Market study on Cashew shell byproducts

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Implemented by nitidæ landscapes & value chains

Promove Agribiz

ProEcon Promove Agribiz, implemented in Mozambique by GIZ and funded by the European Union and the German Government, aims to improve framework conditions in the private and financial sector in Mozambique, that allow an increased participation of Mozambican MSMEs in the economy, leading to inclusive development.

One productive sector in Mozambique that still did not unleash all its potential is cashew processing. Global markets becoming increasingly demanding and the emergence of ultra-mechanized factories in close competitors Vietnam, India and Ivory Coast have severely affected the long-lasting processing industry in Mozambique. Despite the progressive mechanization of the factories, the sector faces difficult years since the closing of some factories end of the 2010s.

However, at the factory level, the potential of cashew shell by products is unexploited in Mozambique. They are given very little value and then become a factor hindering competitiveness of the industry. In contrast, Asiatic competitors do benefit from revenues of shell valorisation, as cashew shell can be converted to numerous valuable products, such as fuel and raw material for the chemical industry.

Therefore, Promove Agribiz in partnership with Nitidæ launched a comprehensive assessment of the opportunities that the value addition of cashew shell could bring to Mozambican economy. The overall objective of this action is to demonstrate Mozambican cashew processing competitiveness and sustainability potential through the development of pilots featuring cashew shell byproducts as fuels (in forms of shells, CNSL oil, or shell cake). As the shell can be transformed into several derivatives, each may be appropriate for use in domestic and commercial cooking, industrial heat and power, and for the production of green charcoal for use as wood / wood charcoal substitute.

Nitidæ

Nitidæ is a French non-governmental organization, which aims to conserve precious natural areas, while developing neighbouring communities. For this, Nitidæ conceives and implements projects that combine the preservation of the environment and reinforce local economies. With a team of 200 employees, Nitidæ develops projects in Senegal, Madagascar, Burkina Faso, Mozambique and Ivory Coast among others.

It also provides technical expertise to agri-food companies and public institutions to improve the performance of agricultural value chains, decrease environmental impact and stimulate local economic development together with the organization of producers and local communities.

Since 2018, Nitidæ works in close partnership with the Instituto de Amêndoas do Mozambique, Instituto Público (IAM,IP) to strengthen the cashew nuts value chain, by a diversity of actions including agricultural counselling, support on cashew public policies elaboration, market information services, and promoting linkages amongst the cashew stakeholders. Through the ACAMOZ project, Nitidæ provides an extensive knowledge of the cashew value chain in Mozambique, as demonstrated by the assessment on competitiveness of cashew nuts processing at national level published in 2020 called *Competitiveness of cashew processing in Mozambique* [1].

[1] The report can be downloaded at https://www.nitidae.org/files/21fa92bb/competitiveness_of_the_cashew_nut_industry_in_mozambique.pdf

IAM, IP

The mission of the *Instituto de Amêndoas do Mozambique*, *Instituto público* (IAM,IP) is "to promote, in a sustainable way, the increase in the production and quality of nuts, the organization of marketing and the structuring of the processing industry, increase the income of rural families, create jobs and value for the country in coordination with all interested entities.

Its attributions include the definition of policies and strategies, the coordination of the stakeholder's cashew value chain, as well as those of others kernels under their tutelage. Its competencies include the support to the cashew production, the internal and external promotion of the cashew nut industry and other kernel. It is also responsible for elaborating and implementing, in coordination with specialized national and international institutions, the research, the transfer of technologies for the production, the cashew trade and the processing, the cashew apple included. Since 2021, the IAM,IP also includes in its mandate the support to the development of the Macadamia value chain.

AICAJU

The *Associação dos Industriais do Caju* (AICAJU) is the union representing cashew nut processors in Mozambique. AICAJU is a non-governmental, non-partisan, public organization, with legal, financial and administrative autonomy. AICAJU aims to represent its members in the discussion and approval of all collective labour contracting agreements in their entirety, but also that could collaborate with official entities in the definition of the industry's industrial, agricultural and commercial development policy.

All AICAJU's members have shown great interest in developing technical efficient solutions knowing the energetic, therefore economic untapped potential of cashew shell byproducts. Some of them already took some concrete steps to convert their shells into a new product. Nevertheless, these different initiatives do face some constraints to secure markets, to find the appropriate technologies or access to finance to fund their projects.

Table of contents

Glossary

AFREC – African Energy Commission

AICAJU – *Associação dos Industráis do Caju* - Association of Cashew processors of Mozambique

BECT – Biomass Energy Certification and Testing Center

CNSL – Cashew Nut Shell Liquid

EXW – price Ex-Works, i.e. delivered at producer's gate

FOB – price Free On Board, i.e. introducing the point at which a seller is no longer responsible for shipping costs

H2CP – High Calorific Cashew Pyrolyser

HFO – Heavy Fuel Oil

IAM, IP – *Public Institute of Almonds of Mozambique* – Mozambican Institute of Almonds

IEA – International Energy Agency

IFPELAC – *Instituto de Formação Profissional e Estudos Laborais Alberto Cassimo* – Occupational Training and Professional Studies Alberto Cassimo

INE – *Instituto Nacional de Estatística* – National Institute for Statistics

IPOMA – *Instituto Polivalente de Marrere* - Polyvalent High School of Marrere

ktoe – thousands of tons oil equivalent

LPG – Liquefied Petroleum Gas, usually conditioned in gas bottles

MIREME – *Ministério dos Recursos Minerais e Energia* – Ministry of Mineral resources and Energy

MT – Metric ton

MZN – Mozambican Metical

RCN – Raw Cashew Nuts

toe – tons of oil equivalent

Executive summary

The cashew sector is one of the focus of the Promove Agribiz project in the province of Nampula, which aims to improve framework conditions in the private and financial sector. In the case of Mozambican cashew processors, a weak access to finance and a complex business environment lead to a competitiveness gap in comparison with its direct Asian and African competitors. Cashew shell waste management practices and lack of economical valorisation are one of the main factors clearly defining a difference.

Motivated by this observation, Nitidæ, under a grant provided by Promove Agribiz, realized a market study on the cashew shell byproducts with the aims to identify ways to market the shell, and to quantify the potential demand in the domestic market. Cashew shell is a highly energetic biomass and can be source to several valuable derivatives, from which CNSL – the liquid contained in the shell at 25%, with similar properties to fuel oil – and the residual shell cake – the ligneous part of the shell, that can be used as a solid fuel, or further transformed to charcoal. This appears as an interesting opportunity, especially in the edge of the energy transition towards cleaner and renewable energy as Mozambique is setting up strategies to support green industrialization. As this study reveals, the domestic cashew processing sector can play a relevant role in speeding up this transition by providing green fuels to the manufacturing sector. The 12 cashew factories currently running in Mozambique generate around 41 000 MT of shells every year, and 86% of these volumes are available in Nampula province, around the factory premises. While only 25% of the shells generated in the country get a value through the CNSL extraction today, the study shows that some experiences of use of shell derivatives for fuel in the domestic market could be quickly replicated and further developed to reach 100% value addition and guarantee maximum benefits both to national cashew processors and to fuel consumers. Cashew shell byproducts CNSL and cake are better valorised by industrial clients, reaching a respective potential substitution of 8 300 tons oil equivalent and 30 000 tons of firewood, entailing a significant potential contribution to the country's climate engagements. By valorising the shell, cashew shell enters the circular economy and closes the loop of the cashew value chain, while providing an additional revenue to cashew processors ranging from 6% to 13% of their raw nut procurement costs, directly impacting their competitiveness – thus filling the competitiveness gap with Asiatic processors. Not only as an energy product, the shell could also provide interesting outcomes in carbonized form, namely as biochar, providing at a time promising soil amendment properties and carbon storage.

The best scenario to release this potential, considering the current geography of productive fuel consumers, is the valorisation of cashew shell through a primary separation of the cashew shell liquid (CNSL) and use of the shell cake. Through the sales of both resulting products in the domestic fuel market, especially in productive (industrial) settings, the economic, energetic and environmental benefits are maximized.

The energy strategy of Mozambique is at the junction between development of renewable energies and promotion of coal and gas fields. The fuel valorisation of cashew shells makes part of the green industrialization aimed by the Government of Mozambique and could benefit from the country's developing expertise in energy.

I. Introduction

As part of its long-term support to local cashew value chain, Nitidæ implemented an assessment on *Competitiveness of cashew processing in Mozambique*. This study, dated 2020, makes a thorough assessment of the factors affecting the competitiveness of Mozambican cashew processors against main international cashew processing actors, such as Ivory Coast, Vietnamese and Indians. One of the conclusions of this work stresses the unexploited potential of cashew shell by products in Mozambique, which are nowadays given very little value and then become a factor hindering the competitiveness of the industry (Figure 1).

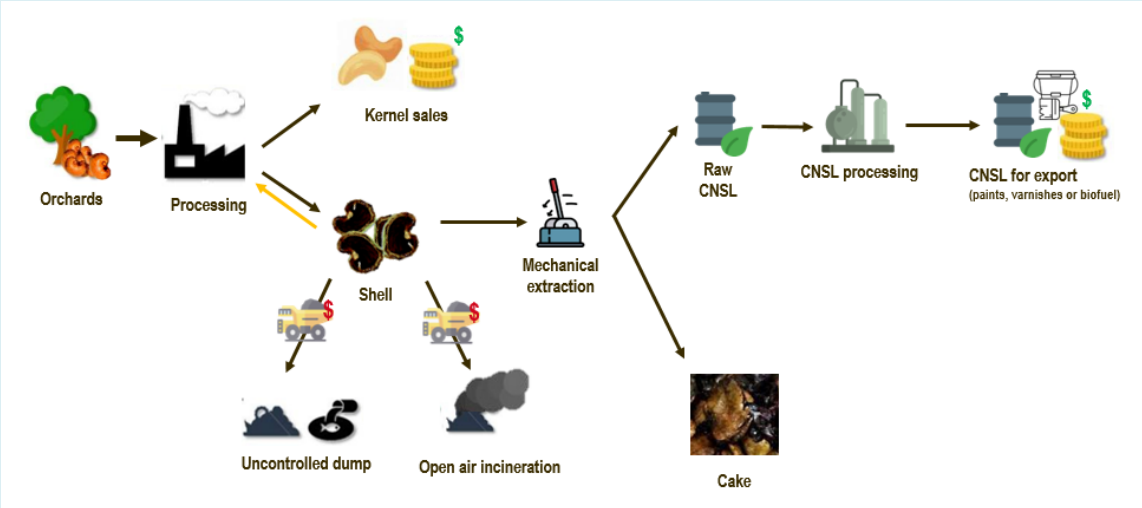


Figure 1. Current use of cashew nut (kernel and shells) in Mozambique.

As explained through the scheme in Figure 1, cashew shell is source to two main byproducts, which are the extractible CNSL and the de-oiled cake. Both can be further transformed in diverse materials, including production of polymers for paints and friction materials from CNSL, or even soil amendments from the solid fraction (see Figure 2 below).

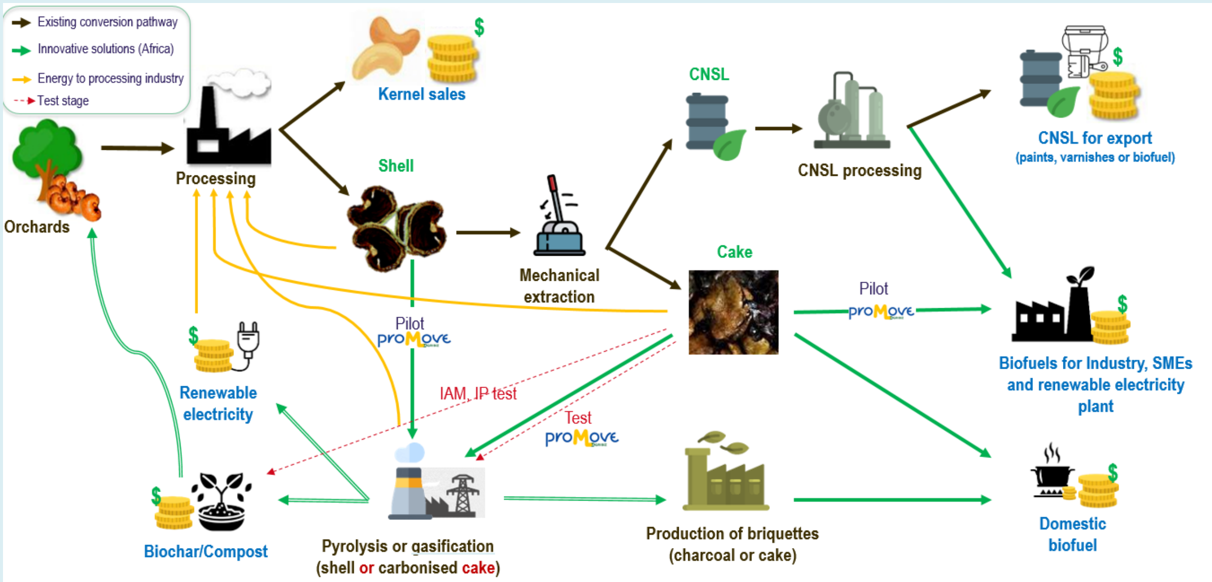


Figure 2. Multiple potential conversion paths of cashew nut shells in Mozambique.

1. Why a market study

Indeed, giving value to the **shell would grant cashew processors an additional revenue accounting up to 12% of the cost of the raw nuts they purchase**, which are their main running costs. Even if cashew processors did not process the cashew shell themselves into final marketable products, they could still sell the shell to other private processors and harness back up to 6% of the nut value. In other words, there is a potential to create new value chains around the cashew shell (Figure 2), promoting a circular economy in the country and injecting an additional revenue in the Mozambican economy that is at least 6% worth the national cashew nuts purchase volume.

On a broader context, the current energy crisis which is in turn linked to the recent global climatic awareness, sets out again the question of self-sufficiency and raises public and private interest on renewable energies. **The shell spot price has seen an unprecedented rise in the last two years, due to a revalorisation of the CNSL price (linked to oil prices) and a rapidly growing demand of solid, calorific biomass – as a result, both the shell and the de-oiled cake are more and more sought for.** Cashew shells undergo international trade, and only recently African countries are entering this new market. The time has come for Mozambique, which relies on 60% on biomass[2], to harness this bioenergy potential, which can be profitable both for domestic consumers and international fuel buyers. The specific context of energy use in Mozambique must be considered to account for the real domestic potential of the shell fuel. Furthermore, cashew waste recycling contributes to the creation of circular economy pathways, and demonstrates that a zero environmental impact is possible while contributing to the decarbonisation of the economy.

Figure 3. Stocks of shell waste in the surroundings of a cashew processing factory.

The second reason to focus on cashew shell is the most visible: the shell is the heaviest part of cashew nut. It accounts for more than 70% of the raw nut weight. **Cashew processing factories generate enormous streams of waste every day, which yields an image of a dirty, unsustainable export industry (Figure 3).** While the reality is just the opposite: African cashew processing industry is more oriented towards environmental and social quality produce than its Asian competitor. Processors in Africa often abide by a number of responsible production and trading labels, while Asians are generally turned to mass production and cost optimisation. Also, processing locally grown cashews in Africa avoids around 75% of the emissions due to transport when compared to the

[2] Source : AFREC, *Africa Energy Balances 2019*. Part of « biomass and waste« in the country's Total Primary Energy Supply.

average itinerary[3]. It can be concluded that waste management is one of the main aspects hindering the efforts of the African cashew industry, that needs to show a spotless look to stay competitive in front of Asian rivals.

In order to assess the potential of introducing shell-derived products in the Mozambican fuels market, Nitidæ conducted a field study on shell byproducts market in Nampula and Maputo provinces while, in parallel, worked closely with selected actors, amongst whom three cashew processors (CNCaju, MoGroup, ADPP) and technical training centers (IPOMA and IFPELAC) to implement two pilots: 1) a cake fuel feed solution adapted to an existing wood-fed industrial boiler and 2) a pyrolysis furnace (H2CP) carbonization device.

[3] Most African cashew nuts – who account for 60% of the total world production - are exported raw to be processed in Asia, before heading to the Western countries – which provide 80% of worldwide's cashew kernel export.

2. Current cashew processing scenario

In Mozambique, during the cashew season 2022-2023, over the 16 AICAJU members, 12 factories declared to be running. The average annual nut processing capacity is between 5,000 and 6,000 tons RCN per factory, with the busiest ones running at 10,000 tons and the smallest processing only 70 tons/year. In total, they produce around 41,000 tons of shells per year. Table 1 below features shell volumes currently generated, and the maximum potential of byproducts would all the shells undergo further processing.

Max byproducts potential *[Metric tons per year]*	Processing units	Total processing capacity RCN	Shell generated	Potential cake	Potential CNSL	Potential charcoal from cake
Total active factories 2022-2023	12	65 070	40 994	31 884	9 110	6 377
in Nampula province	9	50 070	31 544	24 534	7 010	4 907
in Gaza	1	6 000	3 780	2 940	840	588
other provinces	2	9 000	5 670	4 410	1 260	882

Table 1. Distribution of cashew shell waste and maximum potential of byproducts in Mozambique, season 2022-2023

Most processing factories incur in waste management costs as cashew shells are not marketed in any way. They rather need to be evacuated, and most are burned near the factory or in a nearby area. This cost can vary between 1 and 5 USD/MT of processed RCN, depending on whether the factory can easily burn the shells within the plant area or whether it needs to be transported to another location, paying a service provider, or employing their human and material resources to move the shells.

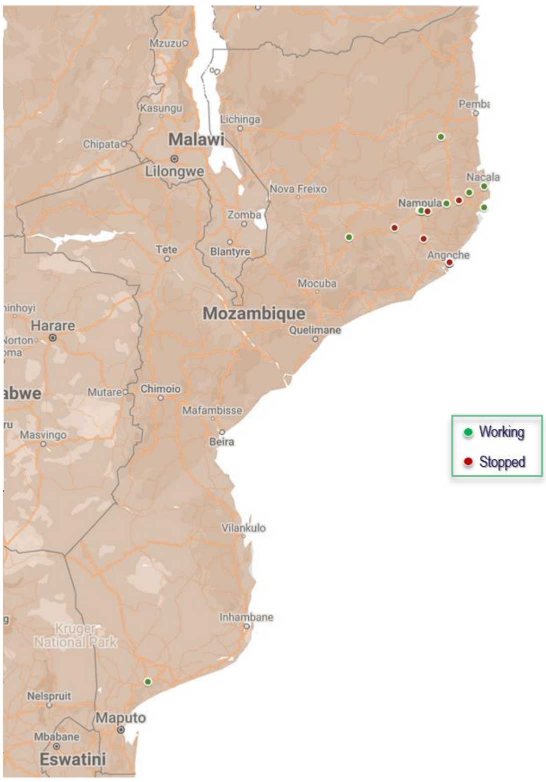


Figure 4. Locations of cashew processing factories in Mozambique

Currently, 9 of the running factories are established in Nampula province, and 3 of these have a CNSL extraction facility installed or under installation, allowing for a value addition through the sales of the separated products, i.e. CNSL and the de-oiled shell cake. Two of these factories sell their CNSL primarily to the export market, though they are eager to sell in the local market provided that there is a demand steady enough to absorb at least a part of their produce. Only one active factory is located in the Southern part of the country, in the province of Gaza, and is planning the setting up of a CNSL extraction unit. Thus, this factory could consider the shell byproducts market with the neighbouring Maputo district. These four factories are the only ones processing their shells to CNSL, meaning that those not processing their shells do not obtain any added value from them: this is 31,000 MT shells every year.

The de-oiled cake though, hardly finds a buyer and this most times means an added waste management cost. Out of the 10,800 MT cake produced, around 5,000 MT are recovered by the cashew processors themselves or by neighbouring industries as a fuel for their thermal needs. Table 2 provide numbers about the typical situation in Mozambique's cashew processing sector. From these, it can be concluded that only about one third of cashew shells and byproducts are given value in Mozambique.

Current situation *[Metric tons per year]*	Processing units featuring CNSL extraction	Total processing capacity RCN	Shell generated	Shell waste	Cake generated	Cake waste	Potential charcoal from generated cake	CNSL produced
Total active factories 2022-2023	4	65 070	40 994	27 140	10 780	4 410	2 156	9 110
in Nampula province	3	50 070	31 544	19 315	9 310	1 470	1 568	7 010
in Gaza	1[4]*	6 000	3 780	2 722	2 940	2 940	588	840
other provinces	-	9 000	5 670	5 481	-	-	-	-

Table 2. Distribution of cashew shell waste and current use of byproducts in Mozambique, season 2022-2023

The majority of the cashew processing units (8 out of 12, representing 2/3 of the shells generated in the country) do not implement any particular scheme to give value to cashew shells, out of their use as fuel for their process heat needs – which is a classical procedure, only recovering 10 to 15% of the generated shells. Figure 5 below illustrates the proportions of waste generated in one cashew processing unit that does not consider any added value to the shells.

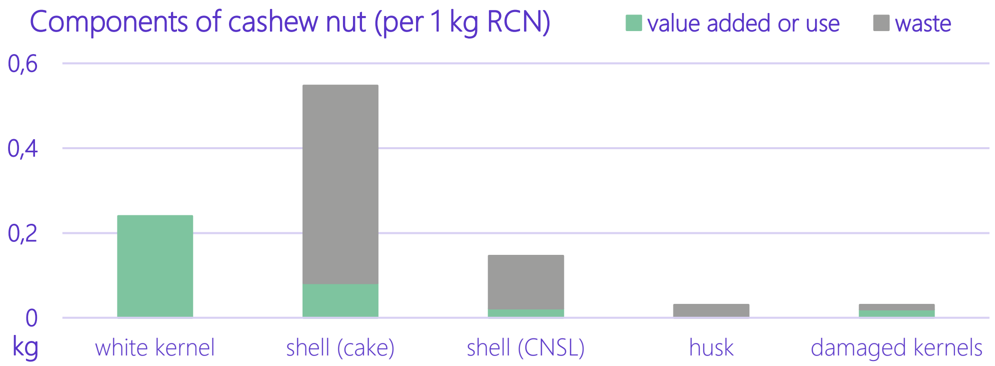


Figure 5. Components of cashew nut and use in a standard factory with no particular scheme for shell valorisation

[4] The cashew factory in Gaza is planning the setting up of a CNSL extraction at the end of 2023

3. Waste-to-energy: Value addition through energy uses of biomass in a favourable global context for bioenergy

Cashew shells are an excellent source of energy. Their calorific value is higher than woody biomass – 21 MJ per kg shells, compared to 16-17 MJ per kg for tropical wood. Nevertheless, shells are not commonly appreciated as such for fuel purposes as they are blamed for creating high amounts of black soot and corrosive fumes. This is due to the high content of volatile matter (the CNSL liquid) that is released in a short time, without burning entirely in most combustion devices. This is nothing else than unburnt CNSL. Though, once the liquid phase is separated, both byproducts are much easier to deal in standard combustion devices, such as boilers, ovens, or furnaces.

There is a growing trend to extract the CNSL from the shell as the global consumption of this organic liquid is steadily increasing. Not only CNSL is sought as a green substitute to fossil oil-based phenolic products for the chemical industry, also the recent energy crisis is leading the biggest oil consuming countries to seek for sustainable and ready-to-use organic liquids. CNSL being highly calorific, non-edible and mainly composed of only a handful of molecules, it is a good subject to become a biofuel, either through direct combustion or refining by distillation.

Therefore, CNSL trade is linked to oil prices and, historically, when oil has peaked CNSL demand grows and so does its price, as it can be seen in Figure 6 below.

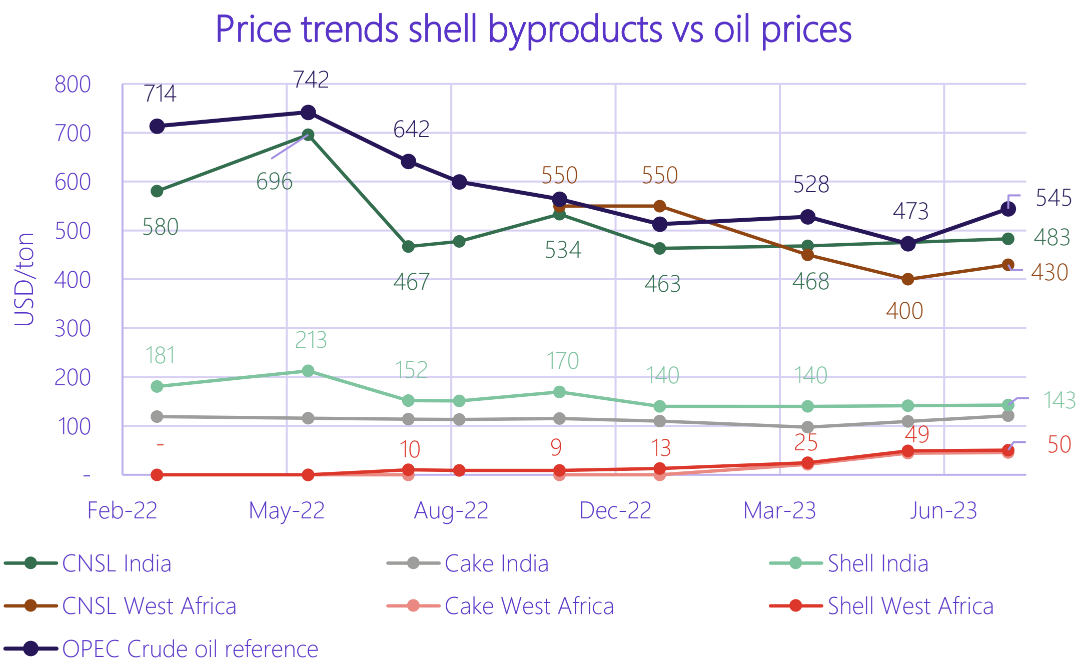


Figure 6. Price trends of shell by products and oil prices.

Some facts from countries all over the world provide an overview of the global interest on cashew shell and its derivatives. There are several paths to convert shell into valuable products, as can be seen in Figure 2. However, for many reasons, energy recovery from both CNSL and shell cake seems to be the most promising conversion path in Mozambique.

- In Asia, cashew shells are valued as a byproduct that provides a substantial additional income. CNSL is a raw material for chemical industry, mainly employed in resins, paints and friction materials. Shell cake is consumed for heating purposes, raw or blended with other biomass feedstock.

- It happens that the market price of the shell definitely influences in the decision making when it comes to buy new raw stocks of raw nut or stop processing. As an example, earlier this year Vietnamese processors were hesitant to buy more RCN (purchase cost around 800-1000 USD/ton) as shell price recently reduced to about 76 USD/ton compared to 145 USD/ton two weeks before. In other words, sales of shell make 6 to 13% of the raw nut procurement cost, which is in turn the main running cost in cashew processing, and being at the lower side of the shells profit margin can become the reason to stop nut processing.
  Indeed, competing cashew processors in India and Vietnam benefit from a well-established market for the shell as a raw material for other industries. Only a few process the shell themselves into CNSL and get an additional benefit from this value addition. In any case, shells are processed to separate the two main components and both are sold to the domestic, regional or global market.

- In 2022, India – third largest consumer of crude oil in the world - approved amendments to the national biofuel policy to reduce the country's dependency on oil imports to meet its energy demands. This has had important impacts on demand for biofuels, which come to substitute fossil coal or heavy oil. A number of biomass combustion devices have now become widespread in many small to big industrial sites in India. Some energy services companies help in the switch from fossil fuels to biomass[5]. In many cases, they recommend the use of cashew shell cake on its own or blended with other dry biomass feedstocks. India has become a net importer of cashew shells, who are traded at prices depending on the crude oil trends (see *Price trends of shell by products and oil prices.*Figure 6).

- According to the International Energy Agency, wold's biofuel demand is projected to rise by 6% or 5 700 million liters between 2022 and 2024 in advanced economies, with most of the increase occurring in the United States and European Union[6]. In fact, both the EU and the US have set higher ambitions to renewable fuel use goals while reinforcing the requirements to guarantee renewability of imported biomass fuel[7]. The new legislation, added to increasing

[5] E.g. Steamax (www.steamaxindia.com) amongst others.

[6] Source: IEA, 2023. *Renewable Energy Market Update. Outlook for 2023 and 2024.*

[7] In the EU, the Renewable Energy Directive (EU/2023/2413) sets out a target of 42.5% renewable energy in the overall final consumption of energy for 2030. The transport sector is deemed to experience the highest increase in biofuels share, as it contributes to 19.3% of the overall EU use of energy, and maritime and aviation are difficult to electrify. The amended Directive (Oct 2024) sets out a minimum overall target of 5.5% of final energy in the transport sector to be provided by advanced biofuels, biogas and renewable fuels of non-biological origin (e.g. hydrogen). At the same time, the use of most

biorefining capacities allow the use of a diversified mix of natural energy sources. Ahead of palm or soya oil to biodiesel, there is an increasing demand for non-edible crops or waste materials to be transformed into diverse liquid fuels – then called **advanced biofuels**. Only in the European Union, the use of renewable diesel (a type of advanced biofuels) has increased by 900 million litres in 2021-2022, while the US more than doubled the renewable diesel demand (+2 000 additional million litres in the same period). Both the EU and the US make the most of the 40% expansion in the global consumption of renewable fuel. As far as import statistics can tell, there is some CNSL in these biofuel blends.

- Even the wooden part of the shell, i.e. the shell cake has joined **the biomass mix for industrial and household heating**, as it is a 100% renewable feedstock and can be guaranteed exempted from deforestation. As IEA reports, the share of district heating[8] increased globally from 11% to 14%, while modern bioenergy made the largest contribution to the increase in renewable heat consumption, owing essentially to rebounding activity in industry. These facts explain the steady demand undergoing in West Africa of either shell and cake, bound for the European countries, and the small price difference between FOB Abidjan shell and cake (see Figure 6).
- **In West Africa**, a switch in the cashew shell market has been experienced in the last months. Only a year back a big proportion of the residual shells was still managed as waste - cashew industries needed to pay for its elimination/dumping. A few processors sold to other domestic industries (mainly in cement, tiles, foundries and textile sectors). **Shell conversion rates reached 40 to 50% at national levels in some countries** (Benin, Côte d'ivoire…). While the internal demand has been steadily growing, newly-came international buyers have entered West African markets in 2022 and 2023, incurring in an unprecedented rise of demand. Namely in Côte d'ivoire, every shell stock is marketed nowadays. Sale prices attain 50 USD/ton FOB Abidjan and shells are even exported in bulk.
- From a Mozambican perspective, apart from the high oil rates overlooking any market dynamics since late 2021, further signs of this global rush for renewable fuels support the idea of considering cashew shell products as a fuel.
    - Launching a CNSL refining activity for chemical purposes would be possible in Mozambique but the country is not sufficiently positioned to fully benefit from this conversion path. Firstly, polymer industry in Mozambique is not fully developed and diversified to absorb refined CNSL as a raw material. Also, as shown in Table 2, CNSL extraction capacities are, for now, insufficient to process all the shells available in the country. As a result of the limited experience, the liquid extracted in the few facilities running does not necessarily meet the technical standards to become a convenient raw material for polymers. There is still some way off achieving a structured extraction sector before the demanding chemical sector becomes a realistic market target in Mozambique. Using cashew shell derivatives for fuel should not need of those stringent requirements,

crop-based fuels is capped to the levels of 2019 and should be lowered to a minimum by 2030. In 2021, the EU's global share of advanced biofuels was only of 0.8%, while that of crop-based biofuels was 3.7%.

[8] District heating is a term employed in the context of building heating, common in temperate and cold countries. It relies on a centralized heat production to be delivered to a big number of final users in the same zone, usually one town or district. District heating is a growing trend, compared to individual or building-sized heating systems, as it proves to be more efficient and allows the use of bulky fuels such as biomass.

and as such it looks like a straightforward strategy to guarantee a profitable market to the incipient volumes of shell derivatives.

- Mozambican Government has set the goal of achieving Sustainable Energy for all (SEforAll) as well as the Sustainable Development Goal number 7 (affordable and clean energy) in 2030. One of the action pillars is the ***Estratégia nacional de biocombustíveis***, a national law passed in 2009 setting the frame to the national efforts[9]. Clean cooking through renewable biomass sources is one of the main focus of the text. Indeed, the Government is willing to introduce domestic biofuels in kitchens, as households rely at 63% on woody biomass[10]. Only recently, cashew shells retained the attention of the Mozambican Ministry of Energy (MIREME) as a source for locally produced green charcoal[11,12].
- However, the ambitions regarding liquid biofuels no longer seem to be in the frontline. The *Estratégia Nacional de Biocombustíveis* initially showcased a clear ambition of a progressive substitution of petroleum products by liquid biofuels (bioethanol and biodiesel) of domestic origin. Little was developed on a commercial scale in the 2010 decade, and the national determination on biofuel development was definitively stopped by the extinction of the *Comissão Interministerial de Biocombustíveis* in 2016[13].

All the points developed above show that we are in a propitious moment to develop energy uses from cashew shell, rather than – for the CNSL stream – considering a material value addition (i.e. CNSL as monomer for the chemical industry). Mozambican policies on biofuels are to be further developed though, just as other countries are doing, in order to draw attention and create the appropriate frame for the use of cashew shell derivatives.

[9] Boletim da República, Resolução nº22/2009

[10] Source: AFREC, Africa Energy Balances. Edition 2019

[11] Source: Greenlight, 2023. Estudo de Mercado e consumo relacionado à introdução de bio briquetes para uso doméstico ou produtivo (periurbano) na Bacia do Baixo Zambeze em Moçambique.

[12] Green charcoal is a charcoal produced from a renewable biomass. See more details on *Green charcoal* in Annex 6.

[13] Boletim da República, Decreto Presidencial nº 1/2016

4. Methodology and assumptions

4.1. Market segments in scope

The aim of this work is to identify outlets for cashew shell byproducts in the Mozambican domestic energy market. More specifically, the cashew shell can be converted into diverse fuel materials, namely: **cake** and **CNSL** – produced through the shell expelling step – and **charcoal** – through carbonization of the shell or cake. Each of these products has a different composition which makes it suitable for substitution of a specific fuel.

Thus, the market study included 3 components launched in parallel.

Figure 7. Main market segments of the market study. Conventional fuels are substituted by shell cake byproducts.

1. **CNSL**, Cashew Nut Shell Liquid (also named shell oil), is a viscous, dark-brown, calorific liquid. It is extractable from the cashew shell, at a rate of 20%. Due to similar viscosity and calorific value, CNSL can be used as an equivalent to heavy **fuel-oil** (HFO), a widespread low-cost fuel in the manufacturing industry. CNSL is somehow more acid, which could be a challenge in some cases. An informative brochure on this new fuel was developed, see Annex 1.
2. **Shell cake** shares some features with firewood (solid state, easy to handle, similar calorific content), so it is a good candidate to substitute wood in industrial environments. Today, many small industries such as bakeries rely on local **firewood** as their only fuel. Some bigger

industrial players also use firewood in their boilers. An informative brochure on this new fuel was developed, see Annex 2.

3. **Charcoal** is the solid product of pyrolysis of biomass. This applies to wood, but also to the cashew shell, and of course also to the **shell cake**[14]. Carbonized shells or cake can be compacted in briquettes, being a green substitute to **wood charcoal** in which many people rely for regular domestic use. A brief on cashew shell charcoal is available in Annex 3.
Additionally, there is an increasing demand for **biochar** for soil amendment purposes, and carbonized biomass can fulfil this role. Because of its promising and quickly rising niche market, biochar is the only non-energy product considered in this market study.

4.2. Geographical scope

The scope of the study considers the geographical scale of intervention of the Promove Agribiz program, the localization of cashew processing factories as well as the presence of potential consumers of cashew shell byproducts. **As a result, the study scope considers Nampula and Maputo provinces**.

4.3. Players interviewed

The main aims of this work were **cashew processors, industries, small and medium-sized companies and collective kitchens with energy needs,** and using large amounts of non-renewable fuel. Indeed, the manufacturing sector **concentrates a strong demand with a reduced number of users.** Furthermore, industrial and productive fuel users are generally ready to switch to a new fuel even if that means making investments.

The biggest **firewood** consumption in Mozambican towns seems to be at bakeries level. Although some of them have electrical ovens, the grand majority relies on firewood. Several bakeries and the national bakery network association (AMOPAO) have been surveyed. Bigger industrial players also do use firewood in Nampula province. Collective kitchens such as in hospitals and other big structures have also been scoped.

Liquid fuel users surveyed include industrial players in Nampula and Maputo province, using fuel for thermal (heating) purposes. Some general information about the sector was obtained through discussions with the state company Petromoc and the Ministry of Mineral Resources and (MIREME).

Shell/cake charcoal has been considered as a fuel for the domestic sector (households) or small productive sectors. These fuel users are very diverse and also rely on a diversity of energy sources for their cooking and heating needs. As there are several studies available that are assessing these aspects, this market study did not include the characterization of the volumes and types of fuels at household level. **Instead, the work focused on the economic analysis and characteristics of an industrial charcoal production to assess whether it can compete with artisanal wood charcoal in the domestic market**.e The market surveys were addressed to gross sellers and big potential end

[14] Even if it is technically feasible, to-date, no commercial solution exists for the carbonization of shell cake.

consumers, like restaurants, because they could be direct clients of a cashew nutshell charcoal producer. Green charcoal producers have also been interviewed in an attempt to better understand the market specificities and the best distribution strategies.

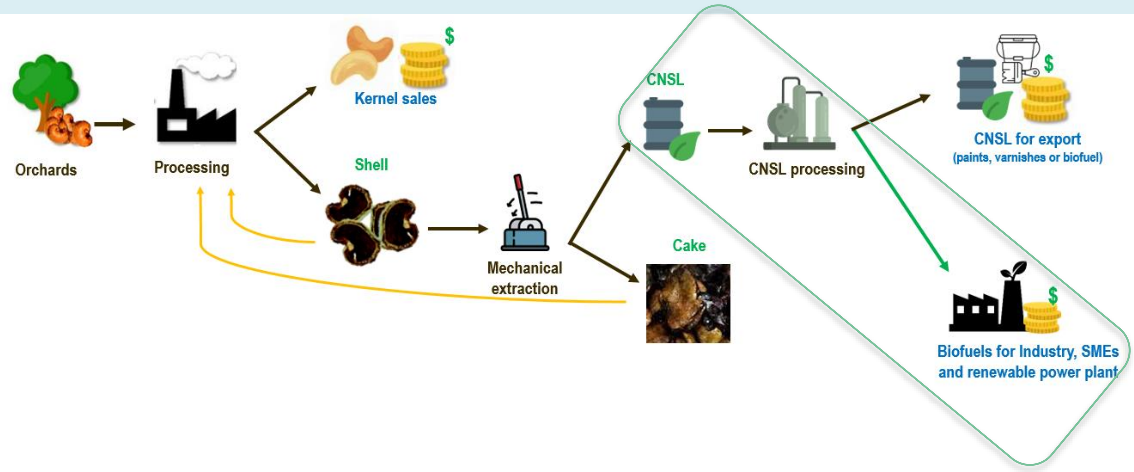
The survey phase was implemented between March and October 2022. A total of 30 surveys were administered in province of Nampula, and 33 in the province of Maputo (mainly Maputo city and the Matola industrial area). Interviewees representing every entity surveyed were either the person in charge of the fuel management –including supplies-, the operations manager or the Director. A sample of the fuel of interest was presented to the interviewee so that he/she can appreciate the fuel features: granulometry, viscosity, residual oil content, etc. A list of the interviewed structures is available in Annex 8.

4.4. Pilots as proof of concept

Not only a study on shell byproducts market was done. As the present study is a highly prospective one, the complete realization needed of some samples of the product, as the contrary (a market study with no samples) would probably lead to incomplete or partial results. Two pilot experiences were implemented in parallel:

- A shell cake fuel feeding solution adapted to an existing wood-based industry. Shell cake is not directly applicable to every wood burning equipment. This is the case of one factory in Nampula, consuming 20 to 25 tons of wood logs per day to produce steam and heat for the manufacturing process. Switching to shell cake would avoid unsustainable firewood consumption and become an interesting outlet for shell cake, especially as the factory belongs to a company holding who is also active in cashew processing. The managers showed interest in testing shell cake as fuel in their boilers, but until now did not realize any test, as the cashew shell is known to be problematic in combustion devices due to the content of corrosive oil and different texture (i.e. particle size). Nevertheless, shell cake should not feature these problems as the CNSL content is residual. Thus, some essays with the shell cake were undertaken in a pilot boiler at the factory premises. This allowed to build enough experience to demonstrate that the fuel switch is not only technically feasible and environmentally sustainable, but that the required investment in adaptation to the boiler makes economic sense to the industrial user. A specific Business model has been built in parallel to this work, to be published separately. The case of this factory can apply to other similar manufacturing industrialists.
- An H2CP carbonization device. As there is not any medium-scale carbonization device running in Mozambique, an experience from operating a shell-specific pilot kiln would also yield valuable information about operating questions, including investment and charcoal production costs. The availability of reliable data on these two parameters is important to the market study, and basic to construct a credible business plan further on. For this, two H2CP kilns were locally built in partnership with IPOMA technical training center in Nampula. The cashew processors CN Caju (Nacala) and ADPP (Itoculo), both in Nampula province hosted the kilns. CN Caju is currently extracting CNSL so the available feedstock to carbonize is the shell cake, while the small ADPP factory produces several hundreds of tons of shell waste every year. The specific Business models of ADPP has also been developed.

II. Market opportunities for CNSL



As presented in the Introduction, the scope of this market study includes only fuel uses of CNSL. The polymer industry stays an option but only on an export basis. Considering the absence of polymer industry in Mozambique and the multiple benefits of creating a circular economy at domestic level, bioenergy use seems like the best option for a rapid deployment of the shell valorisation.

The only fuel segment approached was industrial heating, as the CNSL properties are very close to those of heavy fuels and as such it could be used as a drop-in fuel, i.e. in direct substitution to the conventional one. *CNSL fuel pro*perties are presented in Annex 1.

Figure 8. Thermal aluminium furnace powered with industrial fuel

1. Demand for liquid fuels

1.1. Industrial international consumers

As exposed in Section I.3 above, there is an increasing demand for liquid fuels, driven by progressive adhesion to the global efforts in climate change mitigation, and favoured by high petrol prices who turn biofuels more price competitive against the conventional fuels (Figure 6). As an example, CNSL imports in the European Union experienced an unprecedented rise since 2021 (Figure 9). South Korea also became a major importer of CNSL in the past few years (Figure 10). China is only a minor importer. CNSL is sought as drop-in marine biofuel[15].

The main worldwide supplier is uncontestably Vietnam, then India far away. Small Indian exports can be understood by its internal CNSL market – essentially for the chemical industry.

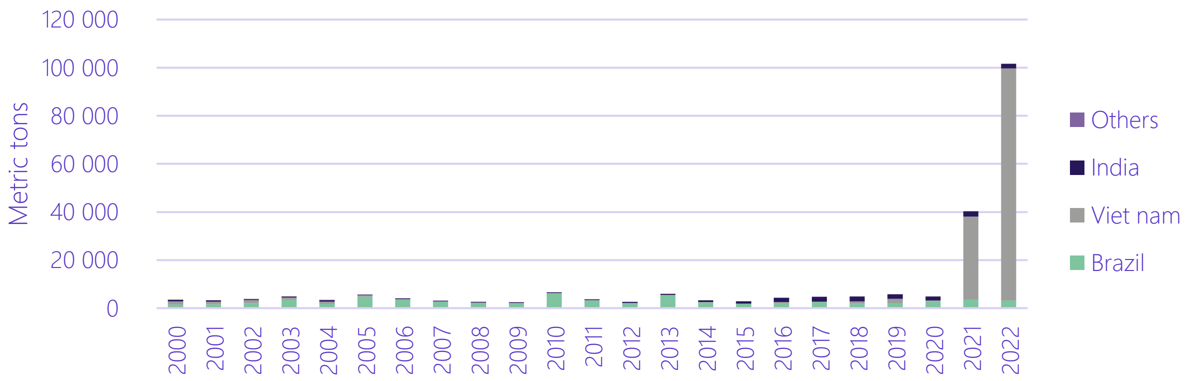


Figure 9. CNSL imports to EU. Source: Eurostat

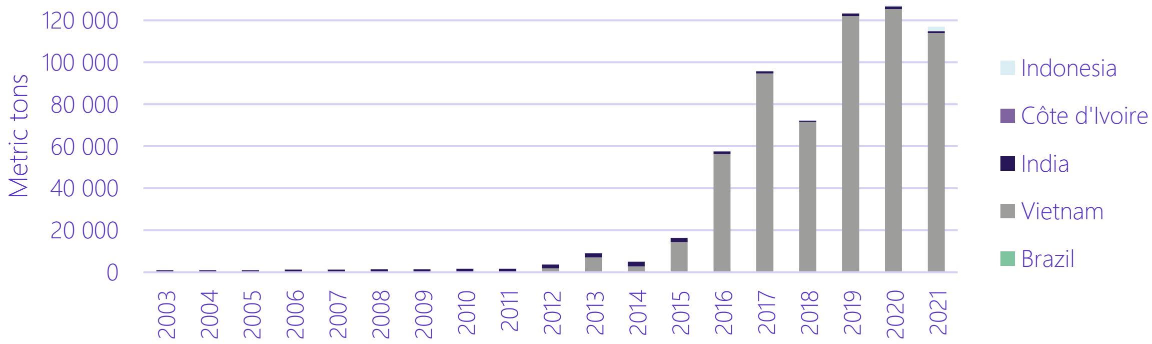


Figure 10. CNSL imports to South Korea. Source: UNComtrade.

Out of the traditional use for resin and polymer production, across the globe CNSL is increasingly traded, and volumes match with IEA's recorded increase in renewable diesel and advanced fuels. Especially, countries featuring important bunker ports such as South Korea or The Netherlands feature a growing CNSL consumption.

15 Source: https://www.manifoldtimes.com/news/vps-shipowners-turn-to-highly-reactive-cashew-nut-shell-liquid-cnsl-biofuel-blends-for-marine-fuel/

1.2. Import and distribution in Mozambique

Mozambique holds significant proven reserves of natural gas. Recent discoveries place the coastal zone, especially the Rovuma basin, as one of the largest in Africa. The country is currently set out to a structural transformation to integrate the new incomes and know-how from natural gas exploitation, aiming to become a major worldwide LNG exporter.

Mozambique remains an exclusive importer of oil products, via the monopolistic multi-shareholder company IMOPETRO. Oil products are imported and distributed through IMOPETRO, on the basis of the demand by the authorized distributors in Mozambique.

According to the latest statistics available, Mozambique imports of oil products are around 2,000 ktoe (Figure 11). These can be roughly divided into gasoline, gasoil, aviation fuels and kerosenes. The latter include heavier fractions of petroleum, some of them called HFO, used in industrial settings but also in kerosene lamps. According to their characteristics, CNSL can readily substitute kerosene respective markets[16]. Figure 11 below compares the import volumes of oil products, while displaying the potential part of substitution by Mozambican CNSL.

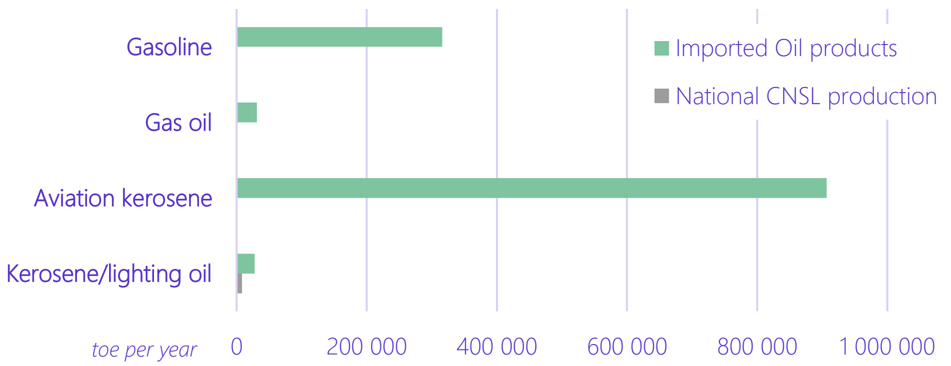


Figure 11. National consumption of oil products vs equivalent kerosene potentially substituted by CNSL[17]

CNSL potential production in Mozambique would be equivalent to around one quart of the current imports of kerosene and heavy oils in the country. However, if CNSL should be considered a liquid fuel – or biofuel –, the legislation is still unclear on the production, transport and distribution conditions of such products.

[16] See Annex 2

[17] Source: IMOPETRO, https://www.imopetro.co.mz/?page_id=4099&lang=en and Nitidæ

1.3. Industrial consumers in Nampula and Maputo provinces

Nine responding industries acknowledged to use liquid fuels for their manufacturing needs. Most of them are located in Nampula province, as access to pipelined gas has allowed industries around Maputo to switch to this efficient energy source. However, this is not the case in Nampula, where major manufacturers rely on great quantities of liquid fuels, ranging from diesel to HFO, and even including waste oils. Particularly in Nacala, some actors get supplied on waste marine oil from the port. The table below synthetizes the distribution of industries interviewed and features their total annual fuel oil equivalent demand.

Number of respondents	9	Sectors	Declared demand [toe/year]
Maputo province	2	Food industry: Edible oil, dairy	400
Nampula province	4	Food industry: Beverage, confectionery, edible oil	11 800
	3	Heavy industry: Foundry, mining	9 300

Table 3. Demand of oil equivalent from surveyed industries in Maputo and Nampula provinces

After having introduced the cashew shell oil to the different entities representing, 5 in Nampula and 1 in Maputo showed interest in the product. They actively asked for the possibility to make trials with higher quantities of CNSL in their burning equipment, while asking for further technical support to adopt this new fuel.

A rating of the interest raised by the interviewed companies is presented in Table 4. The estimated global demand per sector has also been extrapolated according to assumptions based on the provincial company registries and information gathered during the data collection phase.

Willingness and ability to switch fuel

Manufacturing sector	Declared interest	Current use of fuel & Barriers	Annual fuel demand, as declared (and extrapolated*) [toe/year]
Edible oil	+	Use of gas or biomass. Only gas users would switch if it demonstrated to cut costs	630 (1 520)
Dairy	++	Use of electricity and diesel. Would switch if it helped cut costs. Eager to try at their premises if technical support is given.	40 (120)
Confectionery	++		50 (60)
Beverage	++		11 600 (13 330)
Foundry	+++	Use of a variety of liquid fuels. Already some experience, need of more technical support to go further.	1 200 (1 450)
Mining	++++	Interested, willing to test, need of more technical support to go further, have set goals for introduction of renewables	8 000 (9 170)

Table 4. Interest in switching to CNSL, as stated by interviewed company representatives

** The extrapolated firewood demand corresponds to the average declared consumption multiplied by the estimated number of companies in this productive sector.*

$$Fuel\ demand_{extrapolated} = {}^{Total\ Fuel\ demand_{declared}}/_{number\ of\ surveys} * Total\ number\ of\ actors_{estimated}$$

In general, fuel consuming companies owned by foreign capitals showed a particular interest as the lower environmental impact is an attractive advantage of CNSL, while climate policies are becoming more and more demanding in that sense.

CNSL as substitute to furnace oil

The surveys revealed some experience in the use of CNSL as a fuel. One corrugated sheet manufacturer in Nampula province is used to burn the cashew shell liquid for its operations. A second foundry in the province showed interest in adopting this fuel, as petrol prices keep rising and greatly affect production costs. The factory requested some samples of locally produced CNSL and a first combustion demonstration was done. The conclusions were promising though some instability was perceived in lighting, meaning that the quality of the biofuel should be improved. More experiences should be undertaken to help both supplier and client achieve a satisfactory quality.

Other manufacturing industries currently relying on electricity for process heating witnessed their aim to switch to a liquid fuel, as electricity rates are steadily increasing. **The use of CNSL would be a definitive incentive for them, as the price per calorific content shall be smaller than the fossil oil equivalents** (see II.2.2 Marketing considerations below). **These companies asked for technical assistance in the selection of appropriate combustion equipment.**

More recently, a new clinker production facility to be established in Nampula province stated that it would be eager to buy cashew shell cake and CNSL for its great processing needs.

2. How can cashew shell meet demand: Green fuel from CNSL

2.1. Local production and quality of CNSL

In the current scenario, 4 factories in Mozambique are producing, or will produce soon, CNSL. Taking a closer look, CNSL quality is not the same from one to the other, as CNSL treatment process is not completely implemented everywhere (see Annex 4 for further reference on CNSL processing). The geographical availability and type of CNSL in current conditions in Mozambique is displayed in the figure below.

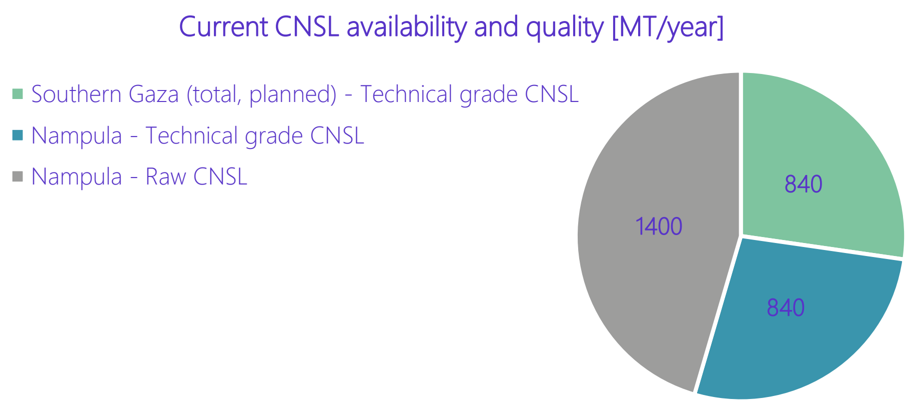


Figure 12. Current CNSL availability and quality (metric tons per year).

Raw (untreated) CNSL features acidity, higher moisture and viscosity values than the customary allowances for fuel use (see Annex 1 for further guidance on fuel parameters). This explains the reluctance of some buyers to get supplied with a fuel whose quality is not well determined. The main CNSL producer in Nampula province sells to a buyer that admits this particular quality – in exchange, the price is rather low compared to the FOB rates for technical CNSL.

The intermittent functioning of cashew factories, as some are running only when specific market conditions are gathered, is also a factor of instability of the CNSL offer. If all the residual shells of the running cashew factories were extracted, a maximum potential of 9 100 MT/year of CNSL, equivalent to 8 200 toe/year, could be obtained in the provinces of Nampula and southern Gaza (see Figure 13 below).

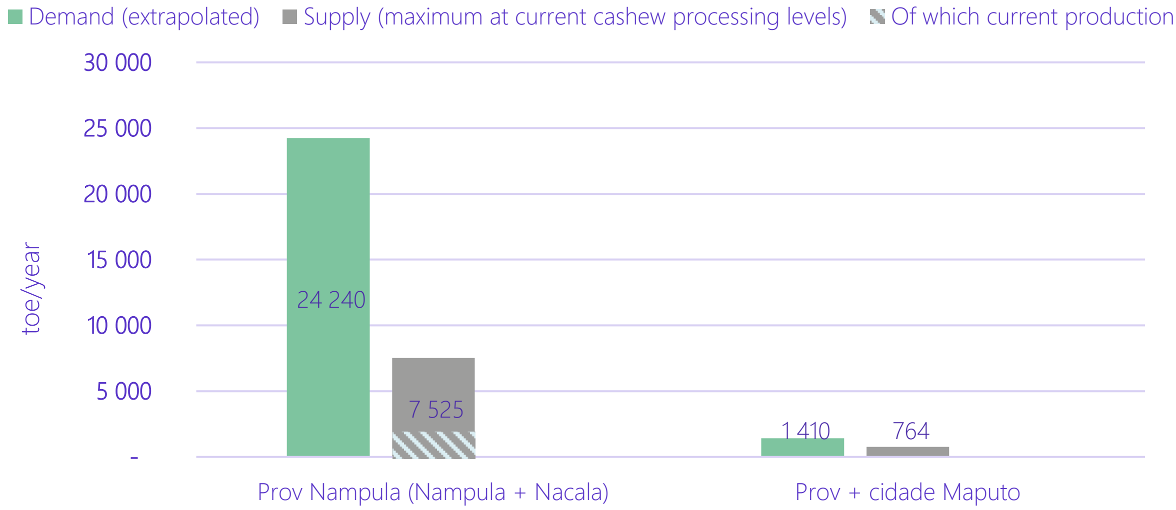


Figure 13. Extrapolated CNSL Demand vs Supply, by province [toe/year]

There is enough CNSL potential (8 200 toe/year) to supply a part of the total liquid fuel demand in both provinces. By now, only a fraction of the shells is crushed and therefore only 25% of this potential is produced. An additional 9% capacity should be soon installed, in province of Gaza close to province of Maputo.

The condition to access the Mozambican market would be a stable CNSL quality and brought to minimum values of acidity, which calls for more control and knowledge by local CNSL processors.

2.2. Marketing considerations

The profitability of local vs export sales will depend on the quality of CNSL achieved – proportional to the sales price attainable – and the global context – as petrol prices condition CNSL price trends.

In the national market, the selling price should be in line with the HFO (heavy fuel oil) type fuel price, currently at around ~860 USD/ton (bulk sales, see Figure 6).

Of course, international market is a good option today due to high crude oil price which is expected to remain high in the near future; but we cannot give any bet for the further future and that is why a focus on the local market may yield much more stable perspectives. Indeed, **regardless of the crude oil price variations, fossil fuel prices in Mozambique do not change that swiftly due to State regulations. In this context, CNSL would always be a cheaper solution for local buyers**: gasoil prices are currently around 90 MZN/L, and kerosene 75 MZN/L (equivalent to 1 190 USD/MT and 990 USD/MT respectively). A CNSL plant can be profitable with CNSL price from 260 USD/MT EXW. Even adding transport to consumer (10 to 50 USD/MT depending on destination) and considering that conventional fuels are sold bulk at around 70% the pump price, CNSL could easily be traded 200 to 400 USD/MT cheaper compared to petrol-based fuels and be a profitable business.

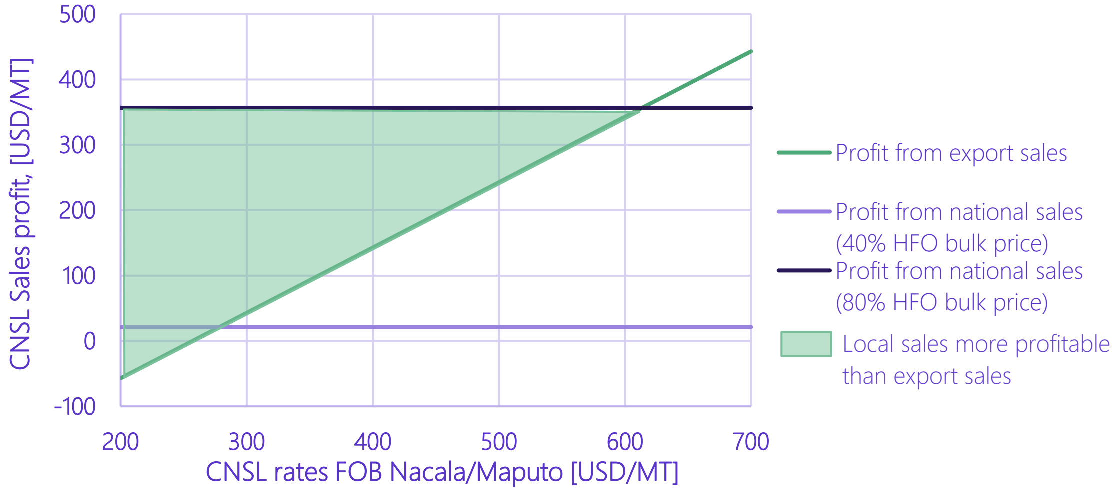


Figure 14. Profit simulations for CNSL local sales vs CNSL export sales

Figure 14 above compares profits obtained by one hypothetical Mozambican CNSL supplier in case of export sales, -i.e. after deduction of CNSL production cost, packaging and fobbing- and domestic sales –through an estimation of maximum and minimum sales price for CNSL equivalent to 80% and 40% the kerosene price in Mozambique. Transport costs – either to port, or to client's gate – have been deemed equal to 0 for a fair comparison.

For example, in the case of a CNSL producer based in Nacala (transport to port for export = 0) and selling to export FOB 400 USD/MT, the sales profit is around 150 USD/MT. But this profit could be more if CNSL was sold locally, at 60% the kerosene bulk price at client's gate. In this case and considering negligible transport costs to buyer's premises, the profit would be 200 USD/MT – and higher if CNSL could be traded at a closer price to kerosene's. From the Figure above, it can clearly be seen that it would be difficult to be more profitable by selling abroad because the CNSL international price should still rise a lot (around 700 USD/MT FOB compared to 450 USD/MT now) to reach the maximum profit for local sales, which seems very unlikely.

CNSL local markets look more advantageous than export, as logistics are much simpler and fuel prices remain more stable in the national level. CNSL could be marketed up to around 80% of the HFO local price, or even higher shall the switch to a renewable fuel be seen as an added value.

3. Conclusions

From the facts presented above, the following conclusions can be drawn:

- CNSL has multiple marketing opportunities, either in the domestic or the international market.
  - CNSL consumption for fuel use has become a major trend in CNSL importing countries, with the EU[18] and South Korea leading the importer rankings. Thus, Mozambican CNSL producers could find export market opportunities in South Korea.
  - The demand for CNSL in the local market, mostly driven by food processing, foundry and mining sectors, can absorb all the potential CNSL production of the Mozambican cashew processing industry (Figure 13). Especially in Nampula province, there are few alternatives to conventional liquid fuels and the demand is very high, while concentrated in a few actors.
  - The domestic market, mostly represented by industries from agro-processing, mining and foundry sectors, is largely more profitable and stable than the international market. As such, it should be explored primarily by any CNSL producer.
- Industrial users of liquid fuels are actively seeking cheaper alternatives and CNSL looks like an interesting option. There is already some experience in Mozambique in the use of CNSL for fuel, demonstrating that it is technically feasible. However, the different characteristics of CNSL demand for adaptations of most burning devices. Industrialists need technical assistance to adapt their equipment in order to integrate CNSL into their energy mix.
  - Lower environmental impact is an attractive additional advantage of CNSL. Indeed, given the great volumes consumed per year, climate funding could be leveraged to help the technology switch succeed.

As a conclusion, there is a clear opportunity both from the demand and the supply side and the cashew sector ought to seize it, in coordination with the Ministry of Commerce and Industry to facilitate a conducing environment for the generalization of CNSL extraction. Achieving total extraction of available cashew shells and ensuring a competitive quality, would provide substantial benefits to several segments of industry, not only increasing competitiveness of cashew processors but also other manufacturing key sectors.

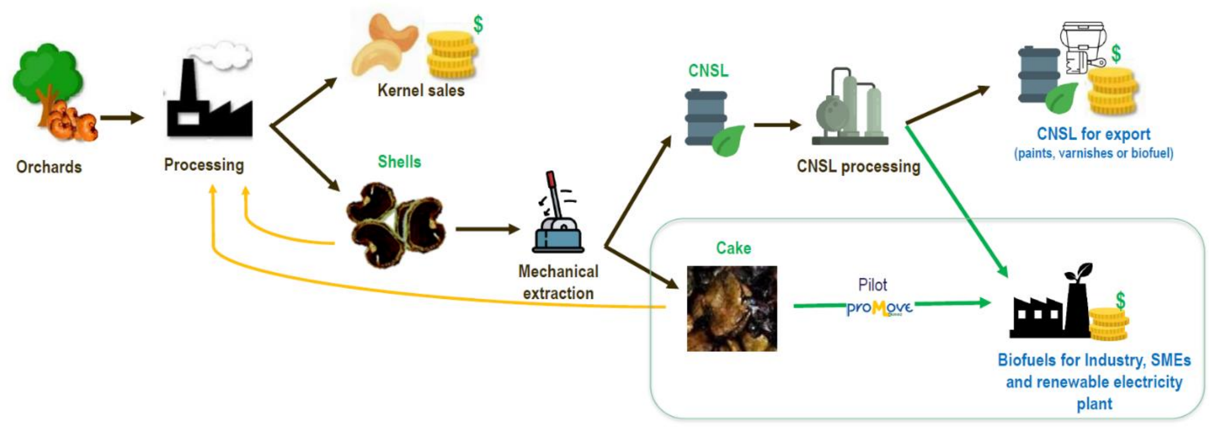
The main barrier is currently the low volumes of CNSL being extracted, today only 25% of the cashew shells in the country are valorised (meaning are crushed to extract CNSL). Awareness about the business opportunity, and access to finance are the main constraints. Given the relatively big shells feedstock in Nampula province and the financial challenges encountered by cashew processors, **there is room for a third party to enter the CNSL business, and become a waste solution provider for the cashew industry while being a profitable biofuel producer.**

As a final precautionary remark for the cashew sector and CNSL developers, it would be advisable to keep an eye on eventual upcoming regulations on production and trade of liquid fuels, especially to ensure a coherent legal frame considering both different but complementary conventional fuels

[18] See *Footnote number 7*, page 13.

and biofuels that are to be produced, refined and traded in the country in the years to come. In fact, there is an opportunity for the country to specialize in biofuel production, in parallel to the capacitation on oil&gas refining. Indeed, oil&gas majors have already shown some interest in CNSL as a substitution source to petrol.

III. Market opportunities for shell cake



Shell de-oiled cake is a woody biomass and as such it is suitable to substitute firewood. Productive uses of firewood range from small-scale activities such as street food or restaurant businesses using some kg of fuel every day or occasionally, to bakeries or manufacturing industry, where fuel volumes range from some hundreds of kg to several tons per day.

Productive users generally keep track of their fuel consumption and are prone to switch to a more advantageous alternative, even if that means a change in the combustion device. This point is particularly important as shell cake consists in loose coarse particles, a very different shape to wood. The combustion device or the feeding habits should then be adapted. Comparative features of shell cake and different customary wood fuels can be found in Annex 2.

A second particularity of shell cake is the residual CNSL content which should be brought to a minimum in order to guarantee a fine combustion. This demands a special focus on fuel quality from CNSL/cake providers.

Figure 15. Solid biomass burner adapted to cashew shell cake for a proper combustion at a small scale.

1. Demand for firewood

1.1. Firewood demand for productive use in Nampula and Maputo provinces

Productive firewood users were interviewed, with the following repartition:

Number of respondents	18	Sectors	Demand (MT/year)
Maputo city + province	9	Bakery	1 500
Nampula province	3	Collective kitchens: Educational, hospitals, military	360
	3	Bakery	620
	2	Food industry: edible oil	3 000
	1	Manufacturing industry: textile	7 000

Table 5. Demand of firewood from surveyed actors in Maputo and Nampula provinces

The first outcome is that no representative use of firewood was found in the hostelry and restaurant sector. **Restaurant owners essentially rely in a mixture of charcoal and gas, depending on the recipe to be cooked and availability of the preferred fuel**. **Only collective kitchens** (school canteens, military mess, hospital and humanitarian services) **do use regularly some amounts of firewood in complementarity with charcoal and gas.** Volumes range around one or several hundred tons per year in each centre. These results are in accordance with the findings of Greenlight in Maputo city and province[19]. In fact, in urban areas charcoal is preferred as solid fuel because of cleanliness and low fumes production, while wood use is restricted to the domestic context, and generally applies to low income or peri-urban households. Gas (LPG) is widely used in urban center such as Nampula, Nacala, Maputo where there is distribution network.

The main firewood users in urban settings are bakeries. They largely rely on this fuel, which is considered as the least costly possible for their high temperature needs, with only a few using electric ovens (in Maputo). According to the interviewees, an average-sized bakery uses on average around 200 tons of firewood every year. On the other hand, **industrial users concentrate, in a small number of actors, a very high consumption of firewood in Nampula province**. While they are a minority in the industrial landscape, the volumes consumed are startlingly big: they attain dozens of tons per day, meaning thousands of tons yearly. Business owners justify the choice of this fuel by the lowest price per calorie. They are generally aware of the high environmental impact of using firewood and some of them do use residual biomass in priority (cottonseed husk, waste from sawmills).

When asked about the possibility of integrating shell cake in their fuel mix, or completely switching to shell cake, all of them showed interest in this material. However, the concerns about the suitability of their combustion device were diverse. Table 6 synthesizes the users' feedback per productive sector. The overall weight of each sector, in terms of firewood demand, has been estimated.

[19] Source: Greenlight and MIREME, 2022. *Biomass energy study for the South of Mozambique.*

Willingness and ability to switch fuel

Productive sector	Declared interest	Current use of fuel & Barriers	Annual firewood demand, as declared (and extrapolated*) [tons/year]
Collective kitchens	+	Use a mix of firewood, charcoal and gas. Shell cake would be considered if it demonstrated to cut costs, to be easy to handle and not to give a taste to food.	360 (3 700)
Bakery	++	Use of firewood, a few uses electricity. Would switch if it helped cut costs. Some are eager to try at their premises if technical support is given.	1 820 (39 400)
Food industry	+++	Use of firewood and other residual biomass. Some experience in handling shell cake, but the % is limited. Would be eager to increase rates or switch to 100% cake if technical support was provided.	3 000 (4 500)
Manufacturing industry	+++		7 000 (7 000)

Table 6. Interest in switching to shell cake, as stated by the interviewed structures

** The extrapolated firewood demand corresponds to the average declared consumption multiplied by the estimated number of companies in this productive sector.*

$$Fuel\ demand_{extrapolated} = {}^{Total\ Fuel\ demand_{declared}}/_{number\ of\ surveys} * Total\ number\ of\ actors_{estimated}$$

Even if bakeries use individually big quantities of firewood, most of them were reluctant to a switch, as they argued that their produce would reek of smoke produced by cake combustion, just as it does when they inadvertently use treated wood. Although professional baking ovens do not allow direct contact of fuel fumes with the product, it could happen that some internal surfaces are cracked due to intense use. Only one third of the interviewees stated interest on the idea of a switch to a new fuel, though most of them would prefer to witness before trying themselves.

All the interviewed industrialists showed interest to try a new biomass in their combustion devices. At the moment of the interviews, all had tried burning cashew shells or shell cake in their boilers and considered these fuels are suitable for their business though had a strong position on the need to include it in a fuel mix, due to the high residual CNSL content, considered to be corrosive.

1.2. Firewood demand for domestic use in Nampula and Maputo

As stated previously, the domestic sector consumption was not investigated in this study. There is extensive literature on the topic, and conclusions from these and from previous experiences in biofuels show that it would be very difficult to introduce shell cake at a household level. The cake handling specificities and its composition make it compulsory to consider a special stove for this particular fuel. The most recent market study shows that only 2.75% of consumers in Southern Mozambique own an improved cookstove[20], and that the awareness about this kind of stove was relatively low (especially in urban areas) while it benefits from various consumers sensitization programs.

[20] Source: Greenlight and MIREME, 2022. *Biomass energy study for the South of Mozambique.*

Shell cake as a domestic fuel. A case study in Nampula

Pamoja has been promoting shell cake as a substitute for domestic charcoal use in Nampula since 2018[21]. To allow domestic consumers to use this new fuel, Pamoja is selling improved cookstoves along with the cake. In fact, the shell cake cannot be safely burned in bulk in standard stoves. The high price of the stove is, though, an entry barrier for the users and this affects the fuel sales venture. Despite the marketing efforts, lower fuel price and diverse subsidies, Pamoja holds a client portfolio of about 2,000 users after 4 years established in Nampula, consuming around 5 tons of shell cake per month. The combination of fuel and stove is also extended to other communities in the country through private and CSR fundings, moderately rising the demand for this fuel.

The case study of Pamoja is an example of how the technological solution as well as a fine market targeting are prominent, when it comes to introducing an alternative fuel. Nitidæ considers that the industrial sector, which is currently consuming enormous quantities of wood and other fuels in the targeted provinces, features the potential of a much bigger biofuel demand concentrated in a few actors, which would be a greater incentive for cashew industries to add value to its waste shells. Also, as previously stated, the industrial sector is more incline to test and invest in new burning equipment to shift to renewable fuels.

2. How can cashew shell meet demand: Green fuel

2.1. Local production of cashew shell cake

According to the findings during the market survey phase, the extrapolated estimation of firewood demand for productive purposes (bakeries, manufacturing industry and collective kitchens) in both Nampula and Maputo provinces, along with the maximum firewood substitution by shell cake is as follows:

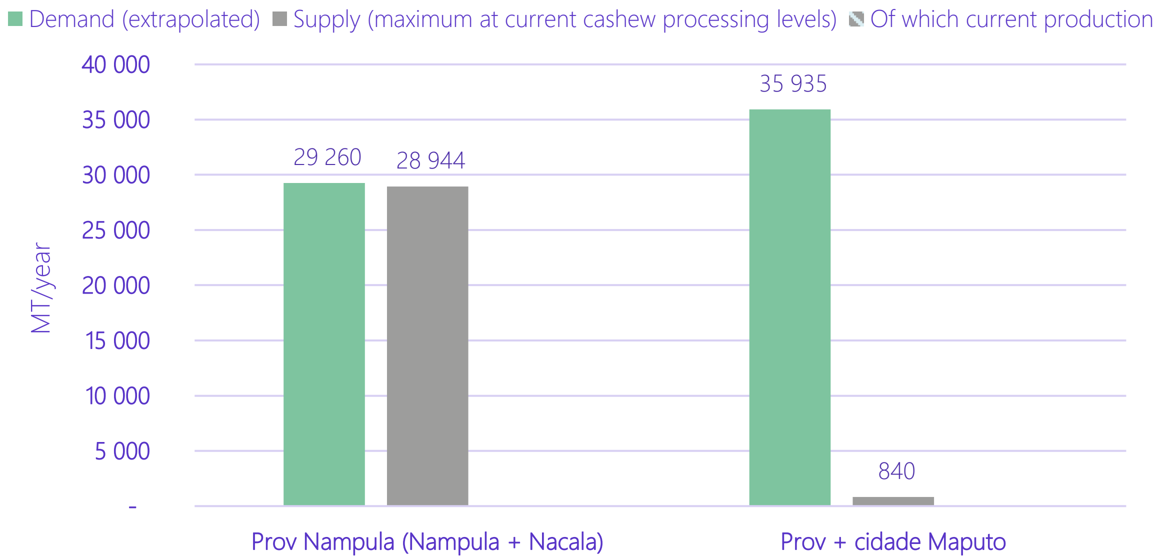


Figure 16. Extrapolated shell cake (subst. to firewood) Demand vs Supply, by province [toe/year]

In Nampula province, the total potential of cake would be able to meet the firewood demand. This means that, in theory, the provincial cashew industry alone could supply this portion of the productive sector who is currently driving deforestation. This would be a remarkable outcome boasting the sustainability of

[21] http://www.pamojacleantech.com/newpage/

Mozambican cashew sector. However, in the practice, only 7 800 tons of shell cake are produced from the currently crushed shells in the province, and the newly established clinker factory is very likely going to absorb all these volumes[22]. As a result, there will be no cake available to feed the productive sector, unless new shell crushing capacity is installed.

In Maputo and surroundings, the demand for productive uses is essentially represented by bakeries. According to the trends witnessed during the market survey phase, it is also possible that energy-intensive industries such as breweries and cement factories also consider using biomass for fuel in the medium term. The only cashew processor nearby (located in Macia, Gaza province) would only be able to meet a small part of the demand. This means, in turn, that it has diverse chances to find a suitable buyer.

2.2. Renewable solid fuels in productive settings. The Asian case.

As conventional fuels become costly, and especially as environmental concerns motivate regulations to green energy sources, the residual biomass use becomes a growing trend. India is home to a big variety of agricultural waste, and much is located around the agri-processing units. Thus, biomass such as rice husk, mustard seed husk, almond shells or wood shavings are increasingly sold as biofuels. Stringent regulations and high prices of mineral fuels in India motivate many of these agri-processors and also other manufacturers in the surroundings to use biomass as their thermic source.

Cashew shells do also participate to this trend. Shell cake is usually combusted in a mix with other biomasses, or alone, in automatic feeding devices. It can also be compacted into pellets for ease of transport, and to improve the stability of its properties during long storage times. Shell cake pellets are used in the local industries but also sold to the export market.

Figure 17. Cashew shell cake sold mixed with other waste biomass (left), and shell cake pellets (right)

Users in Asia adopt biomass burners to substitute wood firing, but also diesel, HFO or coal. A number of manufacturers of biomass handling devices have emerged, and so do biofuel producers and dealers. Similar trends are observed in other countries such as Vietnam, China and Indonesia, where technological solutions are locally available and affordable.

The switch to biomass is possible not only thanks to appropriate technology, but because it is profitable, i.e., the cost of fuel supply compared to the traditional fuel is lower. This allows for a return on the investment

[22] Source : O País, 2023. *«Dugongo» constrói mais uma fábrica de cimento.*

on the new combustion device. Biomass suppliers claim savings of more than 30% when firewood or diesel is substituted by biomass[23].

Figure 18. Auto feeders with conveyor (left) and biomass burners (right) are the most extended technologies to cleanly burn waste biomass, as they require minimum changes in the existing heating device (boiler or kiln).

When shell cake is compacted into pellets, the bulk density is increased by around 30%, and so does the energy density. Pelletization could be an appropriate solution when the product must cover long distances to meet the buyer, though the savings in transport costs are to be compared to the high-power expenses due to the extrusion equipment.

2.3. Price considerations

Market value of firewood may be very variable depending on various factors, like quality of wood (tree species, appropriate length/diameter of logs, humidity), availability and delivery options (transport costs integrated in the price vs. consumer organizing the collect and transport). The values in the figure below represent average values from our surveys but they should be considered carefully as they are based on a limited number of samples.

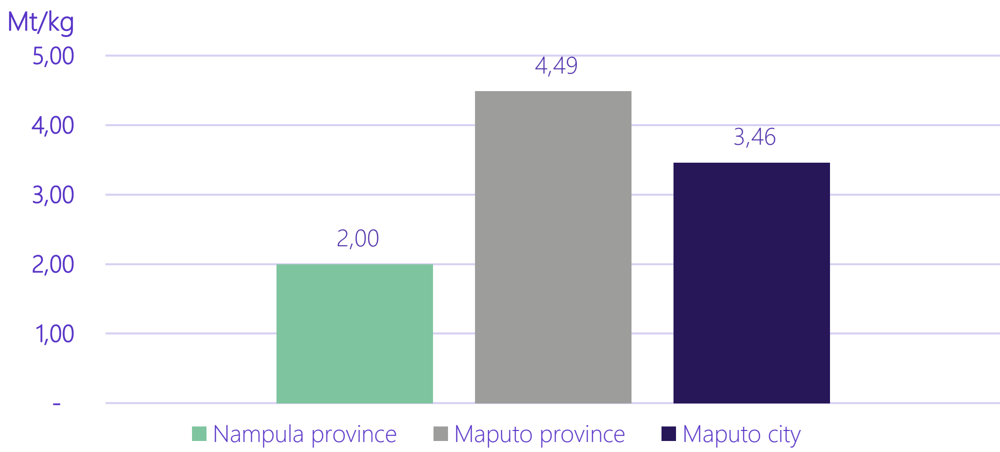


Figure 19. Average weight unit price of firewood, by area. Source: Nitidæ, 2022

[23] Source: Steamax, 2022. *Ready to go green? Renewable energy combustor*, https://drive.google.com/file/d/1Dek1oSdiEWsEJS1ThRabJ72JpgssXNDX/view

Fuel users are unanimous in saying that firewood is the cheapest fuel option, and they are right: the cost per energy unit of main fuels and origins have been compared in Figure 20 below. Firewood is the least costly way of heating, even when the case of firewood collection –zero cost- by the user is not considered. So, for heating needs that are not sensitive to smoke generation, soot or manual feeding, firewood is the best budget option.

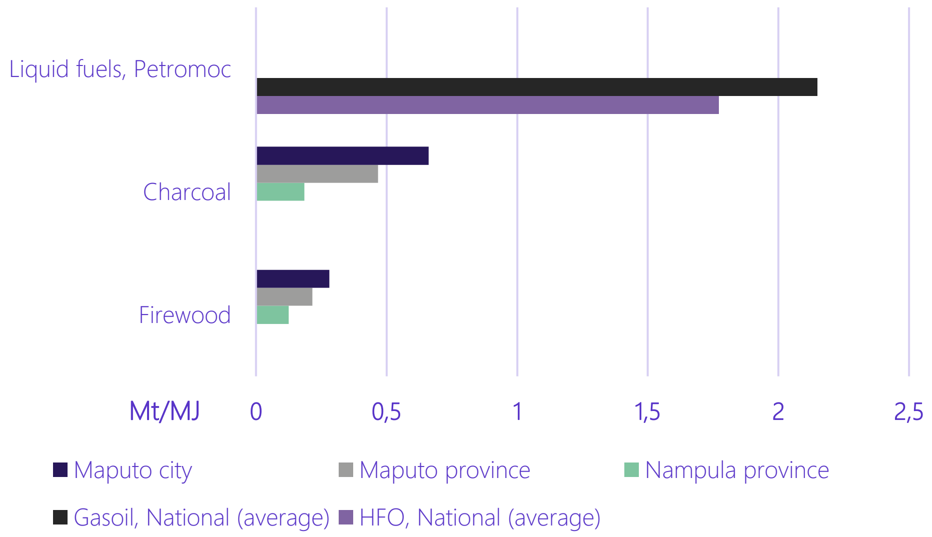


Figure 20. Average energy unit price of main fuels (MZN/MJ), by area. Source: Nitidæ, 2022-2023

Cashew shell cake has an equal or slightly better calorific value than firewood, though due to its particular texture and composition, good combustion needs of procedural or equipment adaptations. Taking into account that firewood users are very sensitive to fuel prices, there is little chances that they would be interested in switching to shell cake unless there is a price signal for it. **This means that shell cake should be sold at a lower price than firewood, per kg, or in the best-case scenario, at the same price.** On the other hand, compacted shell cake features an advantageous energy density and maintains moisture to the lowest levels, so it could be sold at a higher price. As an example, in India pelletized shell cake gets around 40% higher market value than loose cake.

As a general conclusion, cashew shell processors shall not expect impressive gains from sales of this byproduct, even the volumes obtained are around 70% of the weight of the shell itself. CNSL is the main product of shell processing, with shell cake becoming a residual product. Given the little interest of cake and the fact that it does not undergo any further processing, production costs should be considered as 0.

CN Caju, the first cashew processing factory to sell all the shell fractions – after all…

CN Caju started CNSL extraction in 2020. However, the factory does not achieve a fine shell crushing and CNSL is not entirely recovered. As a result, there is still a high residual CNSL rate in their cake. Even if CNSL marketing is a priority because of its high added value, shell cake could also be sold to the numerous factories around the province. However, only recently CN Caju achieved to sell its cake.

Only in 2021, an agri-processing factory in Nacala agreed to collect part of the shell cake produced by neighbouring cashew processor CN Caju. The shell cake is used as a partial substitute to wood in the agri-processor's multi-fuel boiler. While it acknowledged that it would be possible to increase the cake rate in the fuel mix, the real use is conditioned by the quality of the shell cake. The industrialist complained about dirty combustion, excessive soot generation and fears of corrosion. Also, he would not agree to pay for this biomass, as considered too problematic to have a market value.

Recently, CN Caju could get into an agreement with a cement and clinker manufacturer. Cement factories need intense heat and are less concerned by fuel quality, so CN Caju's oily shell cake is a good option. Additionally, the new buyer agrees to pay a price for the fuel – which is said to be between 3 and 5 MZN per kg.

The experience of CN Caju is an example of how much the fuel quality is decisive in the adoption by some users – and so it is regarding the price fixation.

Firewood is a low-cost fuel. Even if it is not preferred by all productive actors, those relying on it are attached to its quality and price.

Shell cake, as a substitute to firewood, does not feature salient benefits such as a neatly higher calorific content, easier handling or cleaner combustion. In most cases, satisfactory and clean combustion require an adaptation of the combustion device.

As a consequence, in order to adjust to the demand, the shell cake price should be fixed at a more competitive price than firewood. In this case, the user can recover its investment in the feeding equipment. This makes sense from a cashew shell processor perspective, as its main produce is CNSL – shell cake being a bulky residue.

The cake's residual CNSL content is a key quality parameter. It can be considered that the lower this value is, the better value for the product could be earnt. Also, pelletizing the shell cake is a good option, especially in case the fuel needs to be transported for long distances.

2.4. Pilot combustion of shell cake in Mozambique

As an original approach to the study of the conditions for commercial use of shell cake, Nitidæ approached one big firewood consumer and conducted some experimentation on the use of this innovative fuel replacing firewood.

This long-term established factory in Nampula is using around 25 tons of wood per day to produce the process steam. The factory holds an agreement with the provincial authorities to exploit wood from natural woodlands while guaranteeing afforestation –with quick-growing species. This fuel, in the form of thick woodlogs, is sourced around Meconta, 80km from Nampula, causing direct harm to the precious Miombo ecosystems and costing millions of meticais each year on fuel supply.

Figure 21. The factory boilers are manually fed with miombo wood logs

Switching to a sustainable fuel – the cashew shell cake - would avoid this massive firewood consumption and release the immense pressure on the Miombo forest. Various cashew factories located nearby (less than 15 km), and producing large quantities of residual cashew shell, could supply this factory. The shell cake is the most appropriate form of this fuel, as it contains minimum quantities of the corrosive CNSL liquid and is thus neutral to the burning equipment. The high fuel consumption rate of the factory makes that it could entirely recover the shells produced by the factories running in Nampula and surroundings.

As a means to prove the benefits of the fuel switch, comparative tests were performed on one of the boilers in the factory, during March and April 2023. The shell cake was fed manually and no mixing was done with other biomass. The results suggest a better heating efficiency with the use of shell cake. Indeed, the fuel quantities were dramatically smaller (around 30% less) compared with normal use of firewood. During the tests, a satisfactory cake feeding procedure has been adopted which guarantees a satisfying steam production rate. Manual feeding is still possible but, because of the rapid combustion of the small-sized cake, **a switch to automatic feeding is recommended to optimize the combustion of the shell cake**. **The current manual feeding procedure may be responsible of overconsumption of fuel and increased particulate emissions**, though these have been reported not to be disturbing.

The savings due to fuel switch have been assessed, based on the tests results. The simulations consider the switch from the current scenario (boiler working on firewood, manual feeding) to the biomass scenario (boiler working exclusively on cashew shell cake, automatic feeding).

Table 7. Financial scenario for a switch to automatic feeding of shell cake in one of the boilers in Nova Texmoque

General assumptions				
Working days boiler	250			days/year
Fuel origin	Nacala	Meconta	Nampula	
Delivery distance	200	75	10	km
Unit firewood cost, delivered		2 100		MZN/ton
Unit cake cost, delivered	3 350	2 275	1 286	MZN/ton

	Current scenario		
Operating costs	Firewood origin	Meconta	
	Average consumption firewood	6 067	kg/day
	Annual firewood consumption	1 517	tons/year
	Annual costs firewood	3 185 100	MZN/year
		50 080	USD/year

	Switch scenario. Addition of a biomass burner				
Operating costs	Annual consumption cake			1 085	ton/year
	Cake fuel origin	Nacala	Meconta	Nampula	
	Delivery distance	200	75	10	km
	Fuel cost (cake)	3 635 867	2 454 133	1 395 739	MZN/year
	Annual fuel cost savings	-450 767	715 967	1 789 361	MZN/year
		-7 088	11 257	28 135	USD/year
Investment costs	Biomass burner (India make)		35 000		USD
	Shipment		1 000		USD
	Silo + Civil works		5 000		USD
	Technical assistance installation + calibration		6 275		USD
	TOTAL investment		34 775		USD
	Return on investment	-	3.1	1.2	years

The financial simulations presented in the Table 7 above show that the delivery distance has a great incidence on economic savings. Considering the cake fuel sourced in Nacala and sold at 1 MZN per kg EXW, there would not be any net savings from the fuel switch, as the transport costs add too much to the cost of the fuel delivered at Nampula. By finding a closer cashew cake supplier (from factories in Meconta and Nampula), the financial savings would be at least of 22% per year. In monetary terms this means 0.7 to 1.8 million MZN annual savings, depending on the origin of the cake fuel. As a conclusion, and as shown in the table below, **the financial savings can, on their own, pay in less than 2 years, any additional equipment needed for the optimum handling of this new biomass fuel**.

The switch towards an automatic feed allows for operational advantages:

- More constant and change-reactive steam supply for the factory
- Operator work is much reduced; as manual work is brought to a minimum.
- Working conditions are in any case safer compared to manual feeding, because the exposure to fire or fumes is eliminated.
- Improvement of boiler lifetime by providing smooth working conditions and an even temperature in the burning chamber, compared to batch feeding which creates fumes with high particulates content and hot spots.

Other automatic biomass feeding and combustion equipment could be considered, such as biomass burners, that could mean a lower initial investment. Anyway, this case study is a prominent example of the financial and technical suitability of the switch to a renewable fuel, even considering an important investment on adapted equipment. This could be the case of other productive users nowadays relying in massive volumes of unsustainable firewood. Given the virtuous change, the least profitable cases could benefit of additional financial support in terms of climate finance.

The advantages of switching to shell cake fuel are not only counted in terms of monetary savings and environmental benefits, but also operational, as an automated feeding allows for an efficient use of fuel and safe operation. The investment in the fuel feeding equipment is quickly recovered.

3. Conclusions

From the previous data, the following conclusions can be drawn:

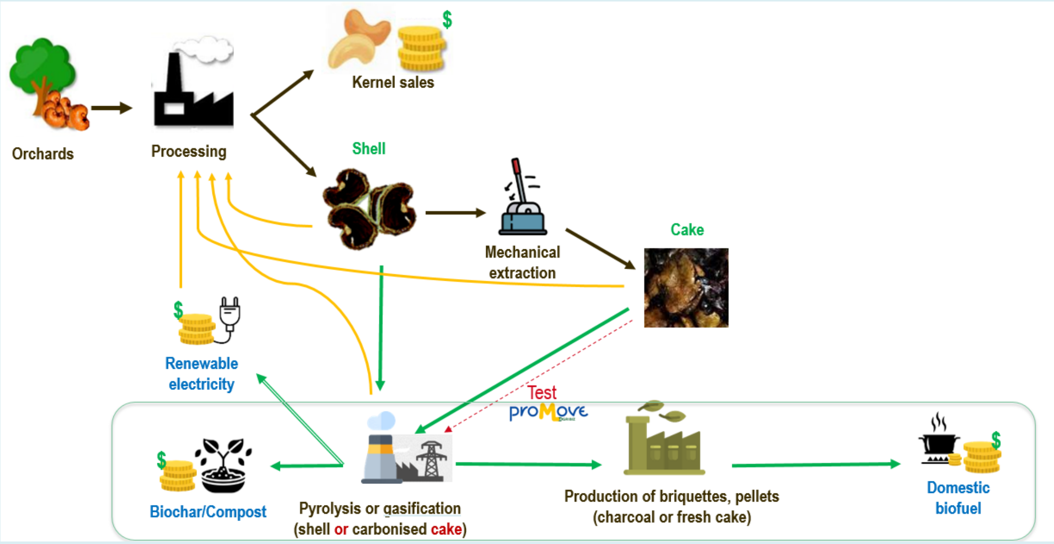
- There is a limited number of profiles of productive firewood consumers.
  - All the industrial use is concentrated in Nampula province, with several factories using biomass boilers. One clinker factory recently established is bond to absorb all the shell cake which is currently produced, as there is a relatively limited availability.
  - In Maputo, industry relies largely on gas and electricity, except from clinker production unit, bakeries and collective kitchens.
  - The interest on cashew shell cake is very dependent on previous experiences from the users and their capacity/willingness to adapt their combustion equipment. There is already some experience in using shell cake in industry.

In Nampula province, the current productive firewood demand is very similar to the maximum potential supply of cake by the cashew sector. Unfortunately, only 30% of the potential capacity is available, as most shells are not valorised (crushed to extract CNSL). The productive firewood and biomass demand is globally growing, due to both demographic and industrial expansion. However, there is no perspective of massive shell cake production.

In conclusion, any new cashew shell crushing venture should easily find a taker for the residual cake, though achieving high substitution rates of firewood could be a technical challenge at some points:

- Shell cake features similar calorific properties than firewood, but very different particle size which is determinant for its handling. Also, combustion quality is very dependent on residual CNSL. As a result, cake is a suitable fuel for professional users. Domestic use embeds technical and sociological challenges, and could be harmful if not handled properly.
- The good news is that there are proven and affordable technological solutions allowing to valorise shell cake at high to 100% mixture rates. There is an opportunity for knowledge and technology transfer by Asiatic partners.
- Shell cake being a substitute to cheap wood fuel, price is an important parameter to raise buyer's interest on a substitution feedstock. Thus, shell cake should always be sold cheaper than firewood.
- Small and medium productive users of firewood may encounter challenges in embracing this new fuel. The case of bakeries would be especially interesting to address as estimated total volumes of firewood are very big (see paragraph III.2.1 above). This sector could be subject to a dedicated action to promote a switch to renewable biomass.
- The exemplary case of the pilot factory boiler switch to shell cake could be the case for many other industrial actors: Thousands of tons of firewood or hectares of fragile miombo woodland could be saved every year by harnessing the fuel potential of shell cake. Return on investment by the fuel user could be as low as 2 years in this case.

IV. Market opportunities for shell/cake charcoal



Cashew shell or cake feature low moisture and a high content of carbon, especially in ligneous form. They could both be transformed to charcoal, as shown in the figure above. The resulting product consists in loose particles which must be compacted into briquettes to be comparable to the customary wood charcoal fuel.

In Mozambique, the use of mineral coal has been reported amongst industrial users – mainly heavy industry (aluminium, cement and big breweries). This consumer profile was not considered in principle. In fact, the current state of the carbonization technology and knowledge would likely not fit for the general industry case.

Hence, only wood charcoal users have been scoped in the market study. The charcoal user profiles sought as buyers of shell charcoal range from households to small productive users (restauration activities).

More references about the comparative wood charcoal vs. sustainable charcoal properties can be found in Annex 3. Details about production of charcoal from cashew shell and cake are presented in Annex 5 below.

Figure 22. Lighting and burning cashew shell charcoal briquettes. Source: Greenlight.

1. Demand for charcoal

The existing literature allows to characterize the volumes of charcoal consumed per inhabitant in the main towns of the country. The demand is huge and steadily growing, barely at the same path of urban population growth. Considering a daily average of 2 kg charcoal per household, only the yearly domestic demand accounts for hundreds of thousand tons in the cities of Maputo and Nampula. In comparison, the total potential of charcoal from shell is limited to some thousand tons (see Table 1, page 11).

Rather than focusing on comprehensive surveys to charcoal domestic end-users and sellers, our focus was to better understand what marketing positioning should be chosen for green charcoal to substitute unsustainable wood charcoal. Productive charcoal users as well as wood charcoal producers and resellers were merely interviewed to get a general picture of the sector. The domestic demand for charcoal has been accounted for in the overall demand estimations, see section IV.3 below.

1.1. Charcoal demand for domestic use, restaurants and collective kitchens

The repartition of the interviewees is the following:

Number of respondents	41	Sectors	Demand (MT/year)
Maputo city + province	11	Restaurants	31
	2	Poultry: Chicken growers	40
	4	Wood charcoal resellers	69
	5	Wood charcoal producers and sellers	1 500
	1	Green charcoal producer and seller	480
Nampula province	3	Collective kitchens: Educational centres, military, refugees	534
	5	Restaurants	12
	2	Manufacturing industry: cement, brewery	4 500
	4	Wood charcoal producers and sellers	121
	4	Wood charcoal resellers	276

Table 8. Demand of wood charcoal from surveyed actors in Maputo and Nampula provinces

Charcoal users

As it was the case among firewood users, **collective kitchens use big amounts of charcoal, if individually compared to restaurants and households.** They use charcoal as well as wood and/or gas. They stated being open to use another charcoal source, though they need to be sure of the suitability for their appliances and recipes. They would also agree to pay more for this product, provided that the quality was more constant and better on average. Their declared charcoal demand – more than 170 tons per year on average per centre - has been confirmed by the gross charcoal resellers.

Restaurants indicated to use on average 2.4 (in Nampula province) to 2.8 tons (Maputo city and province) of charcoal per year, which is the equivalent to the yearly consumption of 3 to 4 households each[24]. When asked about their preference for wood charcoal compared to other fuels, they mostly prefer charcoal to firewood because of the ease of handling, clean burning and the greater energy density; while using gas for the main cooking operations, and only charcoal in specific tasks (e.g grilled meat, fish or *caril)*.

[24] Mean trend as reported by (Greenlight, 2022. *Biomass energy study for the South of Mozambique)*.

Regarding the domestic use, as literature confirms, the vast majority of the inhabitants in Nampula and Nacala consume charcoal as their primary fuel. As reported by the MIREME biomass fuel study in the South Mozambique[25], LPG is used by 63% of the households in Maputo and Matola, mainly in combination with other fuel sources (37% rely on LPG and charcoal). **A total of 75% of the households use charcoal, either as a primary or secondary fuel.**

Households buy charcoal to retailers located in markets or within the neighbourhood, at truck unloading points or – especially in the Nampula province – by buying directly to producers who access town by motorbike or bicycle drivers. A representative 10 to 15% get their charcoal delivered at home. Charcoal is consumed to cook some specific dishes (*cariles*, *feijoadas*, etc.) that require long cooking times, and because it can be acquired at a little price in smaller quantities, making it more affordable for household' economies running on a day-to-day basis. In Maputo, the high prices of charcoal bring LPG to be more and more widely used, in contrast to a relatively low penetration of LPG in Nampula province (see charcoal price comparison in Table 9).

Weight in kg *Price in MZN*	Bag weight	Price dry season	Price rainy season	Average unit price dry season	Average unit price rainy season
Nampula province	50-100	280-550	350-700	5,5	7,2
Maputo city	50-75	1000-1500	1200-1800	18,9	24,3
Maputo province	50-100	750-1200	900-1800	14,5	18,0

Table 9. Price ranges of wood charcoal in Nampula province, Maputo city, Maputo province

Finally, **in the Maputo area there is a reported rising use of charcoal by chicken growers**, using it to warm up the henhouses during the cold night time. These users are less sensible to the charcoal quality, and as they buy in bigger quantities than households, they seek competitive prices above all. At least two have resource to green charcoal; this case is further described in the following section.

Coal users

Other productive users interviewed were, in Nampula province, two industrialists that were primarily approached for a survey on their liquid fuel use habits. It turned out that they are big coal consumers, and they get their supplies from the mineral coal ore in Tete province. The cement manufacturer features a small consumption compared to the brewery: 29 tons compared to the 4 450 tons yearly consumed respectively. The relatively low consumption by the cement manufacturer is due to the absence of clinker production step. In fact, most cement units in Mozambique do not produce the clinker themselves, which is the most energy intensive step. On the other hand, the brewery gets regularly supplied with coal, which is used in tandem with diesel for the factory's big heating needs. Both industrial players showed interest in a new fuel source and said that they could agree with paying green charcoal slightly more than the coal. The reality is that the coal price per kg is purchased between 0.1 and 0.2 USD[26], depending on the international market rates and origin – it sometimes happens that South African coal is sought. This is equivalent to MZN 6.4 to 12.7 per kg, a neatly higher price than wood charcoal.

[25] Source: Greenlight and MIREME, 2022. *Biomass energy study for the South of Mozambique.*

[26] Source: https://coal-price.com/chart/mozambic.html

Willingness and ability to switch fuel

Charcoal users	Declared interest	Current use of fuel & Feedbacks	Annual fuel demand, as declared (and extrapolated*) [tons/year]
Collective kitchens	++	Alternatively using of gas, charcoal and/or firewood. Users would switch if it demonstrated to cut costs and did not give a taste to food. Appreciate the powerful but long lasting of briquettes. Many would consider paying a higher price than charcoal. Worried about smelly smoke.	530 (5 600)
Restaurants	++		43 (450)
Households	+		- (646 330)
Poultry	+++	Use of charcoal, some have experience with green charcoal. Less stringent on charcoal quality, but sensitive to price.	15 (960)
Industry	+++	Use of coal. Less stringent on charcoal quality, used to high charcoal prices.	4 500 (1 500 000)[27]

Table 10. Interest in switching to cashew shell/cake charcoal, as stated by the interviewed structures

** The extrapolated firewood demand corresponds to the average declared consumption multiplied by the estimated number of companies in this productive sector.*

$$Fuel\ demand_{extrapolated} = {Total\ Fuel\ demand_{declared}}/{number\ of\ surveys} * Total\ number\ of\ actors_{estimated}$$

The interviews were supported with some samples of cashew shell charcoal briquettes. This helped the respondents give their views on the new fuel in scope. Additionally, in the frame of an assessment on green charcoal briquettes, Greenlight with the support of Enabel performed some Controlled Cooking Tests[28] with some control groups representing collective kitchens, restaurants and households[29]. Table 10 above shows the conclusions from the surveys to charcoal users, while adding the feedback of users after having tried the cashew shell charcoal briquettes. **In general, the interviewees reported that green charcoal briquettes were more economical than wood charcoal, as the burning times are longer.** More insights can be found in Section IV.2.3 *Testing the cashew shell briquettes in real and laboratory conditions*.

Charcoal providers: producers and retailers

In general, charcoal resellers are open to selling new fuel products as long as there is a demonstrated demand for it. They would agree with purchasing and reselling the cashew charcoal at a higher price than wood charcoal if it proved to be better quality. Most of them are aware of the preferences of their clients for a long-lasting charcoal rather than a quick-burning one, so they are eager to include high quality fuel in their offer. They would be ready to buy in bulk and resell at smaller unit sizes as per the customers' requirements.

A few green charcoal producers have emerged in the country. For years they have been providing charcoal from sustainable sources, though their market share is very small and many work only intermittently. As they

[27] The greatest coal consumer in Mozambique is Mozal (aluminium smelting)

[28] More insights on this stove performance measurement protocol can be found at https://cleancooking.org/binary-data/DOCUMENT/file/000/000/80-1.pdf

[29] Source: Greenlight, 2022. *Briquetes de casca de caju - Testes de cozinha e experiência do utilizador*

may be interested in buying shell carbonised products or even to engage into carbonizing themselves, they were considered as a target in this market study. In addition, gathering their learnings on the green fuels sector was paramount to fine-tune the approach of a business case based on cashew shell. Mozambican green charcoal producers showed interest on the shell raw product and were delivered samples in order to test by themselves how to adapt their process to this new feedstock. However, it is very unlikely that they adopt cashew shell, mainly due to geographical constraints. A brief on the Mozambican green charcoal sector and manufacturers' profiles can be found in Annex 6.

Likeliness of buyers to switch to green charcoal: getting the reasons right

When asked about the willingness to eventually pay more for a new charcoal product, respondents in Nampula province was total, with the condition that the quality is better. This acceptance is maybe due to a higher familiarity with cashew products. However, only 4 among the 11 restaurants interviewed in Maputo said being open to a price rise in any case. This reluctance could be explained by the high price of charcoal in Maputo – around 4 times the price in Nampula – and the high familiarity with the use of LPG, which is the most economical fuel available. Other reasons like a better environmental impact seem to arise very little priority.

In line with this, only 2.75% of consumers in South Mozambique owned an improved cookstove, while the awareness rate about this kind of stove was relatively low (especially in urban areas). Awareness about the existence and benefits of improved stoves also resulted to be deceiving.
As Greenlight states, "Fuel mixing is a reality and one cannot expect to shift people to cooking with modern fuel sources only. The new fuel or stove to be introduced should replace the fuel or stove that gives women the most hardship in the cooking process, whether it is time, or health concerns" [30].

There is a general interest by both domestic and productive users on new charcoal sources. The particular combustion features of charcoal make it a preferred fuel for selected operations. Amongst different charcoals, the main criterion of choice is price per unit, which is very tightly related with the fuel quality. With prices rising steadily, wood charcoal is smoothly being substituted by LPG in big urban areas.

In Nampula, cook charcoal users would be ready to pay more, provided that the new fuel is more performant – but are not that eager in Maputo. On the other hand, other productive users of charcoal (poultry growers, manufacturers) are less stringent on quality but rather on costs.

As a conclusion, if aimed for cooking use, charred cashew shell products need to feature the same or better characteristics in order to compete with conventional wood charcoal, starting with a competitive price. Other appreciated parameters are fuel density, heating power and clean and smokeless combustion, while environmental impact is not influencing the product choice.

[30] Greenlight, 2022. *Biomass energy study for the South of Mozambique*

2. How can cashew shell meet demand: Green charcoal from cashew shell

2.1. Local production of cashew shell or cake charcoal

The extrapolated estimation of firewood charcoal and coal demand for productive and domestic purposes in both Nampula and Maputo provinces, compared to the maximum shell charcoal volumes potentially produced (Table 1, page 11) shows that charred shell derivatives could in any case represent a very small part of the market.

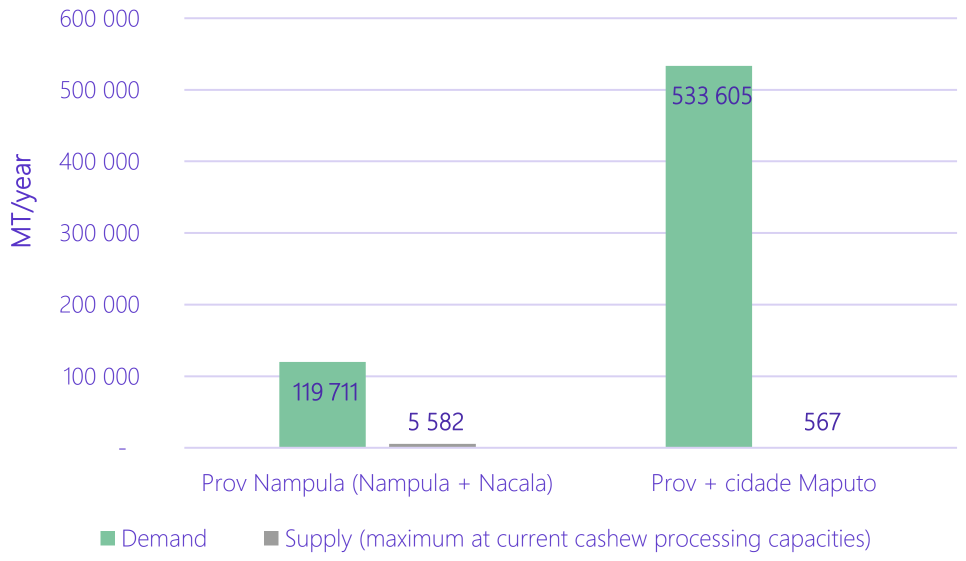


Figure 23. Extrapolated charcoal demand vs potential green charcoal supply from shell cake, by province[31]

2.2. Pilot of semi-industrial shell charcoal production. Technical and marketing considerations

The market study aims to find the relevant market options for cashew shell – or shell cake – carbonized products. However, the shell carbonization path has never been performed in Mozambique, so it is difficult to assess the real production costs of this product. In order to fill this knowledge gap, a pilot carbonization platform was built.

Nitidæ has been promoting **High Calorific Cashew Pyrolysers (H2CP)** for a decade in West Africa. The H2CP is an oven specifically designed for cashew shell valorisation, converting it through the pyrolysis process into **flammable gas** and **charcoal**. The H2CP is adapted to a low-technicity context and can be 100% manufactured with local materials. The pyrolysis gases generated are immediately used as fuel in dozens of cashew processing factories, as a source of heat for their boilers. The residual charcoal is collected at the end of the day and is considered a secondary product, which is generally given out to the factory staff. When charcoal is deemed the main product, the H2CP can be conducted in order to maximize the volume of shells converted per hour, and the yield to charcoal. This is just how two partnering Mozambican cashew processors – CN Caju and ADPP – intended to use these ovens.

[31] Source: Greenlight, 2022 (see footnote nr.22), INE, 2023 *Censo 2017* https://www.ine.gov.mz/web/guest/censo-2017 and Nitidæ.

Two H2CP were built in cooperation with the training centres IPOMA and IFPELAC in Nampula. They were subsequently installed at CN Caju in Nacala, and then moved to ADPP, at just a hundred km away in Itoculo. Both factories had shown interest on the cashew shell carbonization solution as a way to add value with social sense to its shell waste. The aim was to carbonize shell cake available at CN Caju, which is producing several thousands of tons per year. ADPP factory is set in a rural setting and has no means of crushing the shell, so the whole shell would be feeding the H2CP. Once the kilns were in operation, some samples were produced that would help perform market and fuel quality assessments.

Figure 24. The manufacturing of the H2CP ovens was combined with a training cycle, at IPOMA, Nampula city.

Once installed, the operation of the kilns was followed during several months for technical backup and in order to record the use rates. These data helped to fill specific business models for the case of a mechanized cashew processing factory (e.g. CN Caju) and one small-scale factory (ADPP). The Business case documents are to be published separately and will be made available to the cashew processing community.

The case of CN Caju was a first-in-its-kind, as shell cake had never been carbonized in real conditions in a H2CP. The experiences were backed by parallel testing in Nitidæ's Biofuel platform in Burkina Faso. The outcomes of the experiences were that a H2CP was not appropriate to carbonize the shell cake. As the cake forms thick, sticky layers, the air and pyrolysis gases are not able to circulate inside the furnace. The tests experimented with various combinations of operating conditions, only yielded lukewarm results in terms of the kiln capacity to carbonize the shell cake. In addition, given that the H2CP would only be capable of carbonizing around one ton of shell cake per day, CN Caju would need more than a dozen of these kilns to carbonize all their shell cake waste. This means an increased investment in kilns and human resources to operate and maintain the devices. The operational costs of carbonization and briquette production seem too high to compete with local wood charcoal. In conclusion, when big shell waste volumes are available – more than 1,000 tons per year – the H2CP solution does not seem to make operational nor economic sense to one cashew factory.

Figure 25. Flammable pyrolysis gas is produced at the burner of the H2CP. At the end of the operation, shell charcoal is obtained

In the case of ADPP, one kiln would be enough to carbonize all the volumes of residual shells. The operation of the H2CP can be managed by one operator, and it could be the one operating the nut cooking and kernel drying systems. But even in this case, charcoal briquettes could hardly compete with the low prices of wood charcoal, especially in Nampula province. As shown in Figure 26 below, Labour and Maintenance costs are the main operational expenses. Considering the operational expenses alone as the production cost, the production of a kilogram of briquettes costs around MZN 20 – and still, depreciation, amortization and taxes have not been accounted for. As a result, only the case of premium briquette sales in supermarkets would allow a profitable business (see comparative prices below). For this, the briquettes need to feature flawless properties, as the consumers' profile is the most demanding.

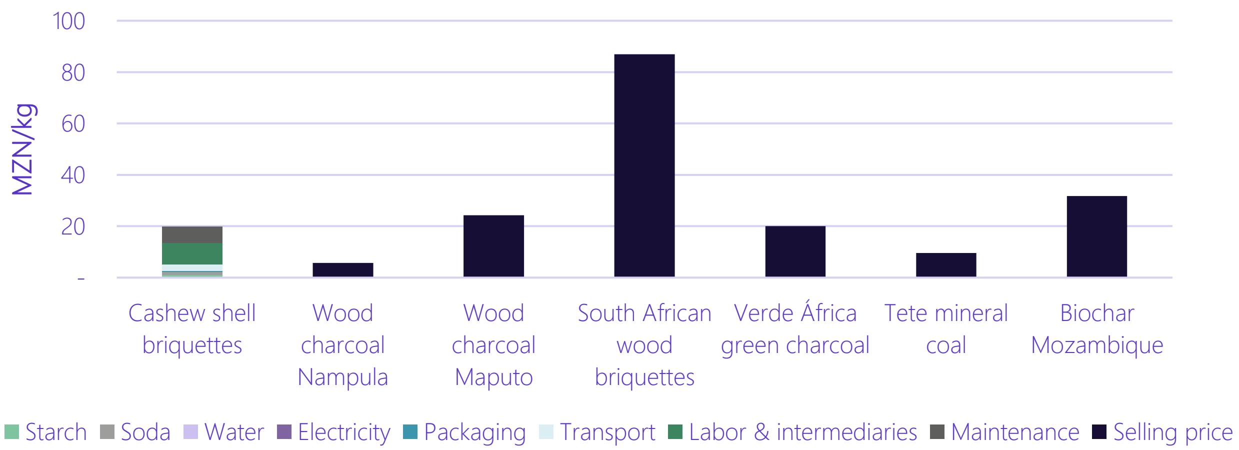


Figure 26. Comparative production costs of cashew shell briquettes vs price of wood charcoal, existing green charcoal products and mineral coal[32]

[32] Only direct Operational costs, so excluding equipment amortization and eventual taxations.

As presented in Figure 26 above, only a few market segments seem to grant a fair price for the briquettes. A fine positioning of the charcoal product is needed to get to harness the best value for green shell charcoal briquettes.

Carbonization of shells is possible in a semi-industrial scale, though shell cake is difficult to carbonize in a fixed (not rotary) kiln. The installation of H2CP kilns in a real setting (ADPP cashew factory) allowed the assessment of production costs and the comparison with current charcoal products in the market.

Considering that the highly competitive wood charcoal value chain entails a harsh challenge to the young green shell charcoal sector, the collective and productive sectors should be prioritized, though only the sales around Maputo would make sense.

2.3. Testing the cashew shell briquettes in real and laboratory conditions

Samples of charred shell briquettes, produced in the H2CPs and subsequently milled and compacted by Alif química in Quelimane city, were transmitted to specialists for performance tests. Controlled Cooking Tests were performed in the presence of domestic, collective cooking and commercial charcoal users, comparing wood charcoal and cashew shell charcoal briquettes. Their impressions after the tests were collected.

Table 11. Feedback of domestic (in blue) and commercial (in green) users after Controlled Cooking Tests. Source: Greenlight[33]

Fuel	Wood charcoal			Cashew shell charcoal briquettes		
Feedback	Liked	Not bothered	Disliked	Liked	Not bothered	Disliked
Lighting the fire	++				//	
Cooking time	++			++		
Extinguishing the fire	++				//	
Fuel consumption		//		+	/	
Fire intensity	+	/		++		
Fire safety		//		+		
Smoke		//			/	-
Odour	+	/				--
Food taste	+		-	++		
Cleanliness on the pan	++				/	-

Cashew briquettes seemed to be more appreciated than conventional charcoal, mainly due to a steadily high heating power throughout all the cooking process. However, the intense and smelly fume generation by the cashew shell briquettes during the lighting phase raised concerns in most of them. Despite the users' validation of the good taste of the meal cooked, the issue of the fumes is to be considered seriously as it may embed health and indoor air pollution issues. Additionally, the use of charcoal is also associated with a more desirable taste of food, especially when it comes to grills and traditional dishes. The release of acrid fumes by the carbonized cashew material could be a heavy drawback for commercialization.

In order to get more insight on quality issues, the Biomass Energy Certification and Testing laboratory in Maputo, supported by the GIZ Promove Endev program, tested carbonized shells – without compacting –, carbonized shell briquettes and wood charcoal samples in their lab facilities. The results confirmed the high

[33] Source: Greenlight, 2022. *Relatório final. Estudo de Mercado e Consumo relacionado à Introdução de Biobriquetes par o uso Doméstico ou Produtivo (peri-urbano) na Bacia do Baixo Zambeze em Moçambique.*

levels of volatiles released by both cashew products and warned about the worrying levels of fine particulates in the fumes composition (Figure 27 below), which translates the presence of traces of CNSL in the produce[34]. Indeed, according to the previous experience with cashew shell charcoal briquettes in West Africa, Nitidæ was already aware of the high correlation between the carbonization conditions, the resulting charcoal quality and the release of acrid fumes during the first combustion moments. It is very likely that the sample shells had undertaken a too short carbonization time inside the H2CP, and this may be insufficient for all the acrid volatiles to degrade off.

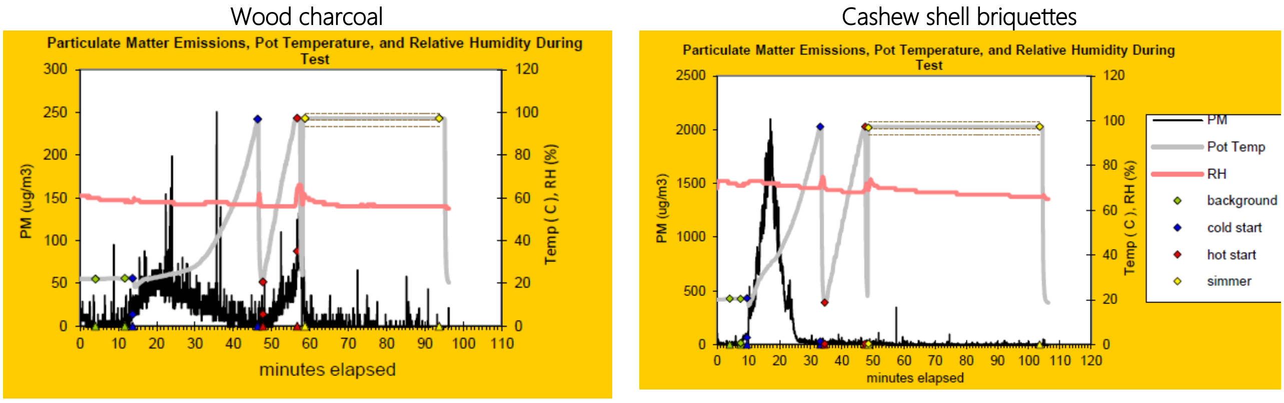


Figure 27. *Particulate emissions (PM2.5) recorded during the standardised Water boiling tests at BECT. Left: wood charcoal. Right: cashew shell briquettes. Mind the different PM scale in each of the charts.*

When comparing cashew shell briquettes with wood charcoal in real conditions, the users globally appreciated the briquettes because of the reduced cooking time and long-lasting combustion, which results in a more economical fuel than wood charcoal. The main drawback was the release of acrid fumes during the start of the operation, rising concerns on safety of use and on resulting food.

As a conclusion, operating conditions during cashew shell carbonization need to be well controlled to ensure a complete removal of the CNSL in the shells. Once the correct carbonization conditions are respected, the fumes release is brought to a minimum and shell briquettes could compete with wood charcoal.

Figure 28. *Cooking tests using cashew shell briquettes (left and middle); the three materials tested by the BECT laboratory for comparative combustion performance and emissions testing (right).*

[34] Source: BECT, 2023. Biomass fuels Performance tests, report

2.1. A new niche market: biochar

Charcoal as carbon sink and soil amendment

Increasing concerns on climate change, primarily caused by record CO_2 levels in atmosphere, and on the acceleration of soil degradation due to intensive agriculture, have brought many specialists to take an interest in green charcoal. Indeed, charcoal contains stable carbon, which is not likely to degrade releasing greenhouse gases as fresh biomass residues do. In fact, even if live biomass absorbs CO_2 to grow, burning or landfilling organic waste releases back carbon into the atmosphere and could be a net contributor to CO_2 emissions. Carbonizing waste biomass – without burning it - means stabilizing the carbon absorbed from the atmosphere, creating a carbon sink. In addition to this, charcoal is claimed to be beneficial for soil, improving its texture, water retention capacity and ion exchange properties.

Both advantages concur to rise an unprecedented interest in carbonizing waste biomass. When green charcoal is used as soil amendment, whether applied alone or with compost, it gets the name of **biochar**. Carbon accounting standards include biochar as one means to carbon sequestration. Thus, biochar not only has an agricultural value but its trade often includes climate-linked compensations.

Biochar market is a reality all around the world, yet it is in an incipient state in Mozambique. Since 2022, several companies in Mozambique announced their willingness to launch biochar production from sustainable biomass sources, while some agri product providers are seeking to include biochar in their formulations. Several cashew processors also consider the recycling of their shell waste into biochar that would be applied in cashew orchards, closing the loop within the cashew value chain.

As explained previously, biochar is the only non-energetic product scoped in this study. From the perspective of a biochar producer, the market rates are highly attractive. Indeed, biochar production costs are lower than charcoal briquette production, as biochar is a less elaborated product than briquettes – no compaction step needed, so no need of binders mixed to the grinded charcoal. As shown through Figure 29 below, the sale price could largely cover the production costs. In the Figure, biochar purchase price by the buyer is considered USD 500 per metric ton, though international market rates can reach USD 800 per ton.

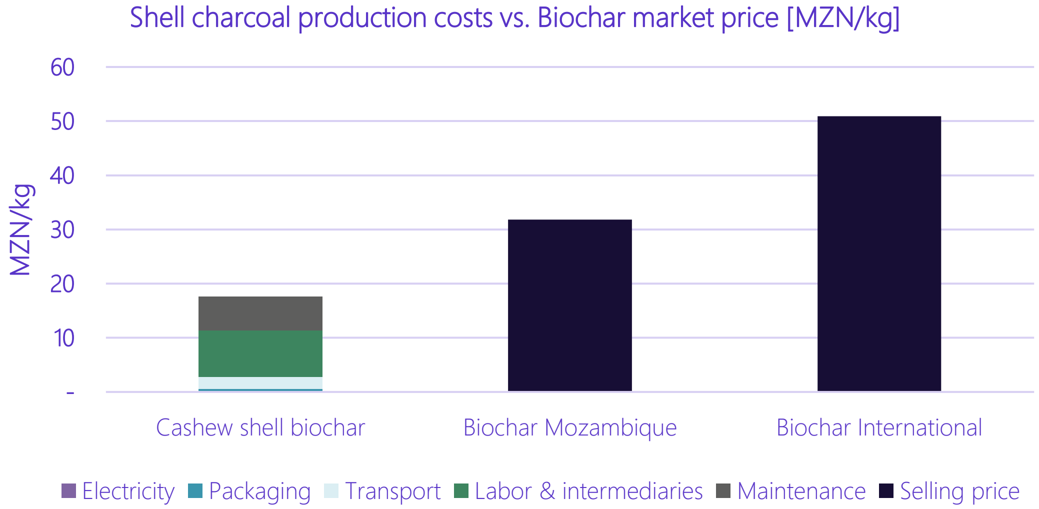


Figure 29. Comparative production cost of cashew shell biochar vs sales price at minimum international rate

Through the screening of charcoal and biochar actors, Nitidæ identified a nursery (Namahita collaborating with Norgesvel, AMPCM and GIZ) producing cashew and others seedlings, interested in purchasing cashew shell biochar to integrate in their seedling substrate. ADPP was put in contact with the buyer, trained in biochar production and assisted to conclude a commercial agreement, becoming the first commercial cashew biochar producer in Mozambique.

3. Conclusions

The following conclusions are drawn from the experience built through this work:

- In terms of volumes, carbonised shells would only meet an insignificant part of the demand.
- Operational costs of producing shell charcoal in a semi-industrial scale with the state-of-the-art equipment does not compete with wood charcoal prices in Nampula, barely in Maputo where the productive sectors should be targeted.
- The domestic and commercial segment –which includes collective kitchens – appreciates the combustion features of briquettes but:.
    - Productive users seek competitive prices, which is difficult to achieve in a semi-industrial scale.
    - Environmental claims are not a reason to prefer a costly green fuel.
    - There is an overall concern on the quality issues raised during the demonstration and testing experiences call for an improvement in the carbonization process and to raise awareness among users about the quality of shell charcoal (smoke, smell when lighting).
- Given the high production cost of briquettes, a specific approach prioritizing premium markets should be considered:
    - Briquettes for grills sold in supermarkets, though as a first approach the composition of shell briquettes should be improved to reach the required quality. The opportunity of a premium market would enable to attain maximum benefits, but the maturity of the sector is still low to access this segment. Indeed, there is little experience in Mozambique in the carbonisation of shells/cake, so developments should be continued in order to achieve an acceptable quality.
    - Biochar, which is an emerging market, seems like a good option for green charcoal made from cashew shells as the purchase price is high while the production cost is smaller than the briquettes. The signing of a commercial agreement for Biochar in Nampula shows the growing interest for biochar application in Mozambique, but also globally, where the interests for the agricultural sector (crop production, nurseries, ration for livestock, etc..) should be investigated further to map market opportunity.
- Given the challenges to produce high volumes at competitive costs with state-of-the-art equipment, it could be appropriate to complete the financial scheme with subsides, appropriate taxation and climate finance. These financial mechanisms are further explored in the Charcoal Business plan to be released separately.

V. General conclusion

In the edge of the energy transition towards cleaner and renewable energy, Mozambique is setting up strategies to support green industrialization[35]. As this study reveals, the domestic cashew processing sector can play a relevant role in speeding up this transition by providing green fuels to the manufacturing sector. By doing so, a circular economy would establish, where cashew shells would become a resource instead of being a costly residue of the cashew processing industry[36] . Adding value to the shells would mean an additional benefit to cashew processing factories, estimated between 5% and 13% of the raw nuts (RCN) procurement cost, which is their main operational cost – thus filling the competitiveness gap with Asiatic processors.

The best scenario to valorize cashew shell would be through a primary separation of the cashew shell liquid (CNSL) and direct use of the shell cake, this way the economic, energetic and environmental benefits are maximized through the sales of both resulting products, CNSL and shell cake. These can supply a significant part of the industrial fuel needs at provincial level, namely in the Nampula province, which indeed features a high concentration of cashew processing (10 out of the 12 factories currently running).

- CNSL extracted in Nampula province could supply around 30% of the Nampula's provincial demand for industrial liquid fuels (an estimated total demand of 24 240 toe[37] per year). In Maputo, the demand is lower but the CNSL available in the only nearby factory could provide around 50% of the estimated needs. A CNSL processing factory could sell locally with having a profit margin between 70 and 350 USD/MT which is the equivalent to 18 and 57 USD/MT RCN. The entire use of this novel biofuel at the national level would yearly avoid around 24 000 ton CO_2 equivalent.
- Almost all the consumption of firewood for productive uses in Nampula province could be substituted by switching to shell cake. In Maputo, shell cake could benefit SMEs currently relying on firewood such as bakeries. By selling the cake at an indicative cost of 1 MZN/kg, CNSL processors would get an additional profit margin of 16 USD/MT cake, which is the equivalent to 8 USD/MT RCN. If all the potential shell cake was used in substitution to unsustainable wood, 19 000 ton CO_2 equivalent would be yearly avoided.
- **Alternatively, the carbonization path looks complex and hardly profitable today, due to unsustainable competition of wood charcoal**, especially in the North. In Maputo, prices allow a narrow margin window. Small productive users and households would be the target, and the first should be prioritized. However, in the future with the predictable increase of wood or wood charcoal prices, and provided that technical improvements and economies of scale are achieved, this situation could change.
  The biochar option is emerging, and though promising from the circularity and climate change mitigation/adaptation perspectives, there is a need to develop knowledge about suitability of shell charcoal for soil amendment.

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[35] https://www.diarioeconomico.co.mz/2023/07/03/oilgas/energia/cop28-mocambique-prepara-plano-estrategico-para-o-inicio-da-transicao-energetica/

[36] From 100kg of cashew nut, around 70% of cashew shell waste is generated

[37] tons of oil equivalent

As of today, only one third of the attainable byproducts volumes is available, as still a majority of the shells are not given any value addition. **Achieving higher levels of shell crushing for CNSL extraction in Mozambique is today the main barrier to the establishment of a circular biofuel economy for the productive sector.** Making the case for Mozambique and attract private actors to invest in shell extraction should be the first trigger to release this untapped potential. The investment capacity of the cashew processors, is however very little and every year constrained by the need to acquire the RCN. There is room for new actors to come and invest in this new bioenergy sector. Some briefs on the specific investment opportunities can be found in Annex 7.

On the fuel consumers' side, there may be technological challenges related to the adoption of appropriate combustion technology. The financial case of fuel switch may crucially improve, both for cake buyer and provider, if climatic impacts were taken into account. Climate-related finance is an opportunity as the environmental services could be remunerated and incentivize the use of CNSL and cake as biofuels.

VI. Annexes

Annex 1. Factsheet: CNSL fuel
Annex 2. Factsheet: Shell cake fuel
Annex 3. Factsheet: Shell charcoal
Annex 4. CNSL extraction process
Annex 5. Operation of a High Calorific Cashew Pyrolyser
Annex 6. Green charcoal: production and market in Mozambique
Annex 7. Investment briefs for cashew shell value addition
Annex 8. List of interviewees

Annex 1. Factsheet: CNSL fuel

CNSL fuel

What is CNSL

The cashew nut contains a thick shell containing a vegetal liquid into its pores. This is called Cashew Nut Shell Liquid, or CNSL. About 20% of CNSL can be extracted from the cashew shell. CNSL is a flammable liquid and, as such, can be used as a biofuel. The renewable energy embedded in CNSL can be harnessed through a fuel burner.

CNSL is abundantly available in Mozambique, around the cashew processing points (provinces of Nampula, Cabo delgado and Inhambane). It is a profitable substitute of classical fuels thanks to its local origin and low price, being it as low as 50% cheaper than petrol based fuels.

CNSL specifications vs mineral fuels:

Specifications	CNSL technical grade	Heavy Fuel Oil 180 (HFO180)	Used engine oil	Lighting petroleum (kerosene)	Diesel (gasoil)
Density 15°C (kg/L)	0,93 - 0,96	0,92 - 0,99	0,88 – 0,95	0.78 - 0.81	0,82 - 0,89
Viscosity 40°C (cSt)	55 - 88	80-180 (50°C)	105 - 202	1 – 2	1,6 - 5,9
Flash point (°C)	>193	>66	128 - 236	>40	> 61
Net Calorific Value (kJ/kg)	>37 000	>40 000	40 000	42 890	45 000
Ash content (%)	<1	< 0,10	>1	<	-
Water content (%)	< 1	< 0,5	n/d	-	-
Sulphur content (%)	<0.01	<1	0.02 – 0.94	<0.15	0.04 – 0.2
Acid number (mg KOH/g)	> 32	< 2,5	2.10 – 16.0	n/d	4,32

CNSL can substitute classical hydrocarbon fuels and other residual or vegetal oils used as fuel. Its calorific value is similar to those of current marketed fuels, being it next to 40 MJ/kg. The main feature in CNSL is its high viscosity, making it only adapted for use without modification in any burning equipment adapted to viscous fuels, such as heavy fuel (HFO) or mineral oils.

Burner

The role of the burner is to mix correctly the liquid fuel with the needed proportions of air, and maintain this mixture in flammable conditions in order to produce a stable flame for heating purposes. The burner plays a prominent role in the quality of combustion, and thus is also responsible of pollutant emission, soot or visible fumes. Each fuel being different, the burner shall be adapted to its specific properties.

Every combustion equipment (boiler, furnace, roaster etc) can be easily adapted to the use of CNSL, by only selecting an appropriate burner. Specific ranges of burners are adapted to every heating needs. Burners adapted to CNSL are available, who include a preheater to lower viscosity. The power range is also very large: 100 kW to 10,000 kW, corresponding to 10-1,000 liters/hour consumption of fuel.

Nitidæ works in the promotion of cashew shell based products in Africa. We provide technical advice on solid and liquid biofuels, resins and other derivatives of cashew shell products. Our role is to advise local producers and consumers, and create links between them, encouraging circular economy.

For any query, please contact us: j.artigassancho@nitidae.org - +258 870043558 - Maputo, Av. Agostinho Neto, 16.

Annex 2. Factsheet: Shell cake fuel

De-oiled shell cake fuel

What is de-oiled shell cake

The cashew nut shell contains a vegetal liquid into its pores. This is called Cashew Nut Shell Liquid, or CNSL. About 20% of CNSL can be extracted from the cashew shell. The remaining residue is called De-Oiled shell Cake, or DOC.

Cashew shells are abundantly available in Mozambique, around the cashew processing points (provinces of Nampula, Cabo delgado and Inhambane). The shell de-oiled cake is a profitable substitute of wood, thanks to its local origin and low price. A minimum remaining oil content makes DOC suitable for fuel use in industrial combustion.

De-oiled cake (DOC) specifications vs firewood:

Specifications	DOC	Manguifera indica (mango tree)	Pterocarpus angolensis (Umbila)	Millettia stuhlmannii (namipiri)
Density (ton/m^3)	0,48	0,75	0,54	0,89
Net Calorific Value at 20% moisture (kJ/kg)	16 370*	15 331	16 891	16 569
Net Calorific value at 0% moisture (kJ/kg)	17 136	17 830	19 809	19 410
Ash content (%)	2%	3%	1%	1%
Water content (%)	< 10%	20 – 50%	20 – 50%	20 – 50%
Residual oil content	<12%	-	-	-

*DOC is always <10% moisture. The displayed value is the lowest calorific value at highest moisture possible

DOC is a high-power content biomass and lights up quickly. It is suitable for use as standalone fuel or mixing with other fuels (either wood or agricultural residues). DOC can be used as furnace fuel in boilers, thermic fluid heaters, kilns, tile production and power generation.

DOC is available all year long from neighboring cashew processors. Compared to firewood, its moisture content is very regular and does not depend on the season. Thus, its calorific content is stable in time.

Burner

A well designed furnace can reduce the amount of cashew shell cake required as well as the smoke when it burns cleanly. However, in some cases it is not easy to modify or change the furnace: in this case, a safe solution is to adopt a biomass burner.

The role of the burner is to mix correctly the biomass fuel with the needed proportions of air, and maintain this mixture in order to produce a stable flame for heating purposes. The burner plays a prominent role in the quality of combustion, and thus is also responsible of pollutant emission, soot or visible fumes.

Every combustion equipment (boiler, furnace, roaster etc) can be easily adapted to the use of DOC, by selecting an appropriate burner. Specific ranges of burners are adapted to every heating needs.

Want to watch it working? Search "cashew shell burner" in YouTube and you will find out!

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Annex 3. Factsheet: Shell charcoal

Green charcoal from Cashew shell

What is cashew shell charcoal

Cashew shells are abundantly available in Mozambique, around the cashew processing points (provinces of Nampula, Cabo delgado and Inhambane). Carbonization of the shell is an alternative to the CNSL extraction. By carbonizing, all the corrosive CNSL is volatilized and the ligneous material becomes a green charcoal.
Carbonization of the de-oiled shell cake, after CNSL extraction, is also possible with appropriate, big-scale equipment.

Once the shells or the cake are carbonized, they can be milled and compacted to make charcoal briquettes. These green charcoal briquettes are an efficient substitute to wood charcoal, thanks to its excellent combustion features.

Cashew shells → **Carbonisation in a pyrolysis kiln** (Conversion yields: 15-18%) → Carbonised shells → **Milling** → Charcoal powder → **Mixing with binder and Briquetting** → Charcoal briquettes

Fuel parameters

Specifications	Net Calorific Value 0% moisture (kJ/kg)	Bulk density (kg/m^3)	Moisture content (%)	Volatile matter (%)	Fixed carbon (%)	Ash content (%)
Cashew shell briquettes	25 000	409	5%	15%	69%	17%
Wood charcoal	30 800	349	3%	16%	80%	4%

Cashew shell briquettes are denser than charcoal and burn slowly, with a safe flame. Due to higher ash content and eventually uneven carbonization, some smoke with a characteristic cashew smell may appear. It is recommended to light the fire in an open space and not to remain exposed to these fumes.
As the cashew shell residue is available all year long, briquettes can be produced on a continuous basis. A briquette production line includes carbonization equipment (such as the H2CP pyrolysis oven), a mill, mixing and briquetting equipment. The profitability of such a business depends strongly on the optimization of the running costs, i.e. ensuring maximum production with adequate and robust equipment. If the smoke emissions are solved, charcoal briquettes could be sold at premium prices such as in supermarkets.

Biochar

Cashew charcoal could be used as soil amendment. The natural honeycomb structure of the cashew shell creates millimetric voids, when carbonized, which could feature interesting properties by improving soil structure. Biochar is nowadays marketed at a very high prices given its additional potential as carbon sink.

For any query, please contact us: j.artigassancho@nitidae.org - +258 870043558 - Maputo, Av. Agostinho Neto, N°16.

Annex 4. CNSL extraction process

To obtain commercial grade CNSL, several steps must be followed.

Mechanical expellers –oil screw presses- are the most commonly used at the industrial level to separate the liquid from the cashew shell. The liquid is collected in one side and the solid de-oiled cake on the other side of the press. The CNSL obtained through this process is rich in anacardic acid and is called natural or raw CNSL.
Anacardic acid decays naturally, releasing some inert CO2 gas. When this happens, the acid molecule becomes cardanol, a stable molecule. This decay should be completely finished in order to store CNSL in safe conditions. Thus, raw CNSL is heated in a reactor for several hours at temperatures around 140°C to obtain technical CNSL (CNSL-T) thanks to the accelerated thermal conversion of anacardic acid into cardanol. The resulting CNSL is hence rich in cardanol and poor in anacardic acid.

A final decantation and filtration is done to remove any sludge and particles from the CNSL. The overall yield CNSL/shells is about 20%.

This CNSL-T, stable, is the CNSL that is usually produced and used in industry. Although mentioning about CNSL in this document, will be in fact talking about CNSL-T as this is the usage. Technical CNSL grade is sufficient to be burnt in adapted burners. In any case, a fine refining of CNSL in order to minimize viscosity, acidity and ash content allows to get better sales value.

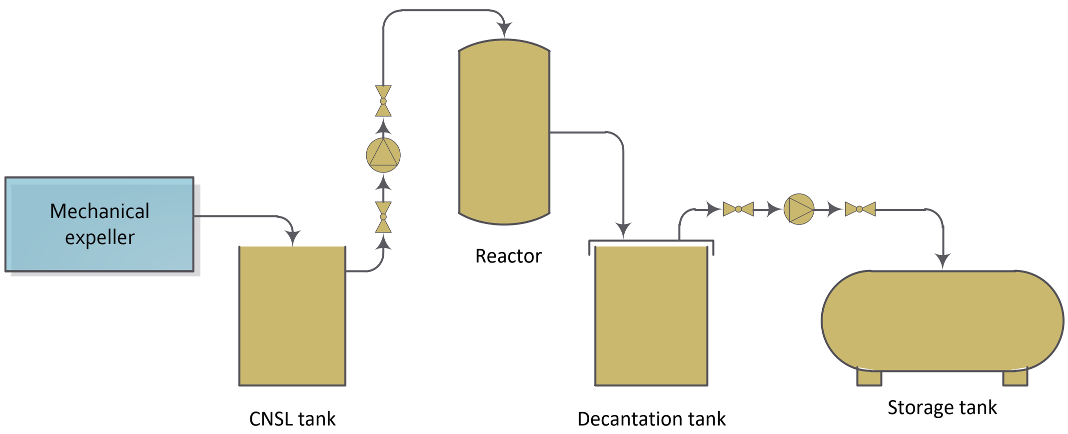


Figure 30. Simplified CNSL extraction process.

The simplicity of CNSL processing allows the same cashew factory to produce and sell the fuel directly to the consumer (no need for intermediaries, only a tanker truck).

The capital investment in machinery is between USD 250 000 and 500 000 for a base production capacity of 2 000 MT CNSL per year.

High Calorific Cashew Pyrolyser (H2CP)

Safely burn shells and generate clean energy in your factory

How does it work?

- Shells are easily fed from the top hopper, accessible from the boiler platform
- Into the pyrolysis oven, shells are pyrolysed, and evacuate a rich fuel gas (containing CO, CH_4, C_2H_6...). Gases are burn straight into the boiler firebox.
- No CNSL leaking. Harmful components are volatilized and burnt in the boiler
- The by-products are carbonised shells, recovered at the end of the batch.
- Charcoal obtained is smokeless and lights quickly (LHV 24,7 MJ/kg at 10% moisture)

Key figures (case of connection of boiler to cashew steaming only):
Start-up time: **4 minutes**
Volume of RCN cooked: **6.8 tons in 8h (85 bags)**
Volume of shells converted: **700 kg in 8h**
Volume of charcoal produced: **105 kg** thus **15% yield**

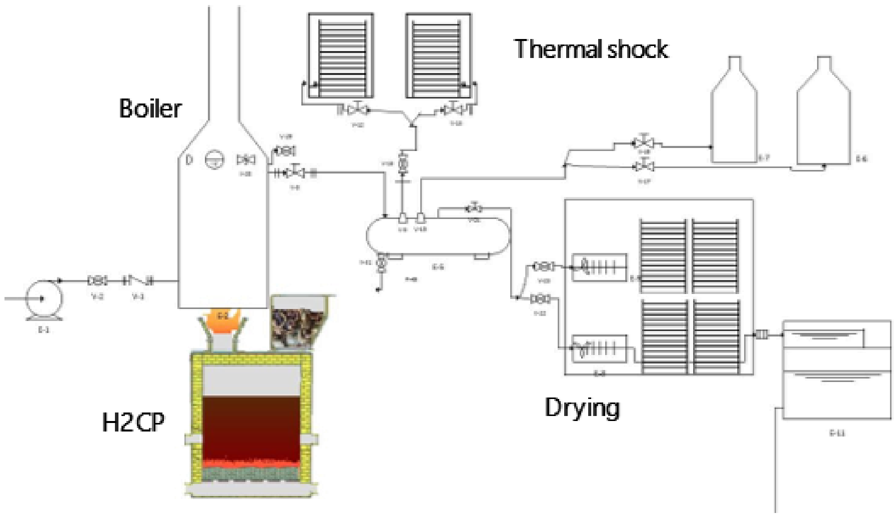
+Important reduction of acrid fumes, until complete elimination

Features:

- **Inlet**: 700-1000 kg shells in 8h
- **Fire power**: 250 kW → steam generation up to 300 kg steam/h,
- **Environmentally friendly**: conversion of 25% shell waste thanks to the pyrolysis technology
- **Reduction of air pollution**: no acrid fumes anymore
- **Energetic by-product**: H2CP produces 10 to 15% charcoal, locally consumed for cooking or used as soil amendment

Mastered, appropriate technology for African context:

- **Local know-how**, materials and maintenance: your project managed by African technicians, from A to Z.
- **Robust technology**: easy maintenance, no electric elements
- **Same staff requirements** than a conventional boiler setup
- **Adapted to factories** at small and medium-scale: up to 5000 tons RCN/year
- **Adaptable to other industries**: dried fruits, vegetable oil refining...
- **More than 20 factories** already installed a H2CP in Africa and are satisfied



Typical connection scheme for cashew processing

When used as a combustion device to substitute wood of fossil fuels,
Return on Investment (RoI) is only a few months!
Shells become a cheap, no-harm fuel

Annex 6. Green charcoal: production and market in Mozambique

For decades, a number of initiatives to lower the environmental impacts of wood charcoal production and use have been explored, including improved carbonization techniques, improved cookstoves and the introduction of more efficient fuels such as LPG. One of the solutions explored since the 2000's is to replace the wooden raw material by another biomass stream, to be carbonized and used as a direct substitute to wood charcoal. This kind of product is called green charcoal.

On the user side, the introduction of green charcoal does not require any change in the combustion appliance (in most cases a cookstove), and features the advantage of adding value to waste, thus creating a circular value chain locally while directly displacing the pressure on forest resources. However, on the manufacturer side, charcoal from waste biomass needs of an organised supply and production chain. The main issues of green charcoal production are:

1. The need to adapt the carbonization process to the input raw material, which requires a certain technical knowledge. Carbonization is often the bottleneck of the process, as production capacity directly depends on the carbonization output volumes. Simple, scratch-level charcoal kilns can carbonize 50 to 100 kg of raw material, while bigger ones can bear several hundreds of kg per batch or even work on a continuous basis. Depending on the material, carbonization takes from some minutes to several hours. In most Mozambican cashew processing units, shells are produced almost every day at a rate of several tons per day, so this calls for several reactors working in parallel or a big one in continuous feed.
2. The additional work and investment needs in processing equipment, compared to the standard case of wood charcoal production. Manufacturing of green charcoal needs of capital investment and requires additional inputs such as a binder and water. Given the big volumes of cashew shell/cake waste to carbonize, it is worth investing in robust and automatic equipment.
3. The eventual challenges in securing regular supplies of raw materials. Residual biomass availability is key, so the location of the carbonization site is prominent in order not to incur in high transport charges. Some feedstocks are geographically spread, while others could be only available at certain times of the year. In the case of cashew shells and cake, they are readily available in the surroundings of the factories, which makes an ideal location to establish the carbonisation unit.

Several manufacturers of green charcoal in Mozambique were interviewed with a double aim: recording their learnings and assessing their readiness and their interest to include cashew shells or cake as raw material.

- Verde África (Maputo). Established since 2018, Verde África has developed a 40 tons per month green charcoal production chain based on residual wood charcoal dust, available in big charcoal distribution points around Maputo. The charcoal dust is mixed with waste cassava and its peelings - rich in starch- and water, and introduced in a screw press (extruder). Once the briquettes are sun-dried, they are conditioned in PP bags and delivered to the users. As there is no carbonization step, the main cost is the transport of the raw materials and products.

  Initially, Verde África oriented their product towards restauration clients. However, due to the choice of the binder, the resulting briquettes are rather friable and this is a drawback especially when cooking, as the charcoal may be stirred from time to time to boost combustion. Also, the briquettes reportedly generate some disturbing smoke that is considered a nuisance by some of the initial clients, which lowered their fidelity. At present, the produce is entirely sold to a reduced number of chicken growers, using them to warm up the henhouses during cold nights. These buyers are not concerned by smoke or fragility, and are happy to buy green charcoal at a lower price than wood charcoal.

Verde África stated only starting to be profitable from 2022, once it reached the full operational capacity. As the availability of wood charcoal dust is limited, the company would be happy to secure bigger charcoal powder supplies to extend their capacity. Thus, they would eventually be interested in charred cashew shells or cake in powder form.

Figure 31. Verde Africa's charcoal briquettes obtained in an extruder (left), then dried in racks

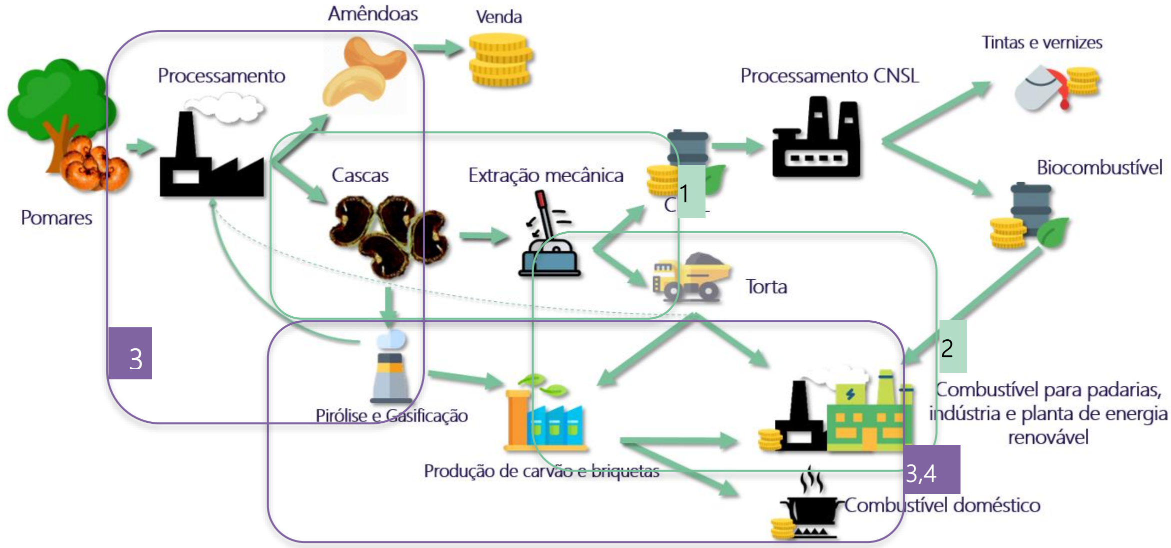
- **Alif química industrial (Quelimane).** This green charcoal producer started in 2021 to carbonize coconut shells and other waste available around Quelimane, in partnership with Pedra a pedra, an innovative company producing coconut timber. Alif quimica's core business is the manufacture and distribution of edible oil products.
  Once the biomass is carbonized and mixed with the binder (cassava flour), the briquettes are produced in a rotating mold machine.
  Alif química only works occasionally, depending on coconut timber waste availability. The director showed interest on cashew shells as these are available all year long, though cashew factories are several hundreds of kilometers away so it is very unlikely that sourcing them would be profitable.

Figure 32. A barrel kiln is employed for the carbonization of coconut shells (left). The milled charcoal is then compacted in a briquetting machine (right).

- **South African Wood waste charcoal producers.** There are numerous producers of wood charcoal from sustainably managed fast-growing plantations in South Africa. These are mainly aimed at producing paper pulp timber. Milling leftovers and lower grades are redirected for charcoal production purposes. Others use invasive bush species to make their charcoal. Carbonization kilns are fixed reactors with capacity of several hundred to some tons of fresh wood. The smaller bits of fresh wood are carbonized through a continuous drier, and mixed with small charcoal particles and dust to be compacted into briquettes. The main producer is E&C Charcoal, who is the main supplier of Spar and Shoprite supermarkets in Mozambique. Other South African manufacturers whose products can be found in Mozambique are Charka and Safari.
  South African briquettes are sold in supermarkets, at the highest market prices: 87 to 100 MZN/kg. Supermarket managers approached in Nampula and Nacala showed mild interest in cashew briquettes and some remarked a characteristic smell, which they pointed as potentially problematic.

Figure 33. Several brands of South-African sourced charcoal briquettes can be found in supermarkets all throughout the country

Shell byproducts: ways to valorise energy



1. CNSL extraction

Today shell crushing is a reality in Mozambique and its full potential has not yet been reached, with many factories still not using the shell for extraction.

Shell oil (CNSL) is still largely unknown to the industry. However, it is an excellent wood protector. Shell oil and *cake* can be used in industrial ovens and bakeries at more affordable prices than diesel or firewood, respectively.

CNSL fuel in bakeries

CNSL for wood protection

Eligible plant type: Capacity >5 000 MT RCN/year; shell treatment business
Country potential: 9 100 MT CNSL[38] :
- Replacement of 8 300 MT of fuel oil (for industry or electricity generation)
- USD 2 500 000 to 5 000 000 per year earned in CNSL sales

29 800 TM cake:
- Supplying all the industrial and productive demand for firewood in Nampula province
- USD 500 000 per year turnover from cake sales

Technicality: Low. Market research is carried out. Three extraction units currently operating in the country.
Current limitations: Access to finance, knowledge of the biofuels sector.
Budget: > USD 500 000 /site
Nitidæ portfolio: Technical advice and dimensioning of CNSL extraction plants in West Africa
Projects Cardoil, 2020-2023. Cashoil, 2022-2023. Coquenstock, 2021.

[38] Based on 65,000 TM RCN processed in the territory, and the geographical distribution and size of existing plants.

2. Shell cake fuel for boilers and furnaces

Shell and cake (defatted shell after oil extraction) are alternative fuels to firewood in industry.

Eligible factory type: Factories with thermal needs and near nut processing plants
The country's potential: 41 000 MT of total shell, of which only 15 400 MT are currently valued. The total potential is the energy equivalent of 53 800 MT of firewood that would be saved from burning, contributing to the fight against deforestation. If only the cake is considered, the equivalent of firewood is 35,500 MT, which is equivalent to 19,000 tons of CO_2 avoided.
Technicality: Low. There are already some automatic feeders in the country.
Current limitations: Adoption of the technology to adapt to the entire production scale. Need to create local manufacturing and operation/maintenance capacity.
Budget: USD 5 000 – 45 000 /unit (depending on the boiler)
Nitidæ portfolio: Project Promove (2022-2023)

3. H2CP Pyrolysis furnaces

It is the most suitable solution for the clean production of steam in the boiler in small and medium-sized processing factories. The kiln produces combustible pyrolysis gas, suitable for use in boilers or kilns; and in parallel cashew shell charcoal, which provides a first experience with this material that benefits factory staff and contributes to reducing deforestation. The oven can also supply heat to other factories besides cashew processors.
In West Africa, more than 20 pyrolysis ovens have been installed since 2013, facilitating a healthier working environment in factories by eliminating the emission of harmful smoke produced in the boiler.

Eligible plant type: Capacity < 5 000 MT RCN/year and vertical boiler
Country potential: 10 700 MT of hulls in 6 small and medium-sized factories
- 1 700 MT shell charcoal
- USD 500 000 – 1 000 000 /year turnover from charcoal sales
Technicality: Low. There is local manufacturing capacity and experience in using ovens
Current limitations: Price of wood charcoal very competitive, need to optimise costs
Budget: USD 6 500 /unit (without boiler)
Nitidæ portfolio: projects Cajouvalor (2011-2014), H2BE, (2014-2015), Agrovalor RCI, (2017-2021)

Pyrolysis in the kiln can be optimised with the sole aim of generating charcoal.

Nitidæ provides advice and participates in research into appropriate solutions for valorising shell into charcoal. The Promove project made it possible to install two pyrolysis furnaces at the ADPP plant, with a treatment capacity of 1,500 kg of shell per load.

Carbonisation platform with two pyrolysis ovens


Biochar
(ground shell charcoal)


Charcoal briquettes

Type of factory eligible: All factories not near housing estates
Country potential: Up to 41,000 MT of recovered shell
- 6 100 tons of charcoal for 8 300 families
- USD 2 000 000 to 4 000 000 /year earnings from charcoal sales
Technicality, current limitations: Media. Technology and feasibility study under development
Budget: 4-furnace device USD 27 000 (processing 4 tons/day)
Nitidæ portfolio: Projects Pyrocita (2022), Promove (2022-2023)

4. Gasifiers for electricity and charcoal

If the volumes of shell are sufficient, it is possible to feed an electricity generation system for the benefit of the plant. The industrial-scale pyrolysis process, gasification, generates a gas that powers an electricity-generating motor. Shell charcoal is also recovered from this process.
In Benin and Côte d'Ivoire, Nitidæ is developing this innovative scheme and is studying market opportunities for gasification charcoal.

Eligible plant type: Capacity > 6 000 MT RCN/year
Country's potential: 30 200 MT of recovered shell in 6 large-capacity factories
- 3x250 kW electric[39] in each plant
- Energy supply covers 90% of needs, possibility of injecting surplus into neighbouring electricity grids
- 4 500 MT/year of charcoal for 6 100 families (6 000 MT RCN plant produces 630 tons/year)
- USD 1 430 000 to 2 250 000 /year turnover from charcoal sales
(6 000 MT factory: USD 200 000 – 318 000 /year)
Technicality: High. Requires local training in operation.
Current limitations: Need prior study, long project development times (>2 years).
Budget: USD >2 000 000 /unit
Nitidæ portfolio: projects ElectriCI (2016-2020), GAZEL (2020-2025)

Nitidæ works to promote cashew shell byproducts in Africa. We provide technical support on solid and liquid biofuels, resins and other shell derivatives. Our role is to advise local producers and consumers, creating links between them that promote the circular economy.

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[39] 3 groups of 250 kW installed power

Annex 8. List of interviewees

Province of Nampula

Date	Name	Category	Main fuel	Secondary fuel	District
10.03.2022	Academia militar	Collective kitchen	LPG	Wood charcoal	Nampula
22.03.2022	Padaria Nacala	Bakery	Firewood	-	Nacala
22.03.2022	MMI Steel - Kiboko	Foundry	Used engine oil, HFO	-	Nacala
23.03.2022	ACAI Industrias Namialo	Confectionery	Electricity	-	Meconta
25.03.2022	Manuel Zenao	Wood charcoal reseller	Wood charcoal	-	Nampula
30.03.2022	Abdalamuanze Amade	Production and sales of wood charcoal	Wood charcoal	-	Nampula
30.03.2022	Hospital Central de Nampula	Bakery	Firewood	Charcoal	Nampula
06.04.2022	Cervejas de Moçambique	Beverage	Coal	Diesel	Nampula
11.04.2022	Padaria Rovuma	Bakery	Firewood	-	Nampula
13.04.2022	Padaria do Povo	Bakery	Firewood	-	Nampula
14.04.2022	Restaurante Surf	Restaurant business	LPG	Wood charcoal	Nampula
15.04.2022	Restaurante Frango a Rony	Restaurant business	LPG	Wood charcoal	Nampula
17.04.2022	Restaurante Grill	Restaurant business	LPG	Wood charcoal	Nampula
20.04.2022	Restaurante Ti Maria	Restaurant business	LPG	Wood charcoal	Nampula
21.04.2022	Restaurante Mood	Restaurant business	LPG	Wood charcoal	Nampula
26.04.2022	Instituto de Formação de Professores	Collective kitchen	Wood charcoal	LPG	Nampula
28.04.2022	Cimentos Maiaia	Cement manufacturing	Coal	-	Nacala
13.07.2022	Coca-Cola Nampula	Beverage	Diesel	-	Nampula
18.10.2022	António Mania	Wood charcoal reseller	Wood charcoal	-	Nampula
18.10.2022	Alfonso Lairere	Wood charcoal reseller	Wood charcoal	-	Nampula
20.10.2022	RGK Industries (Farinal / GS Industries, SA)	Edible oil refinery & soap manufacturing	Firewood	Diesel, cashew cake	Nacala
21.10.2022	Vendedor estrada Itoculo	Production and sales of wood charcoal	Wood charcoal	-	Monapo
21.10.2022	Vendedor estrada Itoculo	Production and sales of wood charcoal	Wood charcoal	-	Monapo
21.10.2022	GEIR (SanOil)	Edible oil refinery & soap manufacturing	Cottonseed husk	Firewood	Namialo
21.10.2022	Indo África steel	Foundry	CNSL, used engine oil	Furnace oil, HFO	Nacala
24.11.2022	Kenmare resources Ltd	Mining	Diesel	-	Angoche

01.03.2022	Nova Texmoque	Textile manufacturing	Firewood	-	Nampula

Province and city of Maputo

Date	Name	Category	Main fuel	Secondary fuel	District
28.03.2022	Fernanda Cuco	Production and sales of charcoal	Wood charcoal	-	Cidade de Maputo
28.03.2022	Padaria Aliança	Bakery	Firewood	-	Cidade de Maputo
30.03.2022	Dionisia Chongo	Production and sales of charcoal	Wood charcoal	-	Matola
04.04.2022	Milton Machava	Wood charcoal reseller	Wood charcoal	-	Cidade de Maputo
04.04.2022	Alexandra Uaciquete	Traditional brewery	Firewood	-	Bairro Ferroviario
06.04.2022	Adilia Uassiwane	Production and sales of charcoal	Wood charcoal	-	Matola'Machava
11.04.2022	Restaurante e pastelaria Raima	Restaurant business and cake shop	LPG	Wood charcoal	Kamavota - Laulane
11.04.2022	Padaria Lafoes	Bakery	Firewood	-	Cidade de Maputo
12.04.2022	Ana Cossa	Restaurant business	LPG	Wood charcoal	Mahotas
13.04.2022	Delfina Teotonio	Restaurant business	LPG	Wood charcoal	Bairro Ferroviário
13.04.2022	Albino Maria	Wood charcoal reseller	Wood charcoal		Matola - Liberdade
14.04.2022	Denilson Uamusse	Restaurant business	LPG	Wood charcoal	Polana
14.04.2022	Chelton Sitoe	Restaurant business	LPG	Wood charcoal	Matola- Nkobe
14.04.2022	Padaria Nova Era	Bakery	Firewood	-	Cidade de Maputo
14.04.2022	Padaria Germane	Bakery	Firewood	-	Mahotas
18.04.2022	Idelson Manjate	Restaurant business	LPG	Wood charcoal	Albasine
18.04.2022	Miro Ainadine	Restaurant business	LPG	Wood charcoal	Sommershield
18.04.2022	Padaria Belo horizonte	Bakery	Firewood	-	Cidade de Maputo
19.04.2022	Helena Mpfumo	Restaurant business	Wood charcoal	LPG	Sommershield
19.04.2022	Ernestina Cuco	Production and sales of charcoal	Wood charcoal	-	Matola Losalite
19.04.2022	Otília Macuacua	Production and sales of charcoal	Wood charcoal	-	Matola

20.04.2022	Evelina dos Santos	Restaurant business	Wood charcoal	LPG	Sommershield
20.04.2022	Adélia Jorge	Restaurant business	Wood charcoal	LPG	Sommershield
26.04.2022	Padaria Mussa	Bakery	Firewood	-	Marracuene
26.04.2022	Padaria Marracuene	Bakery	Firewood	-	Marracuene
27.04.2022	Angelina Manhica	Restaurant business	Wood charcoal	LPG	Laulane
27.04.2022	Padaria Mercearia Vila de Marracuene	Bakery	Firewood	-	Marracuene
27.04.2022	Padaria Bottlestore Mocambique	Bakery	Firewood	-	Manhica
27.10.2022	Lactimoza	Dairy products manufacturing	Diesel	-	Matola
27.10.2022	Southern refineries	Edible oil refinery & soap manufacturing	LNG	Diesel	Matola
28.10.2022	Verde África	Green charcoal manufacturing ans sales	Wood charcoal	-	Albasine