeted to reduce their environmental footprint, facilitate the circular economy, and develop good farmer cooperatives through support for social and economic development [15]. To achieve these objectives, Togolese clinker plants have expressed great interest in gradually substituting imported coal with agricultural waste [6]. Agricultural waste is regarded as a green alternative fuel because of its potential to recover energy from biomass which would otherwise contribute to climate change [16]. In addition, these alternative fuels have the potential to enable Togolese clinker plants to facilitate their green energy transition and thereby reduce their environmental footprint [17].

1.1. Current State of AF Sourcing in Togo

Figure 1 represents the most common method farmers use to manage agricultural waste—burning. However, the sourcing of the waste underpins the potential use of agricultural waste and creates a green economy. This economy is controlled by three major players: the source (usually the farmers); suppliers (middlemen); and demand (industry), as shown in Figure 1a—the linear model in Figure 1b represents the current (conventional) industrial AF sourcing process. The process is initiated by the industry (demand), which contacts various suppliers across the country for specific AFs. However, the farmers are not involved in these discussions or negotiations, and the industries are not aware of the selling price of the farmer to the supplier. In addition, it is difficult to create a fair tendering and selection among several suppliers since some suppliers may not be contacted during the sourcing process. This means the market and prices are controlled by the suppliers, while farmers and industries may both be defrauded. The major setbacks in the linkage between these actors are selling price transparency and negotiations. This opens up a monopoly, low competition, potential unfair pricing and selling prices for poor rural farmers and high operational (energy) costs for industries.

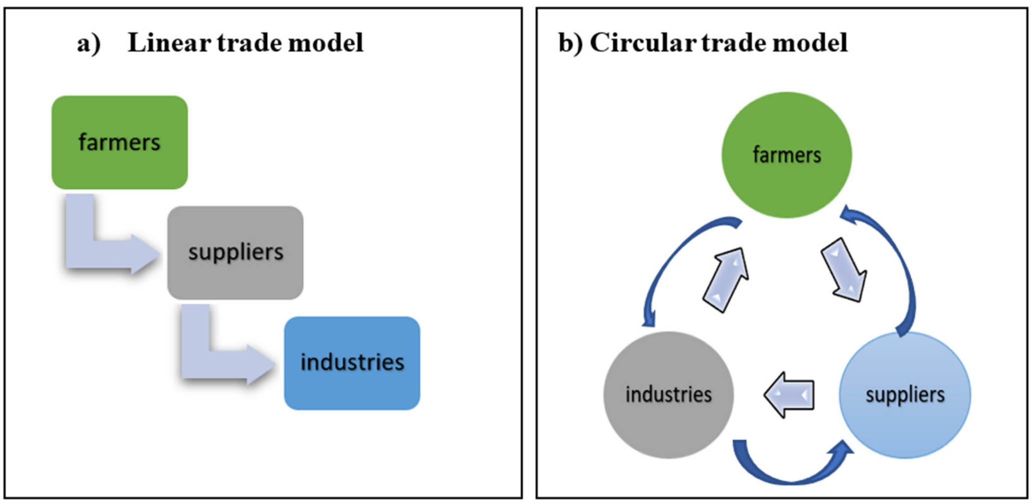

Figure 1. A comparison of the relationship between stakeholders in the linear trade model (**a**) and the circular economy model (**b**).

1.2. The Potential Role of E-Technology in AF Sourcing

There have been several attempts across Africa to use ICT to increase market information access, with mixed results in terms of expected consequences. Across Africa, sustainable energy applications face limitations due to limited literacy, tariffs, handset technology, and internet connectivity. Mobile phone technology has improved exchange and logistics efficiency in commodity markets, addressing information asymmetry in agricultural value chains and improving market transparency for informed business decisions.

Small-scale farmers and traders who operate in rural areas typically have less negotiating power than informed metropolitan consumers. Likewise, increased market transparency is crucial for traders, logistics professionals, manufacturers, and even policymakers and regulators to make educated business decisions (e.g., regarding inputs, commodity supplies, demand, prices, etc.). A customized mobile phone-based biomass market access system S.E-App will be codesigned with key stakeholders to increase transparency in the biomass value chains. Small-holder farmers grow a variety of crops and goods for their consumption and as a source of income. However, they frequently lack advanced production methods, resulting in huge amounts of leftover residues with no known uses.

While in development, the S.E-App should address several issues, such as the limited literacy of rural users regarding text-based messaging, expensive tariffs, handset technology (smart versus non-smart), a lack of affordable internet connectivity for APP-based systems, and a lack of incentive and motivational structures to use the system in the first place when the intended deal was not guaranteed to materialize [16].

The objective of this study is, therefore, to assess the feasibility of innovative digital tools in creating a transparent circular market for the trade of AFs which will facilitate the circular economy of biomass, agricultural waste, municipal waste, industrial waste and AFs in Togo [18]. The scope of the research is to assess at two levels: the technical feasibility of the app to create the platform to link all three stakeholders (Figure 1b) and the economic impact on the farmers and industries. Therefore, this research analyzes the impact of introducing e-technology into sourcing AFs on three stakeholders in the value chain: farmers, suppliers, and industries. As a result, it envisages that e-technology will transition from the current linear sourcing model into a transparent circular economy outcome.

2. Methodology and Description

This study forms part of the national strategy of ecological transition and social responsibility, «Health Safety Environment». The study was carried out to guide the Togolese clinker plants' choices in its new energy mix, which should ensure a transition to greener fuels. Specifically, the study targeted fuels from (i) palm tree residues (Palm Kernel Shells), (ii) cashew nuts (Cashew Nutshell), and (iii) rice residues (Rice Husk).

The information sought by each of the targeted fuels is (i) major production households, (ii) the quantities produced or available and their seasonal availability, (iii) the acquisition cost, and (iv) the company's optimal and sustainable fuel acquisition strategy. The study affected all the Maritime, Plateaux, Kara and Central regions in Togo and the departments of Mono. The study methodology is based on a traditional exploratory approach to market research. It includes a participatory mapping approach, field surveys of fuel producers, local authorities, and decentralized agricultural/forestry departments [19].

2.1. Data Collection

Data were collected over a six-month period through a farmer exploration tour from 20 January to 18 August 2022. The types of agricultural wastes selected under this study are Palm Kernel Shells (PKS), Rice Husk (RH) and Cashew Nutshell (CNS).

A total of 9 collection teams, composed of a pair of two collection agents under the supervision of 2 experts, were deployed. These teams were supported in the field by local guides selected from each community visited [19].

Questionnaires were personally administered, and interviews were conducted with groups where necessary. Both qualitative and quantitative data were collected on the volume and composition of agricultural waste from each site visited and during the interviews. To achieve the specific objectives of the study, data on the distribution of the production areas of the fuels concerned, the quantities produced or available, their current uses, the current outlets for these combustible residues, unit prices and availability periods for these products were collected [20,21].

Three sources of information were used: (i) basic field data, (ii) agricultural statistics data and (iii) study reports. Field surveys were carried out with local authorities (town halls and metropolis), producers (local factories and small enterprises, groups, cooperatives, etc.) and decentralized sectoral administrations in charge of the target sectors. The following methodology was used for each of the steps required for the study [22].

In each community, an individual questionnaire was administered to stakeholders to inform (i) the type of waste available, (ii) the quantity available and (iii) the period of availability associated with each type of waste available. The questionnaire was administered using the KoboCollect data collection tool. Existing data on production areas and production statistics were collected from the Directorate of Agricultural Statistics, Information and Documentation (DSID), town halls, technical directorates (ODEF, MAEP, etc.) and research papers on the sector and projects to support the agricultural sector (PASA, ProDRA, MIFA, etc.).

2.2. Study Area

A map of Togo is shown in Figure 2. According to data from the general census of agriculture in Togo [23], the oil palm industry is present in all five economic regions of Togo, but with an overwhelming majority of actors in the Maritime, Center, Kara, and Plateaux Regions. Rice production is, however, practiced more in the Maritime, Plateaux, and Savannah regions. However, cashew (CNS) has a limited distribution in Togo. It is almost non-existent in the district of Mono and Couffo. Its production area is mainly limited to the Central region (the metropolis of Tchamba, Sotouboua and Blitta) and the northeast of the Plateaux region (metropolis of Est-Mono and limited locations in Anié). Some smaller plantations are found in the Kara region and the western part of the Plateaux region [24].

Regarding the geographical position of Togolese clinker industrial plants and the objectives of this study, which aims, among other things, to optimize the supply, the present study focused on the Maritime region (Gulf, Agoè, Zio, Avé, Yoto, Bas-Mono and Lakes), the Plateaux region (Agou and Haho) and the Central Region (Tchaoudjo, Tchamba, Sotouboua, Kara and Blitta) [25].

2.3. Mapping of the Source Centers of Agricultural Waste

The mapping of production households (source of agricultural waste) was done by a participatory mapping approach combined with using available cartographic data on Togo [26]. The participatory mapping approach enabled the local authorities and stakeholders to provide invaluable information and made it possible to identify the major waste production areas more precisely.

Consequently, the respondents refined these areas initially extracted from the existing maps. The resulting participatory maps were then digitized and exported based on the categorization of the types of waste. All mapping work was done using QGIS 3.22 software [27].

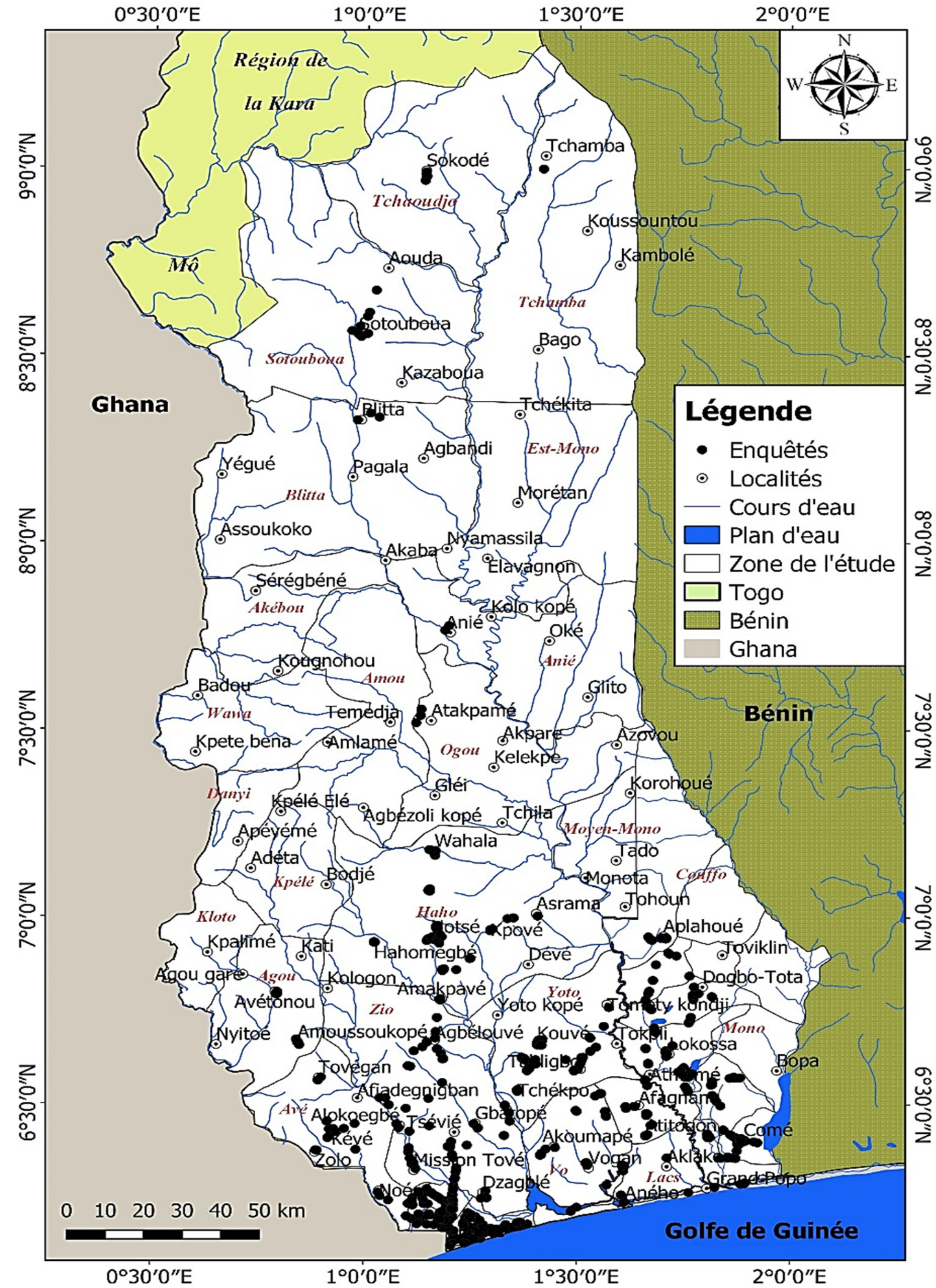

Figure 2. Distribution of respondents in the target study area: (Légende = legend; Enquetes = survey; localites = location; cours d'eau = rivers; plan d'eau = sea; zone de l'etude = study area).

2.4. Assessment of Resources and Their Seasonal Availability

Based on oil palm fruit production and a conventional exploitation account of the processing of one ton of oil palm fruit [28], and by drawing on the work of (DET Athiémé, 2014), an estimate of the production of combustible waste was made for each municipality or metropolis. Based on the operating account of one ton of fruit, it is estimated that 450 kg of shells (45% of the weight of the raw material) and 46 kg of dry pulp (equivalent to 4.6% of the weight of the raw material) are produced [29,30].

In the case of Cashew Nutshells (CNS), the study focused on the dehulling plants of the companies in Tchamba, Sokode and Blitta because they are the only producers of this type of fuel in the country.

By also applying the fruit shell rate of 70% and the degree of self-consumption of these shells by the company itself, it was also possible to estimate the available stocks [31,32].

In the case of Rice Husk (RH), the survey concerned the technical directorates of agriculture and agricultural groups. The quantification of the available resources was also done based on bibliographic knowledge of the quantity of Rice Husk in a ton of rice grains. Indeed, one ton of rice grain produces about 210 kg of rice husk, or about 21% of the raw material [33], MERF (2017) [34].

Based on individual questionnaires (for individuals and companies) and some focus group discussions (for cooperatives, trade unions, associations, groups, etc.), the current patterns of use and the level of self-consumption of residues were assessed. On this basis, an estimate of the selling price of the available residues was made (which are not self-consumed) based on information from the municipalities or, failing that, the metropolis or districts. This cost is expressed per gigajoules after weighing and assessing the waste or residues.

Post-harvest technology demonstrations were decentralized at rice mills or agro-transformation side of partner cooperatives to show the viability of various methods for pressing, pelleting, and transporting rice husks as an AF. To provide a flexible demonstration tool for the addition of agricultural leftovers from other sources into the innovation value chain, these demonstrators are designed to be semi-mobile so they can be moved between partner universities for research.

2.5. AF and Raw Coal Laboratory Analyses

Laboratory analysis was conducted on AF samples collected from the various farms during the exploratory tour. This was compared to coal in terms of the lower heating value (LHV) to assess its suitability for substitution in cement kilns.

2.6. App Development and Utilization

To improve transparency in the sustainable energy value chains, a tailored mobile phone-based biomass market access system was designed with key stakeholders [19,35]. Despite the widespread usage of smartphones, Togo has poor mobile internet coverage in sub-Saharan Africa.

According to Figure 3, the Unstructured Supplementary Service Data (USSD) is positioned as a conduit for delivering corporate mobile services to this consumer category. Therefore, messaging Unstructured Supplementary Service Data (USSD) and an Android application (S.E. App) were developed to provide services to smart and non-smart mobile phone users. Additionally, a web application was developed to enable communication between an Android app and a messaging site on the S.E-App server, as shown in Figure 3.

One of the important communication options for achieving a circular economy is the creation of a flexible SMS-based or Unstructured Supplementary Service Data (USSD) capability for Android apps that can run in areas without internet. This Android app's interactive user-friendliness and demonstration of the system's effectiveness and utility in the circular economy are impressive [36]. The app underwent testing over the course of three months.

An integrated demand-driven user incentive and motivation structure was featured within the Android app known as the S.E-App. The system has demonstrated that it can control the industry's price gaps and make more profits [35,37].

2.7. Economic Analysis

The economic analysis involves a comparative analysis of the three biofuels based on their cost of app usage, energy savings, and average purchasing cost savings. S.E-App cost optimization was calculated as the cost of using the application for the supply chain. The total cost optimization is the difference between the S.E-App cost optimization and the CAPEX used for implementation of the e-commerce application. The payback is the savings accumulated during operation in a year.

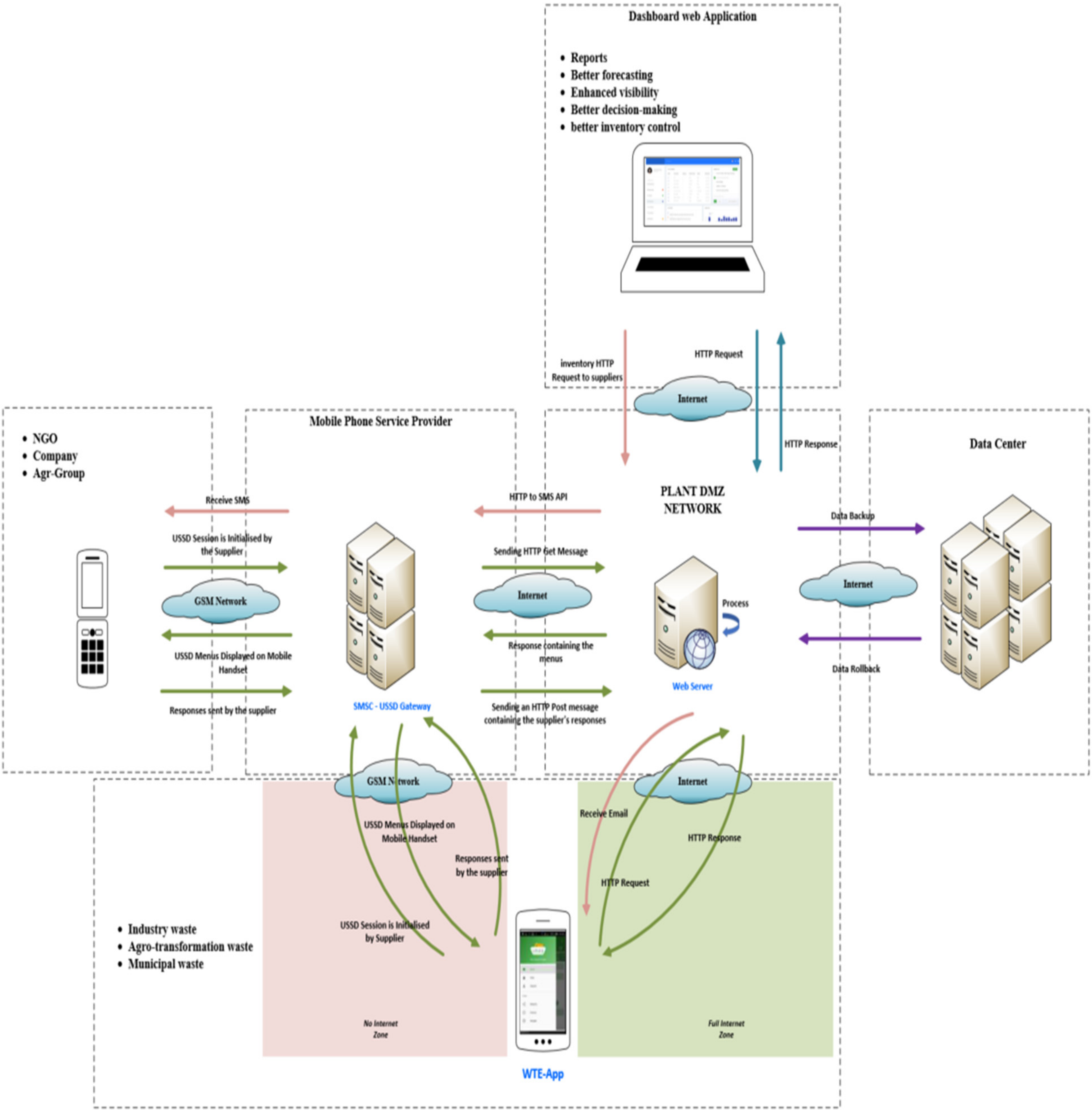

Figure 3. S.E-App Communication Map.

3. Results and Discussions

3.1. Identification of Potential AF Supply Locations through the Farmer Exploration Tour

A total of 664 farmers (respondents) in Togo were identified to be involved throughout the study area (Table 1(a&b) and Table 2 & Figures 2 and 4–6). There was a predominance of individual respondents (73.19%), with small farming businesses/companies representing 25%. Based on the individual waste produced per farm, at least 182,000 tons of combustible waste are available each year in the study area from the respondents alone.

Table 1. (**a**) Extent of available Palm Kernel Shell fuels in the country. (**b**) Distribution of respondents by types of AF produced.

(**a**)

Area	Avé	Bas-Mono	Lacs	Vo	Yoto	Zio	Agou	Haho	Ogou	Total
Husk produced (t)	7538	8016	4007	10,668	18,411	20,790	6737	14,522	15,413	106,104
Husk available (t)	4061	4318	2158	5747	9918	11,200	3629	7823	8303	57,158
Pull produced (t)	771	819	410	1090	1882	2125	689	1485	1576	10,846
Pull available (t)	678	721	360	959	1656	1870	606	1306	1386	9541

(**b**)

Type of Residues	Number	Percentage
Palm Kernel Shell	486	73.19%
Rice Husk	102	15.36%
Cashew Nutshell	76	11.45%
Total	664	100%

Table 2. Distribution of type of respondents and their location.

Type	Grand Lomé	Other Region	Total
Physical Person	131	355	486
Companies	17	149	166
Cooperatives/Association	3	6	9
Others	0	3	3
Total	151	513	664

Figure 4. Rice husk stockpile burned as waste.

Photograph of Palm Kernel Shell

Photograph of pulp

Figure 5. Palm Kernel Shell (PKS) waste.

It was observed that about 62.5% of farmers practiced burning dried farm waste, which could potentially be converted into economically valuable goods for industrial energy. In addition, based on the potential quantities of agricultural waste produced, greenhouse gas emissions are potentially very high and unsustainable for the environment.

The largest waste type is oil palm residues, with over 73,000 tons of Palm Kernel (PKS) Shells and 12,000 tons of pulp available annually, for a total of 85,000 tons of residual palm-based biomass fuel. The focus of production of these PKS fuels is the Maritime region in Togo. They are followed by logging residues from which more than 54,000 tons of fuel can be potentially mobilized, mainly in the Zio, Yoto, Haho and Blitta areas. Because of its widespread use in households, palm nut pulp and logging residues could be subject to higher price growth than other fuels. The lowest acquisition prices are currently associated with logging tailings deposits.

3.2. The Spatial Distribution and Quantities of Alternative Fuels

3.2.1. Rice Waste-Based AF

Rice is a major food crop grown in Togo, mainly in the shallows and flood plains of the rivers. A total cultivated area of 81,601 ha was recorded in Togo in 2016 (INSEED, 2016). In all economic regions of the country, gross production is estimated at 140,952 tons of paddy rice (Table 3). The largest producers at the national level are the metropolis of the Savannah region (Tône, Oti and Kpendjal), but in the two southern regions of the country, the metropolis of Zio and Bas-Mono in the Maritime, Akébou, Anié, Haho and Amou in the Plateaux are also areas of high production.

Two types of combustible residues are produced from the cultivation of rice. These are rice straws and rice bales. The former are usually burned on-site or paid for by traditional mattress manufacturers (to a lesser extent). At the same time, the rice bales are produced in the peri-urban areas of the production areas. Derived from the husking of rice grains, bales are, to a large extent, the main type of fuel that can be mobilized from rice. The quantity of rice bales produced is estimated at 29,600 tons, of which 21,706 tons are movable (MAEP, 2022).

Middlemen collect rice husks from various farming communities at different locations. Location highly influences the transportation cost (very light material). The material was received and ready to feed [38,39].

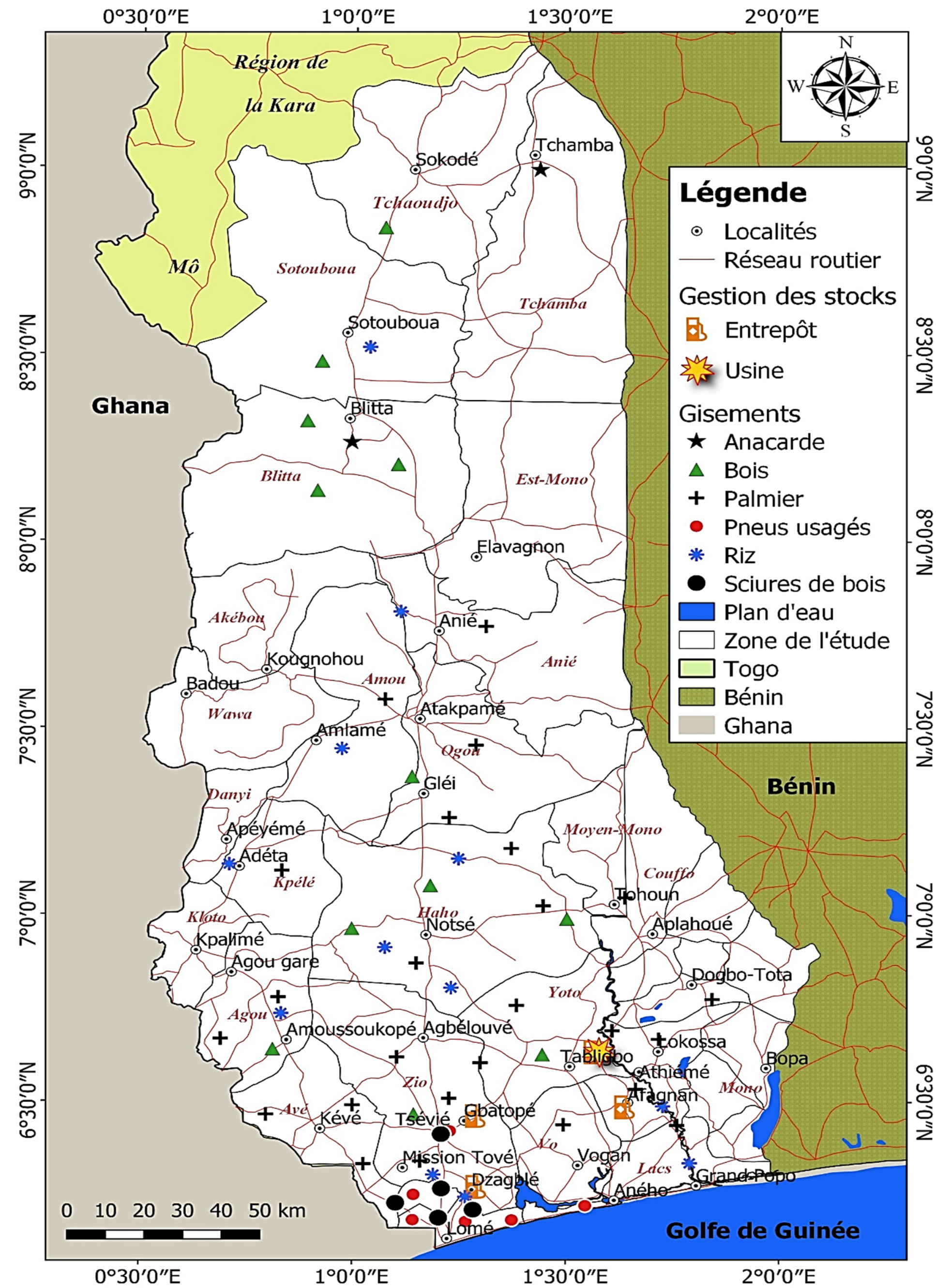

Figure 6. Agriculture Residue Supply Circuit in the Study Area: (usine = plants, gisements = wastes, anacarde = cashew, bois = wood, palmier = palm trees, pneus usages = waste tires, riz = rice).

Table 3. Paddy rice and rice bale production in the study area.

Area	Surface (ha)	Production (tons)	Rice Husk Produced (tons)	Mobilizable Rice Husk (tons)
Maritime	8568	17,931	3766	2761
Plateaux	23,053	25,380	5330	3908
Centrale	12,062	21,023	4415	3237
Kara	11,958	20,216	4245	3113
Savanes	25,960	56,402	11,844	8686
Total	81,601	140,952	29,600	21,706

3.2.2. Palm-Based AF

The mapping of palm grove areas shows a very good geographical representation of oil palm cultivation in the agricultural landscape of the study area. Indeed, the plant is grown all over the area, making it the first cash crop of the Maritime region and the municipalities along the Mono in Togo. In total, three major palm groves stand out in the study area. These are the palm grove areas of the Zio and Haho valleys (comprising the metropolis of Agou, Zio and Avé), that of the lower Mono valley (including all the municipalities of Benin and the metropolis of Yoto, Bas-Mono, Vo, and Lakes), and that of the high valley of Mono (the metropolis of Haho, Ogou and Middle Mono).

The oil palm tree is the first cash crop in the study area in Togo. Four types of combustible residues are produced from oil palm. These are leaves, diet stalks, fruit pulp, and nut shells. The latter (fruit pulp and nut shells) have such high energy potential that they are subject to sustained marketing despite considerable self-consumption. Indeed, the hulls are sought by blacksmiths and cement production plants to feed their kilns and incidentally for building to replace the gravel in the concrete [40].

Pulp (called "kpelebs") is generally sold to households as a fuel or accelerator for the combustion of other fuels (Figure 5). In recent years, almonds have been less and less processed into palm oil. Instead, they are sold directly to traders who export them to Nigeria and Ghana.

Of the total area of 183,372 ha of natural palm groves recorded in Togo as part of the national agriculture census (MAEP, 2013), about 77,145 hectares are found in the Maritime region (42.1%) and 93,804 hectares in the Plateaux region (51.2%). Most oil palm fuel deposits are found in Zio, Yoto, Ogou and Haho (Table 1). With an average level of personal consumption of 46.13% for the hulls, the fuel available in the study area amounts to 73,153 tons of hulls, including 15,995 tons in Benin and 57,158 tons in Togo.

Middlemen collect Palm Kernel Shells from various farming communities at different locations. A farther location will pose a challenge in terms of cost transportation. Currently, this is the most available option. The material is received and ready to feed.

3.2.3. Cashew Waste-Based AF

Cashew is the most promising cash crop in the sub-humid regions of Togo. For a total area of 33,196 ha recorded in Togo as part of the national agricultural census (MAEP, 2013), about 14,969 hectares are found in the Plateaux region (45.1%), 12,208 hectares in the Central region (36.8%) and 3543 ha in the Kara region (about 10.7%). Most plantations are found in Tchamba, Est-Mono, Ogou and Blitta (Table 4).

Table 4. Cashew Plantations in the study area.

Zone	Blitta	Sotouboua	Tchamba	Tchaoudjo	Est-Mono	Ogou	Anié
Area (ha)	366	1173	7859	2682	8688	2294	3670
				26,732			

Only one type of combustible residue is produced from cashew processing. These hulls come from the shelling of nuts in the processing units. To date, only two structures known as «CAJOU ESPOIR and CAJOU CENTAL» are involved in this transformation.

The transformation plants are in Tchamba, Sokode and Blitta. With a processing capacity of fewer than 16,000 tons of cashew per year, the tree plants are unable to handle all domestic production, which was 27,360 tons in 2021. The surplus is exported indirectly via Benin or directly via the port of Lomé to Asian countries for processing.

The hulls produced in both plants are estimated at 8290 tons, of which approximately 60% would be available for sale. This equates to 1974 tons of currently available cashew hulls (Table 5), showing a potential of approximately 11,491 tons of movable cashew hulls if all domestic production were processed on-site.

Table 5. Cashew Shell Production by Cashew Hull Processing Plants.

Plants	Cashew Transformed (t)	Cashew Nutshell Produced (t)	Available Cashew Nutshell (t)
Cajou Central	12,000	8400	5040
Cajou Espoir	4700	3290	1974
Total	16,700	11,690	7014

Based on the type of waste available, the prices on the market and the configuration of the sector, a proposal for a supply channel has been made to ensure a sufficient supply and fuel efficiency in Togo. This model considers all observations made on the ground in relation to the production and organization of the actors at the base. These observations were the subject of an analysis of the strengths, weaknesses, opportunities, and threats of the fuel supply chain.

Data collecting allows us to save and analyze important information about our existing and potential suppliers. It is speedier and less expensive than in-person data and removes any potential bias or human error from the data obtained. As there is no room for human error or careless data entry, information may be entered directly into the system without using paper, resulting in greater accuracy and complete control over the interviewing process. In addition, information can be verified in real-time for trash types, regional waste, and finished, incomplete, and dropped entries.

3.3. Laboratory Results—Comparative Study with Coal

As shown in Table 6, raw coal's lowest heating value (LHV) is approximately 23,500 KJ/kg. The LHV of the used cashew nutshell is about 26,537 KJ/KG, but the moisture of the coal is high due to open storage, but still within target [39]. Therefore, the co-processing percentage is 10.7% of the total raw coal for each residue sample.

Table 6. Fuels Laboratory Analysis.

Biomass	Moisture	Q(net) [KJ/kg]	SiO_2	Al_2O_3	Fe_2O_3	CaO	MnO	TiO_2	MgO	K_2O	Na_2O	SO_3	P_2O_5
CNS	5.5	26,537	57.4	11.72	6.9	2.55	0.02	1.04	0.96	2.91	0.16	1.56	14.45
Rice Husk	8.68	12,731	99.16	0.13	0.00	0.57	0.00	0.00	0.00	0.00	0.00	0.00	0.31
PKS	10.1	18,737	83.43	8.78	4.25	3.3	0.09	0.8	0.31	0.79	0.12	0	0.25
Raw coal	8.2	23,500	61.8	25.6	3.4	2.1	0.01	1.2	0.8	1.9	0.1	1	1.3

3.4. Economic Analysis

The original energy delivery costs are those made to the cement factory without the use of the S.E-App. In the same way, as rice husk's supply cost is 32.06 EURO/t by considering the fuel LHV (12.23 Gj/t) and moisture content (8.56%), cashew shell's delivery price of 44.08 EURO/t is impacted by fuel transportation due to the low density (0.4). This results in an energy cost that is 3.11 (EURO/t).

In addition, for the PKS energy cost, the material impurities impacted the LHV, which resulted in a higher energy cost of 2.27 (EURO/t) as illustrating in Table 7.

Table 7. Cost of fuel.

Items	Fuel	Purchasing Cost		Lab Data		Energy Cost as Landed (EURO/Gj)
		Energy Cost (EURO/t)	Energy Cost (EURO/Gj)	Fuel Moisture Average%	Fuel LHV (Gj/t) Average	
Initial Energies Cost	Raw Coal	67.18	2.28	8.50	32.22	2.47
	Cashew Shell	44.08	2.40	8.34	20.04	2.60
	PKS	32.82	2.06	10.20	17.76	2.27
	Rice Husk	32.06	2.87	8.56	12.23	3.11
S.E-App Cost Optimization	Cashew Shell	12.21	0.66	8.34	20.04	0.72
	PKS	18.32	1.15	10.20	17.76	1.27
	Rice Husk	16.79	1.50	8.56	12.23	1.63
Cost Optimization	Cashew Shell	7.63	0.42	8.34	20.04	0.45
	PKS	6.87	0.43	10.20	17.76	0.47
	Rice Husk	5.34	0.48	8.56	12.23	0.52

3.4.1. Capital Cost (CAPEX)

The management of the global energy matrix continues to be dominated by the replacement of AFs. Energy sustainably accounted for 30% of fossil energy consumption from renewable sources worldwide as of 2016. This translates into about 56.5 EJ. The percentage of renewable energy in the global energy mix is expected to increase to 60% to about 108 EJ, IRENA 2022a, by 2030. This is expected to substitute for 20% of the total fossil fuel energy supply [41].

S.E-App and cost optimization integration have been shown to be beneficial only if substantial energy and OPEX cost savings are obtained [35]. Table 8 shows the platform used (USSD or mobile application) and the development cost.

3.4.2. Operation and Maintenance Costs (OPEX)

At the industry level, labor became more expensive to replace fossil fuels with AFs. Instead of one, there should be 13 shift assistants. In addition, given the workplace, there was always a need for relief workers. Therefore, the crew dealt with less taxing chores like maintaining the weight in the storage area while rising to the second floor and hauling products to the third floor while offering relief. The contract indicated that two workers would be assigned to the PKS load and an additional two to the CNS load.

Two workers are needed to feed the smoke chamber; one person is required as a relief when the hoists are operating, and one worker is needed for less laborious tasks. Additionally, two laborers are required to feed at the pre-calciner and two laborers to move the material from the elevator to the feed point; one relief on miscellaneous jobs and, eventually, the hoist operator.

The daily replacement rate was roughly 10.7%, which equates to 45 tons per day (t/d) of coal being substituted (50 tons per day (t/d) of PKS, 69 t/d of RH, and 39 t/d of CNS). The average labor cost per employee per day was 6.1 EURO/cap/d.

The human cost was only 0.14 EURO/Gj, yet the procedure was only partially automated; the feeding was done by hand. In addition, directors received a management bonus of approximately 6.8 EURO/Gj and 4.3 EURO/Gj, respectively, for their oversight and project performance [41].

Table 7 above illustrates the impact of the sustainable project on local communities.

Table 8. CAPEX needed for USSD and the S.E-App System.

Category	Activities	Unit	Quantity	Daily Cost Excluding Tax (Euro)	Total Cost (Euro)
USSD BUDGET					
Euro	Code	Numbers	2	763	1.527
	Maintenance	Month	12	69	824
S.E-APP DESIGN BUDGET					
Conception and creation	Mission Farming	Day/Man	10	158	1.527
	Preliminary study, collection, analysis and processing of data	Day/Man	15	229	3.435
Platform development (web and mobile application)	Conception, programming	Day/Man	60	458	27.481
	Preparation of the procedure manual	Day/Man	10	299	2.290
	Commissioning and operationalization	Day/Man	10	305	3.053
	Control and quality assurance tests	Day/Man	20	229	4.580
Training and support for users	Skills transfer	Day/Man	15	229	3.435
System monitoring and user support	Periodic update and maintenance (fixed price)	Month	12	763	9.160
Total investment (Euro)					54.96183

3.4.3. Payback Period (PBP) for the Use of the Application

The saving is impacted by the purchasing prices of biofuel, which also affect industrial profit, which can be explained by their low revenue.

3.4.4. Economic Impact of the SE-App

The economic impact of integrating the SE-App into AF sourcing is assessed on the economic gains for (a) the industries and (b) the farmers.

a. Direct savings to Industries

Table 5 shows comparative costs before and after the integration of e-technology into the supply chain. The energy costs were calculated by considering the residual moisture content of the fuel, as demonstrated in Table 9: Saving and Payback of using USSD technology. Furthermore, the savings estimates suggest a net positive difference in procurement purchasing service of more than 65%, or 1.89 EURO/GJ for CNS, 1.22 EURO/GJ for RH, and 1.56 EURO/GJ for PKS.

Table 9. Saving and Payback of using USSD technology.

Time	Y1	Y2	Y3	Y4
Expenses EURO	63.04427	9.9847	9.9847	9.9847
Sustainable Energy Budget (Kt/Y)	10.7	25.5	30.5	50.87
Saving EURO	118.800	420.750	503.250	839.355
Payback EURO	55,755.73	410,765.3	493,265.3	829,370.3

When the 3.61 EURO/Gj cost of fossil fuel is considered the landing cost, the savings are around 2.89 EURO/Gj, or nearly 80% of the reduction in fossil fuel cost.

b. Direct income to farmers

Using an e-technology system, this application improved the effects of e-commerce adoption on the household income of Togolese farmers. Before the application usage, the small-holder farmers' prices were cashew nut shell (0.52 EURO/G), PKS (0.45 EURO/G) and Rice Husk (0.62 EURO/G); by the development of e-commerce, the farmers selling increase—cashew nut shell (2.1 EURO/G), PKS (1.8 EURO/G) and Rice Husk (2.5 EURO/G). The findings indicate that e-commerce adopters earn much more money than non-adopters. This considerable income gain is mostly attributable to the correspondingly significant increase in sales income.

In addition, industry and agriculture are now acting in silo rather than synchronizing their efforts. This e-commerce platform bridged the gap in a way that benefits both parties, both for the sustainable production of biomass and the use of agricultural waste and by-products as a renewable energy source.

The concepts illustrated in this research article show the focus on establishing value chains ranging from producers via processing to transport entrepreneurs, suppliers and to end-users, offering the possibility to become a part of the energy portfolio of industry stakeholders from a variety of sectors in Africa, especially in Togo.

4. Conclusions

The development of information and communication technology (e-technology) systems has made it possible to enhance commodity market logistics and exchange efficiency. In addition, the increasing use of mobile phone technology in rural Africa has made it possible to overcome the information imbalance in the value chains for agriculture. Among the enhanced features of the e-commerce platform are

1. It provides services to smart and non-smart mobile phone customers by merging an Android app and messaging Unstructured Supplementary Service Data (USSD). To connect the message gateway of the S.E-App server and the Android app, a web API employing RESTful technology was designed.
2. Its flexible SMS-based functionality can function in areas with or without internet connectivity.
3. It is user-friendly and interactive. Continuous feedback from stakeholders was necessary for design modifications which translates into the system's effectiveness and usefulness.
4. It has frameworks for continuous customer engagement through user incentives and motivation within the S.E-App that are integrated with stakeholder demand. For example, it has been shown that including messages about human nutrition and health and some market information systems was just enough to keep farmers utilizing the system even when they could not reach a marketing agreement.

Integrating a mobile application was effective in the practical demonstration of a circular economy where farmers could directly market their alternative fuels and receive appropriate prices for their products. In addition, the app created a free and fair market where shady pricing is eliminated while sourcing products through bidding.

Local communities are important stakeholders in the circular economy, and optimizing supply chains for biomass-based, industry, and municipal waste is an important research area. Corruption in procurement cost processing explains this target to eliminate cost variations and gross margins.

This study did not consider the positive environmental impact of eliminating the burning of agricultural waste, which was diverted with an economic value for industrial uses. In addition, the economic gains, such as carbon credits from this system, may provide additional revenue for the financial feasibility of the e-commerce platform. Further research in this area is thus recommended.

Finally, the outcome of this study is expected to help decision makers make improved decisions related to waste supply chain applications for bioenergy consumption and integration of e-technology into energy markets.

Author Contributions: Conceptualization: E.B., S.N., E.A.A., K.A. and M.K.D. Methodology: E.B., S.N., E.A.A., K.A. and M.K.D. Validation: E.B., S.N., E.A.A., K.A. and M.K.D. Formal analysis: E.B. and S.N. Investigation: E.B. and S.N. Resources: E.B. and S.N. Data Curation: E.B. Writing Original Draft Preparation: E.B. Writing Review and Editing: E.B., S.N., E.A.A., K.A. and M.K.D. Visualization: S.N., K.A. and E.A.A. Supervision: S.N., K.A., M.K.D. and E.A.A. Project Administration: S.N. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Data Availability Statement: Not applicable.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Ukoba, K.; Kunene, T.J.; Harmse, P.; Lukong, V.T.; Chien Jen, T. The Role of Renewable Energy Sources and Industry 4.0 Focus for Africa: A Review. *Appl. Sci.* **2023**, *13*, 1074. [CrossRef]
2. Duho, K.C.T.; Abankwah, S.A.; Agbozo, D.A.; Yonmearu, G.; Aryee, B.N.A.; Akomanin, O. Exploring the Russo-Ukrainian War and Its Impact on African Countries: A Timeline Analysis. *Datakng Policy Brief* **2022**, *5*.
3. Azam, W.; Khan, I.; Ali, S.A. Alternative energy and natural resources in determining environmental sustainability: A look at the role of government final consumption expenditures in France. *Environ. Sci. Pollut. Res.* **2022**, *30*, 1949–1965. [CrossRef] [PubMed]
4. Zhang, X.; Wu, Z.; Zhang, X.; Li, L.; Li, Y.; Xu, H.; Li, X.; Yu, X.; Zhang, Z.; Liang, Y.; et al. Highly selective and active CO_2 reduction electrocatalysts based on cobalt phthalocyanine/carbon nanotube hybrid structures. *Nat. Commun.* **2017**, *8*, 14675. [CrossRef]
5. Werther, J.; Saenger, M.; Hartge, E.U.; Ogada, T.; Siagi, Z. Combustion of agricultural residues. *Prog. Energy Combust. Sci.* **2000**, *26*, 1–27. [CrossRef]
6. AfreePress. Énergie Renouvelable: SCANTOGO Mise sur la Biomasse Pour Faire sa Transition Énergétique. MERCREDI 22 JUILLET. 2020. [En ligne]. Available online: https://afreepress.net/2020/07/22/energie-renouvelable-scantogo-mise-sur-la-biomasse-pour-faire-sa-transition-energetique/ (accessed on 1 April 2023).
7. Khatib, I.A. Municipal solid waste management in developing countries: Future challenges and possible opportunities. *Integr. Waste Manag.* **2011**, *2*, 35–48.
8. Sun, W.; Sun, Y.; Xu, L.; Zhang, Y.; Ma, X. Under the Background of Carbon Peaking and Carbon Neutralization, a New Way to Reduce Emissions of Biomass Waste. *Environ. Resour. Ecol. J.* **2023**, *7*, 1–7.
9. Duque-Acevedo, M.; Belmonte-Urena, L.J.; Cortés-García, F.J.; Camacho-Ferre, F. Agricultural waste: Review of the evolution, approaches and perspectives on alternative uses. *Glob. Ecol. Conserv.* **2020**, *22*, e00902. [CrossRef]
10. Gibson, L.; Wilman, E.N.; Laurance, W.F. How green is 'green'energy? *Trends Ecol. Evol.* **2017**, *32*, 922–935. [CrossRef]
11. Scholtz, M.M.; Jordaan, F.J.; Thuli Chabalala, N.; Pyoos, G.M.; Joel Mamabolo, M.; Neser, F.W. A balanced perspective on the contribution of extensive ruminant production to greenhouse gas emissions in southern Africa. *Afr. J. Range Forage Sci.* **2023**, *40*, 107–113. [CrossRef]
12. Zakari, A.; Khan, I.; Tawiah, V.; Alvarado, R. Reviewing the ecological footprints of Africa top carbon consumer: A quantile on quantile analysis. *Int. J. Environ. Sci. Technol.* **2022**, *19*, 11475–11486. [CrossRef]
13. Forestière, Ministère de L'Environnement et de la Ressource. Respect des Normes Environnementales: SCANTOGO, un Modèle, 12 Octobre 2022. [En ligne]. Available online: https://environnement.gouv.tg/respect-des-normes-environnementales-scantogo-un-modele/ (accessed on 1 April 2023).
14. Salguero-Puerta, L.; Leyva-Díaz, J.C.; Cortés-García, F.J.; Molina-Moreno, V. Sustainability indicators concerning waste management for implementation of the circular economy model on the University of Lome (Togo) Campus. *Int. J. Environ. Res. Public Health* **2019**, *16*, 2234. [CrossRef] [PubMed]
15. Rachid, C.; Ion, V.; Irina, C.; Mohamed, B. Preserving and improving the safety and health at work: Case of Hamma Bouziane cement plant (Algeria). *Saf. Sci.* **2015**, *76*, 145–150. [CrossRef]
16. Sri Shalini, S.; Palanivelu, K.; Ramachandran, A.; Raghavan, V. Biochar from biomass waste as a renewable carbon material for climate change mitigation in reducing greenhouse gas emissions—A review. *Biomass Convers. Biorefin.* **2021**, *11*, 2247–2267. [CrossRef]
17. Verma, Y.K.; Ghime, D.; Mazumdar, B.; Ghosh, P. Emission reduction through process integration and exploration of alternatives for sustainable clinker manufacturing. *Int. J. Environ. Sci. Technol.* **2023**, 1–18. [CrossRef]
18. Dodoo, A.; Gustavsson, L. Life cycle primary energy use and carbon footprint of wood-frame conventional and passive houses with biomass-based energy supply. *Appl. Energy* **2013**, *112*, 834–842. [CrossRef]

19. Kouakou, A.C.; Agbodan, A.K.; Bakpo, A.; Koriko, M.; Fiaty, K.; Oudjaniyobi, S.; Jondo, K. Physico-Chemical Characterization of Nine Agricultural Biomasses of the Togolese Flora. *Int. J. Geosci.* **2023**, *14*, 19–35. [CrossRef]
20. Commune de Lokossa. *Diagnostic Economique Territorial de la Commune de Lokossa*; Rapport final 2014; Département du Mono: Lokossa, Benin, 2014; 160p.
21. Sani, A.; JVE Niger (LCB SNV). Les énergies alternatives: Cas de la balle de riz comme combustible de substitution au bois énergie au Niger. Projet EPGAP (Energy, Poverty and Gender in Agro-Processing); Fiche de Synthèse. In Proceedings of the Atelier Reseau Climat et Developpement, Paris, France, 16 April 2015.
22. Jol, H.M.; Bristow, C.S. GPR in sediments: Advice on data collection, basic processing and interpretation, a good practice guide. *Geol. Soc. Lond. Spec. Publ.* **2003**, *211*, 9–27. [CrossRef]
23. Adjanke, A.; Tona, K.; Agbohessi, P.T.; Toko, I.I.; Gbeassor, M. Current situation of fish farming in Togo. *Int. J. Biol. Chem. Sci.* **2016**, *10*, 2015–2024. [CrossRef]
24. Commune de Klouekame. *Diagnostic Economique Territorial de la commune de Klouekame*; Rapport final; Département du Couffo: Aplahoué, Benin, 2014; 112p.
25. Commune de Lalo. *Diagnostic Economique Territorial de la Commune de Dogbo*; Rapport Final; Département du Couffo: Aplahoué, Benin, 2014; 120p.
26. Hassan, Q.; Abdulateef, A.M.; Hafedh, S.A.; Al-samari, A.; Abdulateef, J.; Sameen, A.Z.; Jaszczu, M. Renewable energy-to-green hydrogen: A review of main resources routes, processes and evaluation. *Int. J. Hydrogen Energy* **2023**. [CrossRef]
27. Baghdadi, N.; Mallet, C.; Zribi, M.I. *QGIS and Generic Tools*; John Wiley & Sons: Hoboken, NJ, USA, 2018; Volume 1.
28. Yolou, I. Effets socio-économiques des activités maraîchères dans la commune d'Athieme (Sud-Ouest du Benin). *Int. J. Innov. Appl. Stud.* **2021**, *33*, 202–213.
29. MAEP. *Etude Approfondie sur la Dynamique de L'utilisation du Bois-Énergie au Togo*; Rapport final; MAEP: Cotonou, Benin, 2016; 108p.
30. MERF. *Etude sur la Création et la Gestion Durable des Plantations Forestières et Agro-Forestières dans le Domaine des Particuliers au Togo*; Rapport final; MERF: Lokossa, Benin, 2018; 254p.
31. Commune de Comé. *Diagnostic Economique Territorial de la Commune de Comé*; Rapport Final; Département du Mono: Lokossa, Benin, 2014; 187p.
32. Commune de Dogbo. *Diagnostic Economique Territorial de la Commune de Dogbo*; Rapport Final; Département du Couffo: Aplahoué, Benin, 2014; 135p.
33. GIZ; MERF. *Résultats de l'Inventaire Forestier National du Togo (2015–2016)*; Rapport de Synthèse; GIZ: Lomé, Togo; MERF: Aneho, Togo, 2016; 79p.
34. REDD+, Togo. Dégradation des Forêts (REDD+). (Stratégie nationale de Réduction des Émissions dues à la Déforestation et à la Dégradation des forêts (REDD+) 2020–2029. | FAOLEX). Version Finale, 2020–2029; 176p.
35. Schmidt-Traub, G.; Shah, A. *Investment Needs to Achieve the Sustainable Development Goals*; Sustainable Development Solutions Network: Paris, France; New York, NY, USA, 2015; 137p.
36. Nyamtiga, B.W.; Sam, A.; Laizer, L.S. Security Perspectives for USSD versus SMS in conducting mobile transactions: A case study of Tanzania. *Int. J. Technol. Enhanc. Emerg. Eng. Res.* **2013**, *1*, 38–43.
37. Mastrocinque, E.; Ramírez, F.J.; Honrubia-Escribano, A.; Pham, D.T. An AHP-based multi-criteria model for sustainable supply chain development in the renewable energy sector. *Expert Syst. Appl.* **2020**, *150*, 113321. [CrossRef]
38. Commune d'Aplahoué. *Diagnostic Economique Territorial de la Commune d'Aplahoué'*; Rapport final; Département du Couffo: Aplahoué, Benin, 2014; 123p.
39. Redoglio, D.; Golinelli, E.; Musazzi, S.; Perini, U.; Barberis, F. A large depth of field LIBS measuring system for elemental analysis of moving samples of raw coal. *Spectrochim. Acta Part B At. Spectrosc.* **2016**, *116*, 46–50. [CrossRef]
40. Pamungkas, B.C.; Hadi, H. Potential of biomass utilization in rotary kiln of nickel processing plant. In *IOP Conference Series: Materials Science and Engineering, Proceedings of the Indonesia Malaysia Research Consortium Seminar 2018 (IMRCS 2018), East Java, Indonesia, 21–22 November 2018*; IOP Publishing: Bristol, UK, 2019; Volume 588, p. 012006.
41. Antar, M.; Lyu, D.; Nazari, M.; Shah, A.; Zhou, X.; Smith, D.L. Biomass for a sustainable bioeconomy: An overview of world biomass production and utilization. *Renew. Sustain. Energy Rev.* **2021**, *139*, 110691. [CrossRef]